

A Good Practice Guide on Electrical Energy Storage

Supported by funding from the Department of Energy & Climate Change

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Digital Edition published 2014 in the United Kingdom

ISBN 978-1-874290-20-9

Published by EA Technology

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Registered in England number 2566313

Summary

Electrical Energy Storage (EES) is recognised as a key enabling technology in the realisation of future GB electricity networks. Distribution Network Operators (DNOs) and others have developed their knowledge of deploying this new technology via various trials. To date, members of the Energy Storage Operators' Forum (ESOF) have deployed 12.6 MW / 20.6 MWh of EES, mainly via the Low Carbon Network (LCN) Fund. A further 3 MW / 1.5 MWh is under construction at the time of writing.

These projects are delivering large amounts of learning throughout the whole project lifecycle. The Good Practice Guide (GPG) was commissioned in order to consolidate this learning into a reference guide for those deploying EES. Its intended audience is those involved implementing EES systems (e.g. DNOs, Transmission System Operators, Energy Suppliers, generators etc.), EES suppliers, manufacturers and developers and standards bodies.

The Guide disseminates the key lessons learnt from EES deployments in the UK. It covers:

- The current 'State of the Art' of EES and relevant policy announcements;
- A description of the various EES technologies within the scope of the Guide;
- Codes, Standards and Legislation which apply to EES systems;
- The approach taken and lessons learnt in relation to: procurement, installation and safety case development;
- The applications which can be addressed using EES, how energy storage can be scheduled and examples of the benefits obtained;
- The costs of various EES technologies and potential revenue streams; and
- Methodologies for analysing the cost:benefit case for EES technologies and a number of examples.

The Guide's development has been informed by the compilation of case studies, drawn from DNO energy storage deployments and other demonstrations supported by the Department of Energy and Climate Change (DECC) and the Energy Technologies Institute (ETI). It covers battery technologies (lead acid, nickel-cadmium, high temperature sodium and lithium-ion), flow batteries and thermodynamic cycle energy storage. The scope of the Guide was informed by those technologies which are currently being deployed by members of ESOF and supported via the DECC Energy Storage Demonstration Competition.

The GPG was produced by EA Technology, working with ESOF. Its development was funded by the DECC Energy Storage Component Research and Feasibility Study Support Scheme and ESOF members.

The Guide draws out good practice from existing EES deployments and is designed to be used as a reference document by those deploying energy storage – using various sections at different stages of the project. Figure 1.1 of the Guide shows the sections which can be used at each stage. It is not intended to be treated as a rigid set of guidelines for those developing or installing EES. The Guide is accompanied by an Executive Summary which provides an introduction to the Guide and summarises key learning from storage projects in the UK.

Glossary

A

AC	Alternating Current
ACOP	Approved Code of Practice
ADR	Accord européen relatif au transport international des marchandises dangereuses par route
AGM	Absorbed Glass Mat
ANM	Active Network Management
AP	Authorised Person
ATEX	Derived from the French title of the EC Directive, “Appareils destinés à être utilisés en AT mosphères EX plosibles (implemented in the UK as the DSEAR regulations)

B

BaU	Business as Usual
BESS	Battery Energy Storage System
BETTA	British Electricity Trading and Transmission Arrangements
BIS	(Department for) Business, Innovation and Skills
BM	Balancing Mechanism
BMS	Battery Management System
BoP	Balance of Plant

C

CAES	Compressed Air Energy Storage
CB	Circuit Breaker
CBA	Cost:Benefit Analysis
CCTV	Closed Circuit Television
CDCM	Common Distribution Charging Methodology
CDG	Carriage of Dangerous Good (Regulations)
CDM	Construction (Design and Management)
CHIP	Chemicals (Hazard Information and Packaging for Supply)
CHP	Combined Heat and Power
CI	Customer Interruption
CLNR	Customer-Led Network Revolution
CLP	Classification, Labelling and Packaging
CML	Customer Minute Lost
CMU	Capacity Market Unit
CMW	Capacity Market Warning
COMAH	Control of Major Accident Hazards
COSHH	Control of Substances Hazardous to Health

D

DC	Direct Current
DCLG	Department for Communities and Local Government
DECC	Department of Energy and Climate Change
DfT	Department for Transport
DGSA	Dangerous Goods Safety Advisor
DN	Nominal size of piping (mm)
DNO	Distribution Network Operator
DSEAR	Dangerous Substances and Explosive Atmosphere (Regulations)
DSM	Demand Side Management
DSR	Distribution Safety Rules
DUoS	Distribution Use of System

E

EA	Environment Agency
EAVC	Enhanced Automatic Voltage Control
ECHA	European Chemical Agency
EES	Electrical Energy Storage
EMC	Electromagnetic Compatibility
EMF	Electromotive Force
EMR	Electricity Market Reform
ENA	Energy Networks Association
ENW	Electricity North West
EPRI	Electric Power Research Institute
EPSRC	Engineering and Physical Sciences Research Council
ESOF	Energy Storage Operators' Forum
ESQCR	Electricity Safety, Quality and Continuity Regulations
ESS	Energy Storage System
ETI	Energy Technologies Institute
ETP	Energy Technology Perspectives
EV	Electric Vehicle

F

FALCON	Flexible Approaches for Low Carbon Optimised Networks
FAT	Factory Acceptance Test
FCDM	Frequency Control by Demand Management
FES	Future Energy Scenarios
FFR	Firm Frequency Response
FMEA	Failure Modes and Effects Analysis
FSS	Fire Suppression System
FTA	Field Test Article

G

G59	Engineering Recommendation G59
GB	Great Britain
GE	General Electric (company)
GPG	Good Practice Guide
GVEA	Golden Valley Electric Association

H

HAZID	Hazard Identification
HAZOP	Hazard and Operability (Study)
HEML	Hazard Elimination Management Log
Hh	Half Hour
HSE	Health and Safety Executive
HV	High Voltage

I

I&C	Industrial and Commercial
IEA	International Energy Agency
IEC	International Electrotechnical Committee
IET	Institution of Engineering and Technology
IGBT	Insulated Gate Bipolar Transistor
IP	Ingress Protection
IPPC	Integrated Pollution Prevention and Control
ITT	Invitation to Tender

J

JEVA Japanese Electric Vehicle Association

K

KPI Key Performance Indicator

L

LAES Liquid Air Energy Storage
LCN Fund Low Carbon Network Fund
LCO Lithium Cobalt Oxide
LCOE Levelized Cost of Energy
LED Light Emitting Diode
LFP Lithium Iron Phosphate
Li-Ion Lithium-Ion
Li-Po Lithium Polymer
LNG Liquefied Natural Gas
LPA Local Planning Authority
LTO Lithium Titanate
LV Low Voltage
LVD Low Voltage Directive

M

MCCB Moulded Case Circuit Breaker
MSDS Material Safety Datasheet

N

NaS Sodium Sulphur
NASA National Aeronautics and Space Administration
NCA Lithium Nickel Cobalt Aluminium Oxide
NiCd Nickel Cadmium
NiMH Nickel Metal Hydride
NINES Northern Isles New Energy Solutions
NMC Lithium Nickel Manganese Cobalt Oxide
NPV Net Present Value
NPW Net Present Worth
NTSB National Transportation Safety Board

O

O&M Operation and Maintenance
OEM Original Equipment Manufacturer
OHL Overhead Line
OLTC On-Load Tap Changer
ORA Operational Risk Assessment

P

Pb-Acid Lead-Acid
PCS Power Conversion System
PER Pressure Equipment Regulations
PHES Pumped Heat Energy Storage
PHEV Plug-In Hybrid Electric Vehicle
PLS Prospects for Large-Scale Energy Storage in Decarbonised Power Grids
PNO Private Network Operator
PPA Power Purchase Agreement
PPC Premium Power Corporation (company)
PPE Personal Protective Equipment

PQQ	Pre-Qualification Questionnaire
PS	Maximum Allowable Pressure (bar)
PSSR	Pressure Systems Safety Regulations
PURE	Point of Use Reliability Equipment
PV	Photovoltaic
R	
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
RoHS	Restriction of Hazardous Substances (Directive)
RTU	Remote Terminal Unit
S	
SAP	Senior Authorised Person
SAT	Site Acceptance Test
SBP	System Buy Price
SCADA	Supervisory Control and Data Acquisition
SEP	Sound Engineering Practice
SEPA	Scottish Environment Protection Agency
SFARP	So Far As is Reasonably Practicable
SI	Statutory Instrument
SMCS	Storage Management and Control System
SME	Small/Medium Sized Enterprise
SO	System Operator
SoC	State of Charge
Sola Bristol	Sola Bristol (Buildings, Renewables and Integrated Storage, with Tariffs to Overcome network Limitations)
SPV	Simple Pressure Vessels (Safety) Regulations
SPVD	Simple Pressure Vessels Directive
SSEPD	Scottish and Southern Energy Power Distribution
SSP	System Sell Price
STEL	Short Term Exposure Limit
STOR	Short Term Operating Reserve
SVHC	Substances of Very High Concern
SVS	Scaled Validation System
SWIFT	So, What If? Test
T	
T&D	Transmission and Distribution
TEPCO	Tokyo Electric Power Company
TINA	Technology Innovation and Needs Assessment
TO	Transmission Owner
ToU	Time of Use
TPPL	Thin Plate Pure Lead
TRL	Technology Readiness Level
TSO	Transmission System Operator
TVA	Tennessee Valley Authority
U	
UEL	Upper Explosive Limit
UL	Underwriters Laboratory
UPS	Uninterruptible Power Supply
US DOE	United States Department of Energy

V

V	Volume of vessel (litres) (in the context of pressure systems)
VCA	Vehicle Certification Agency
VESDA	Very Early Smoke Detection Apparatus
VLA	Vented Lead-Acid
VoLL	Value of Lost Load
VRFB	Vanadium Redox Flow Battery
VRLA	Valve Regulated Lead-Acid

W

WEL	Workplace Exposure Limit
WG	Working Group
WPD	Western Power Distribution
WSE	Written Scheme of Examination

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1 Introduction

1.1 Background

Electrical Energy Storage (EES) is increasingly recognised as a key enabling technology, in the development and realisation of future low carbon networks. Such networks are necessary in order to support the wider low carbon-agenda, via the decarbonisation of electricity supply and the electrification of many heating and transport loads. These issues are likely to become increasingly pertinent in the years ahead.

EES systems and technologies are being deployed by various parties (distribution and transmission network operators, generators, in homes and businesses etc.) worldwide, both as pilot demonstrations and trials, and in commercial/‘Business as Usual’ (BaU) applications.

In Great Britain, considerable work in this area has been undertaken by Distribution Network Operators (DNOs). To date UK Energy Storage operators have committed to commissioning over 21 grid-connected energy storage projects, with capacity exceeding 16.5 MW and 28 MWh. These demonstrations are often component parts of wider Smart Grid/low carbon network developments, for example as part of Ofgem supported Low Carbon Networks (LCN) Fund projects. Battery based EES systems represent a new and unfamiliar class of technologies to the UK DNO/TO/SO (Transmission Owner/System Operator) sector and, indeed, to the wider power utilities sector. They present a new range of challenges, including:

- Managing the procurement of systems, in the relative absence of directly applicable codes, standards and Engineering Recommendations;
- Obtaining a complete understanding of system performance, including that under failure or abuse conditions;
- The management of the installation and commissioning process;
- The development of appropriate procedures to ensure the safe and efficient operation of systems including developing appropriate Risk Assessments and Method Statements underpinned by a firm evidence base; and
- Developing a viable business case and realising the maximum potential value (both technical and financial) from the operation of an EES system.

The deployment of EES on Transmission and Distribution (T&D) networks is also driving a requirement to review the prevalent safety, regulatory, standards and licensing landscape. This then needs to inform the development of future documentation, in line with emerging technological and operational developments. The Guide aims to give ‘good practice’ from current storage deployments. It may be used to inform the development of Standards, in the future, but is not intended to form a rigid set of guidelines for those developing or installing EES.

This Good Practice Guide (GPG) on Electrical Energy Storage was therefore developed by EA Technology, in collaboration with the Energy Storage Operators’ Forum (ESOF). ESOF comprises:

- Electricity North West (ENW);
- National Grid (as the TO/SO);
- Northern Powergrid;
- Scottish and Southern Energy Power Distribution (SSEPD);
- SP Energy Networks;

- UK Power Networks; and
- Western Power Distribution (WPD).

The Energy Networks Association (ENA) is also represented at ESOF meetings.

The development of the GPG was funded via the Department of Energy and Climate Change's (DECC's) Energy Storage Component Research and Feasibility Study innovation support scheme¹ and the ESOF members (as set out above).

1.2 Aim, Scope and Objectives

The aim of the GPG is to:

- Provide an essential reference tool to those deploying energy storage (primarily within the GB DNO/TO/SO sector), such as to facilitate the successful implementation and deployment of EES systems on T&D networks.

Specific objectives of the GPG are to:

- Be a readily assimilable reference text, suitable for utilisation by staff involved in the deployment of energy storage. The potential readership could include planning engineers, procurement officers, commercial engineers, standards engineers, project managers, safety managers, commissioning engineers and operational personnel;
- Draw upon and encapsulate the practical learning experiences within the ESOF membership base and beyond;
- Identify, qualify and catalogue relevant Standards;
- Identify and highlight examples of best practice, including those in areas not addressed via Standards;
- Demonstrate the technical benefits which can be derived from the operation of energy storage; and
- Show how these technical benefits can form the basis of viable business cases for the deployment of energy storage.

The scope of the Guide (i.e. the technologies included and parts of the lifecycle covered) has been determined by the current deployments of utility scale EES in the UK. In particular, it has been determined by the experience of the ESOF members, obtained via their various projects and the DECC funded demonstration projects. This experience has been summarised via a number of case studies (as described in Section 1.5), which have been used in order to describe the approach taken in deploying EES and the lessons learnt. The technologies within the scope of this GPG are therefore batteries, flow batteries, and thermodynamic cycle systems. These technologies are described within Section 4 and Appendix 3. It is recognised that other energy storage systems are available and have been deployed within the UK (and elsewhere in the world) in various applications. These include pumped hydroelectric schemes, compressed air, supercapacitors, flywheels and hydrogen energy storage. However, these are out of the scope of the present work due to their lower relative applicability to T&D network applications, and the reduced availability of case study material.

¹ <https://connect.innovateuk.org/web/decc-energy-storage-scheme> Accessed 03/01/2014

1.3 Structure and Content

This Guide is divided into a number of sections, each addressing a particular aspect of EES, as follows:

- Section 2 sets out the current “state of the art” with respect to energy storage. This includes the current deployments of utility scale storage, both in the UK and elsewhere in the world, and complementary activities such as the development of cells and batteries for electric vehicles (EVs);
- Section 3 briefly describes the ways in which EES can be used by various stakeholders across the electricity sector. It also shows the applications being addressed by the trials described within the Guide. It is accompanied by Appendix 2 which provides further details of each application.
- Section 4 provides a description of the technologies which can be used for utility scale energy storage and a comparison of their performance metrics. Further details of each technology are given in Appendix 3
- Section 5 summarises the breadth of energy storage activity currently underway in GB and the key lessons learnt.
- Section 6 sets out the codes, standard and licensing requirements which have the potential to affect energy storage in the UK. This includes codes which are specific to energy storage and other codes/standards/legislation which are likely to be relevant to energy storage installations. Further details are given in Appendix 4.
- Section 7 describes the procurement process for energy storage and summarises the lessons learnt in each procurement stage (development of specification, choice of supplier etc.) by the current deployments of energy storage.
- Section 8 addresses the various facets of the installation process, including the underlying legislative requirements, roles and responsibilities and some of the more practical considerations, e.g. with respect to site selection, access, protection settings etc.;
- Section 9 describes some of the hazards which are associated with energy storage installations. The nature of each the hazard, where it arises from and potential mitigation measures are described.
- Section 10 describes the Risk Assessment process. This includes the relevant statutory obligations, the various processes which can be followed and the lessons learnt from current deployments of energy storage.
- Section 11 shows the applications being addressed by the various trials described within this Guide and some examples of the network benefits being provided. Approaches to the scheduling of EES systems are also discussed.
- Section 12 discusses the factors affecting the costs of EES systems and provides some indicative cost data for each technology covered within this Guide. It then reviews the various revenue streams which can be exploited using EES and their respective values. The business models which can be used when deploying EES are also explored.
- Section 13 describes four methodologies which can be used to analyse the cost:benefit case for deploying EES and the advantages and disadvantages of each. A number of illustrative examples are provided, based on the case studies. This section is accompanied by Appendix 5 which provides cost:benefit analysis templates for three of the methods described in Section 13.
- Section 14 concludes the document and summarises its purpose and some potential future developments.
- Section 15 provides links to a number of reports, presentations and other material which provide more detailed information on the subjects and projects within this Guide.

The GPG was developed by EA Technology, supported by contributions from the ESOF membership over a fourteen month period from September 2013 to November 2014. Various announcements and policy developments are included within the document, along with the relevant dates. Further developments may have occurred during the latter stages of the document preparation, which may not be included.

1.4 How to use this Guide

The content within each of the Sections described above has the potential to impact upon a number of stages of an EES project lifecycle. This is summarised on the flow chart on the following page (Figure 1.1). It is intended that this Guide is used as a reference text, with the relevant sections to be consulted as required throughout a project.

Project Lifecycle and Reference Sections of the Guide



Figure 1.1: Project Lifecycle and Reference Sections of the GPG

1.5 Case Studies

The development of the GPG has been informed by the completion of case studies by a number of the ESOF members and the project consortia involved in the energy storage demonstrations funded via the DECC Energy Storage Technology Demonstration Competition. It is recognised this does not represent an exhaustive list of all owners/operators of EES technology within the UK. However, this approach has allowed the inclusion of considerable detail on each project, via engagement with ESOF and DECC.

Each case study relates to a particular deployment of energy storage and describes the technology deployed, the intended application and lessons learnt. A list of the projects included is given in Table 1.1 below. The case studies are reproduced in full in Appendix 1.

Table 1.1: List of Project Case Studies

Project Lead	Project Title/ Location	Technology	Number of Units and Rating
DNO Led Innovation Projects			
Northern Powergrid (A1.1 to A1.6)	Customer Led Network Revolution (CLNR)	Lithium-Ion	1 off 2.5 MVA/5 MWh 2 off 100 kVA/200 kWh 3 off 50 kVA/100 kWh
SSEPD (A1.7)	Chalvey- Low Voltage (LV) Connected Storage	Lithium-Ion	3 off 25 kVA/25 kWh (single phase units)
SSEPD (A1.8)	Orkney Storage Park	Lithium-Ion	1 off 2 MVA/500 kWh
SSEPD (A1.9)	Northern Isle New Energy Solutions (NINES). NaS. Shetland	Sodium-Sulphur	1 off 1 MVA/6 MWh
SSEPD (A1.10)	Northern Isles New Energy Solutions (NINES). Lead-Acid (Pb-Acid) Shetland.	Pb-Acid	1 off 1 MVA/3 MWh
SSEPD (A1.11)	Nairn Flow Battery Trial	Zinc Bromine Flow Battery	1 off 100 kW/150 kWh
UK Power Networks (A1.14)	Hemsby, Norfolk	Lithium-Ion	1 off 200 kVA/200 kWh
UK Power Networks (A1.15)	Smarter Network Storage, Leighton Buzzard	Lithium-Ion	1 off 7.5 MVA (6 MW)/10 MWh
WPD (A1.13)	Sola Bristol (Buildings, Renewables and Integrated Storage, with Tariffs to Overcome network Limitations) (Sola Bristol)	Pb-Acid	26 domestic and 6 commercial installations complete in December 2014. A total of 100 kW/279 kWh.
WPD (A1.12)	Flexible Approaches for Low Carbon Optimised Networks (FALCON)	Sodium-Metal-Halide	5 off 50 kVA/100 kWh
DECC and ETI Funded Projects			
Highview Power Storage (A1.16)	Liquid Nitrogen Cryogenic Energy Storage Demonstration Project	Liquid Air Energy Storage	1 off 5.5 MW (gross) /15 MWh
Renewable Energy Dynamics Technology UK Ltd. (A1.17)	Vanadium Redox Flow Battery (DECC Energy Storage Technology Demonstration Competition)	Vanadium Redox Flow Battery	1 off 105 kW/1.26 MWh
Isentropic (A1.18)	Isentropic Pumped Heat Energy Storage	Pumped Heat Energy Storage	1 off 200 kVA/600 kVAh 1 off 1.4 MVA/5.6 MVAh

2 Current State-of-the-Art

2.1 The Requirement for Electrical Energy Storage

Global and regional forecasts of the market for energy storage have been prepared by the International Energy Agency (IEA) in Energy Technology Perspectives (ETP) 2014 (reported in the Energy Storage Technology Roadmap²) and Prospects for Large-Scale Energy Storage in Decarbonised Power Grids³ (PLS) and are summarised in Table 2.1 below.

Table 2.1: Global and Regional Energy Storage Market Sizes

Region	2009 (Actual)	2015 (Estimate)	2050 (Estimate)	Note
China, India, the EU and USA (ETP 2014)	-	-	310 GW	Estimated requirement for regulating power and load following in a scenario where the electricity supply has been decarbonised in order to limit global temperature rise to 2 K (°C). Based on a total of pumped hydro, compressed air energy storage (CAES), flow batteries and 'other batteries)
Global (PLS)	100 GW		189 – 305 GW	Electrical energy storage and analogues
Western Europe (PLS)	33 GW	-	40-100 GW	
United States (PLS)	-	-	25-45 GW	

In the GB context the support for energy storage as a technology has increased recently, particularly during the last 5 years and as a direct result of the low carbon agenda. However, it should be noted that whilst the low carbon agenda is the current driver for the deployment of EES, other applications can be pursued and can form the business case for EES, regardless of the deployment of renewable generation.

Estimates of the potential application for energy storage devices have been provided from several sources. DECC has published a Technology Innovation Needs Assessment (TINA) for Electricity Networks and Storage⁴ that estimates the energy storage market size to be 7-59 GW in 2050. Imperial College London, working for the Carbon Trust, has estimated the deployment of energy storage, in the presence of competing options, to be between 4 and 25 GW in 2050⁵, dependent on the relative costs of technologies. Imperial College London, working for the DECC, has produced additional estimates of between 6 and 22 GW⁶, depending on the national pathway for energy supply.

The application estimates are summarised in Table 2.2. Estimates for 2020 deployments are noted to be achievable only if energy storage is available at low costs. The forecast needs of the 2050 energy system indicate that the cost of energy storage can be much higher. Higher deployment estimates typically correspond to low capital costs and/or high shares of intermittent generation and vice-versa.

Table 2.2: GB Energy Storage Market Size Forecasts

Source	2009 (Actual)	2020 (Estimate)	2050 (Estimate)	Note
TINA	-	4-17 GW	7-59 GW	

² <http://www.iea.org/publications/freepublications/publication/TechnologyRoadmapEnergyStorage.pdf> Accessed 08/09/2014

³ International Energy Agency, Working Paper, Prospects for Large-Scale Energy Storage in Decarbonised Power Grids, 2009

⁴ Low Carbon Innovation Co-ordination Group, Electricity Networks & Storage (EN&S) Summary Report, August 2012

⁵ The Carbon Trust, Strategic Assessment of the Role and Value of Energy Storage Systems in the UK Low Carbon Energy Future, June 2012

⁶ DECC, Understanding the Balancing Challenge, August 2012

Carbon Trust (Imperial College)	-	2-10 GW	4-25 GW	Distributed storage case
DECC (Imperial College)	-	2 GW	6-22 GW	Over all pathways

2.1.1 Provision of Flexibility in Power Distribution Networks

Renewable energy generation is being installed at every level of the power system and much of that power system has been designed for unidirectional power flows from central generation, via transmission and distribution and to the end-consumer. The way the distribution system has been designed means that in its present form there is more capacity available to *supply* end-users with energy, than to *absorb* energy from them. The distribution network has to become more flexible to be able to provide connections for low-carbon technologies. Investment is required in flexibility and systems that increase the utilisation of existing assets.

Power system assets are capital-intensive and must be operated for long service-lives to facilitate an economically-efficient power system. These investments must be made at low risk to the asset owner to prevent the deleterious effects of stranded assets. This is more of a problem for DNOs, which are natural monopoly businesses subject to regulatory control via defined cycles (presently five yearly, up to March 2015, then eight years to March 2023); than for renewable energy generators that today have the sale price of electricity guaranteed for up-to 25 years, facilitating their access to the appropriate capital.

This leads to the capacity available to absorb energy, across many regions, lagging the rate of installation of renewable energy^{7,8}, which creates network constraints and in-turn leads to high-value applications for “Smart Solutions” to address those constraints. Energy storage is one of those Smart Solutions that is today being trialled in different ways and at different locations, to facilitate the absorption of low carbon technologies. These trials are often aimed merely at understanding the reliability, security and control that these assets can provide on electricity networks as a precursor to routine deployments. DNO experience is now such that a few deployments are being made where those assets will join more-traditional power assets in being integral to normal power system operation.

The three competing flexible technologies (demand-side management, generation-side response via Active Network Management (ANM) and energy storage) each have advantages and disadvantages. The unique advantages of energy storage over its competitors are:

1. The capability to increase or decrease load on thermally-constrained networks, using an asset under the direct control of a network operator;
2. The capability to provide voltage control on voltage-constrained networks, to increase tolerable power flow;
3. The capability to control power factor to reduce network losses and release network capacity;
4. The capability to be deployed as a single asset at a location chosen to solve a network constraint and not to be reliant upon wide-area communications systems to manage the constraint effectively;
5. Storage offers a guaranteed response (subject to being in the correct state of charge, which can be monitored), in contrast to the actions of third parties on the demand side; and

⁷ At the time of writing, network constraints are limiting renewable generating capacity across many regions of Scotland, North Wales, East Anglia and Kent.

⁸ See, for example UK Power Network’s capacity map for renewable generation:

<http://www.ukpowernetworks.co.uk/internet/en/connections/electricity-generation/generation-capacity-maps/>

Accessed 21/02/2014

6. Storage can be both modular and potentially re-locatable, increasing its flexibility.

Energy storage is therefore a flexible tool for the management of electricity networks, and with flexibility being a key advantage in coping with change, there is the potential for significant deployment to support an electricity system suitable for low-carbon technologies.

Whilst progress is being made in understanding and using Smart Solutions and Energy Storage, the capital investment is at present being supplied from innovation funding⁹. Energy Storage is not the only new technology that can augment a network's capacity for load or generation, but it is one of the most difficult to operate economically and often cannot compete with other solutions (at present), at least on the basis of solving a single problem on a network¹⁰. The business case for storage is likely to change over time, particularly in the light of:

- Capital cost reductions due to improvements in technologies and economies of scale as the market for EES increases in size; and
- Any changes in the regulatory regime which combat the present fragmented nature of the value chain.

The business case for storage is explored in more detail via a number of case study examples in Section 13 of this Guide.

These distribution networks applications are presently driving the installation of EES in GB, though they do not provide, at present, the requisite revenue or ownership model necessary to meet the national need for storage in the GB power system.

2.1.2 The GB Power System Need for Storage

In GB today, the power system need for flexibility to cater for changes in the loading condition of the system is met by varied sources including thermal generation, pumped-hydro storage plants and demand-side actions. The GB Transmission System Operator (TSO) has defined several 'reserve' (or 'ancillary') services that suit the provision of flexibility from these sources and the fractional levels of renewable generation connected to the power system today. These reserve services are described further within Section 12.2.

The provision of capacity in the power system is a different matter as time-shifted demand needs to be met. The GB Capacity Market auctions running from 2014 are a mechanism to ensure that the national power requirement can be met¹¹. A portion of the market has been reserved for demand-side services with a capacity value; energy-storage is eligible in this market.

The role of energy storage in meeting low-carbon objectives has been recognised by the then Chief Scientific Advisor to DECC, Professor McKay noting the need for "an Apollo-programme's-worth of storage¹²". In addition, the Chancellor identified grid-scale energy storage as one the "eight great technologies" which will drive future growth in the UK economy¹³ and stated that "greater capability to store electricity is crucial¹⁴". Energy Storage has also received comment in the Carbon Plan¹⁵ and other policy documents.

⁹ See the Energy Networks Association "Smarter Networks Portal", www.smarternetworks.org, accessed 08/01/2014

¹⁰ Energy Networks Association, Assessing the Impact of Low Carbon Technologies on Great Britain's Power Distribution Networks, July 2012, pp106

¹¹ DECC, Electricity Market Reform Delivery Plan, December 2013

¹² Mackay, Professor D. Chief Scientific Advisor to DECC. "Energy Storage for Electricity Networks". Institution of Mechanical Engineers Seminar. London. Tuesday 13th March 2012.

¹³ <http://royalsociety.org/news/2012/osborne-at-royal-society/> Accessed 24/02/2014

¹⁴ Quotation reported by various publications, including The Guardian Environment Network:

<http://www.theguardian.com/environment/2012/nov/09/george-osborne-uk-energy-storage> accessed 16/01/14.

¹⁵ HMG, The Carbon Plan: Delivering our low carbon future, December 2011

Recent public sector investments in storage, to complement the above, include:

- £14 million invested by the Energy Technologies Institute (ETI) in project led by Isentropic Ltd to demonstrate pumped heat energy storage¹⁶;
- £30 million of funding announced from the EPSRC for grid-scale energy storage¹⁷;
- £15 million funding awarded to four consortia via the Energy Storage Technology Demonstration Competition (DECC)¹⁸;
- £2.4 million awarded to seven winning companies via the Energy Storage Component Research & Feasibility Study Competition (DECC)¹⁹;
- The establishment of a Centre for Doctoral Training in relation to Energy Storage and its Applications at the Universities of Sheffield and Southampton (funded by the Engineering and Physical Sciences Research Council (EPSRC))²⁰; and
- £4 million fund for the establishment of a SuperGen Hub in Energy Storage, under the auspices of Professor Bruce, at the University of Oxford. This hub is managed by the EPSRC²¹.

2.2 Complementary Drivers

Since 2009 the American Recovery and Reinvestment Act has invested \$2 billion in battery manufacturing technology (cell-level), \$390 million in the Electrification of Transport and \$680M in Smart Grid and Energy Storage technologies (whole systems)²². Many automobile manufacturers are also in the process of launching various models of EVs, accompanied by the required investment in battery research. In the UK, public funding is also being used to develop batteries for EVs. For example, a £13 million “UK Energy Storage R&D Centre” was created in September 2012, for the advancement of electric and hybrid vehicle batteries²³. The development of batteries for the Electrification of Transport is an area that is expected to yield cost reductions for EES devices in first or second-use applications.

2.3 Global Electrical Energy Storage Deployment in 2014

Currently operational grid-connected energy facilities are dominated by pumped hydroelectric energy storage – in terms of both rating and capacity. The IEA Technology Roadmap estimates that at least 140GW of large-scale energy storage is connected to electricity networks worldwide and 99% of this capacity is comprised of pumped hydro. The remainder comprises a mix of batteries, CAES, flywheels and hydrogen storage². An indication of the level of deployment of batteries and other technologies is provided in Figure 2.3.

Policy developments in a number of countries are driving the uptake of energy storage by various stakeholders. These policies and incentive mechanisms include:

- An Energy Storage Procurement Framework and Design Program established in California. This scheme establishes a target of 1.3GW (relative to peak demand of 60GW) of energy storage to be procured by utilities in California by 2020, with

¹⁶ <http://www.eti.co.uk/eti-invest-14m-in-energy-storage-breakthrough-with-isentropic/> Accessed 18/12/2014

¹⁷ <http://www.epsrc.ac.uk/newsevents/news/2013/Pages/85million.aspx> Accessed 24/02/2014

¹⁸ See <https://www.gov.uk/government/news/8-million-boost-for-energy-storage-innovation> Accessed 17/02/2014

¹⁹ DECC Energy Storage Innovation. Electricity Storage Network Symposium. Presentation by Sally Fenton. Wednesday January 2014. Available from: http://www.electricitystorage.co.uk/index.php/download_file/view/49/153/ Accessed 12/11/2014

²⁰ <http://www.epsrc.ac.uk/newsevents/news/2014/Pages/19newcdts.aspx> Accessed 20/01/2014

²¹ <http://www.epsrc.ac.uk/newsevents/news/newssupergenthub/> Accessed 22/09/2014

²² See recipient database available at <http://energy.gov/downloads/recovery-act-recipient-data> accessed 09/01/2014

²³ <http://news.bis.gov.uk/Press-Releases/Multi-million-boost-for-UK-electric-vehicle-battery-technology-67f95.aspx> Accessed 20/01/2014.

installations operational no later than 2024. This mandate is partly driven by a need to support reliability, grid operation and renewables integration against a target of reducing emissions by 80% by 2050 compared to 1990 levels²⁴.

- The Ontario Government announced plans to procure 50MW of energy storage by the end of 2014. A number of systems have been procured relative to this target, based on battery, flywheel, hydrogen and thermal energy storage²⁵.
- An incentive scheme has been launched in Germany to subsidise the installation of energy storage alongside PV generation (ratings of less than 30kW). The funding takes the form of a small grant (€3,000 relative to an average cost (PV plus storage system) of €20,000 to €28,000) and a low interest loan²⁶. At the time of writing, it was estimated that 6,000 solar energy storage systems had been installed under the scheme²⁷.
- Subsidies are available to individuals and businesses in Japan to install lithium-ion (Li-Ion) battery storage alongside renewable generation. The subsidy will pay up to two thirds of the cost of the system, capped at \$9,846 for individuals and \$982,000 for businesses²⁸.

The United States Department of Energy (US DOE) maintains a global database of energy storage projects²⁹ that shows 800 MW of battery, flow battery and thermodynamic energy storage EES projects underway, as of September 2014. The majority of these projects are based in the United States, which has 343 MW either commissioned or planned.

Figure 2.1 presents the cumulative capacity of these projects, from 2004 onwards, for European countries, the United States and Canada.

²⁴ As described at the "From Megawatts to Gigawatts" California's Energy Storage Procurement under the California Public Utilities Commission (CPUC) Framework. 7th November 2013.

²⁵ <http://storage.pv-tech.org/news/ontario-selects-technologies-for-34mw-grid-storage-trial> Accessed 28/08/2014

²⁶ <http://die-sonne-speichern.de/faq/> Accessed 24/01/2014 (website in German)

²⁷ <http://cleantechnica.com/2014/06/09/solar-energy-storage-system-market-germany-approaching-boom/> Accessed 28/08/2014.

²⁸ <http://www.pv-tech.org/news/japan-launches-subsidies-for-lithium-ion-battery-storage> Accessed 04/06/2014

²⁹ See <http://www.energystorageexchange.org/projects>, accessed 13/11/2013

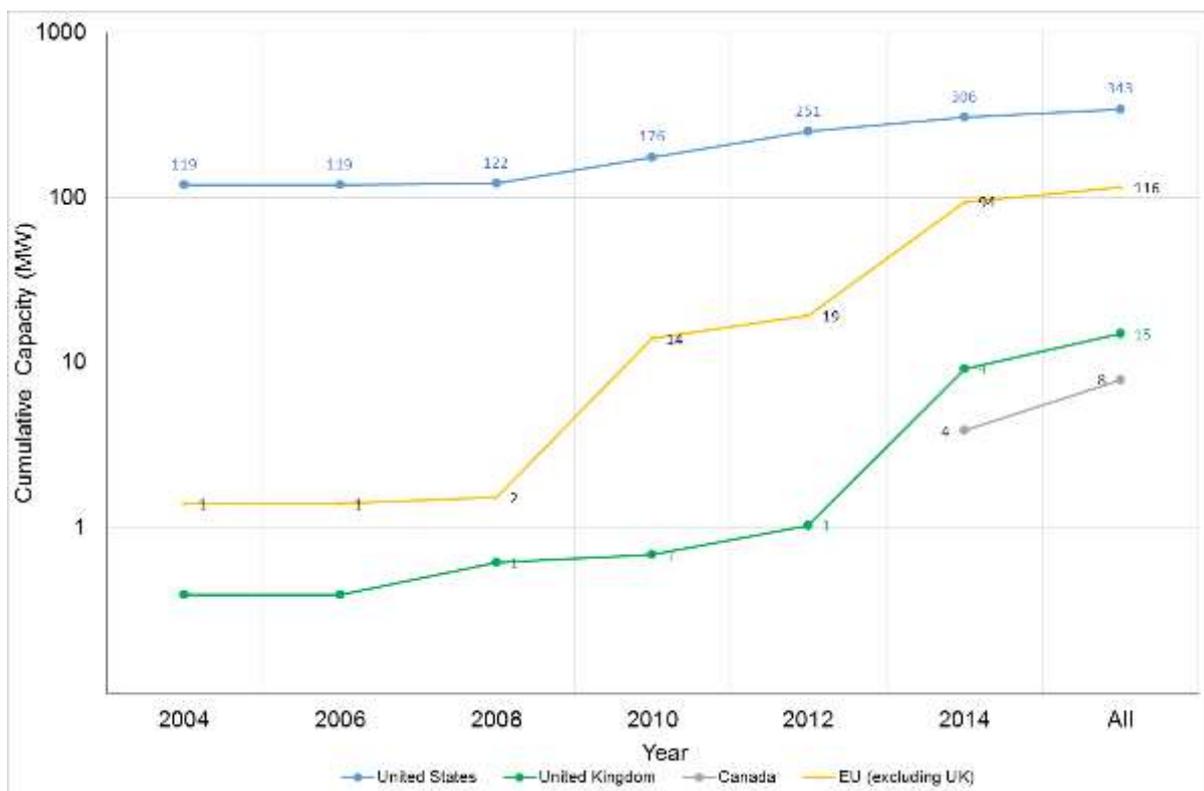


Figure 2.1: Electrical Energy Storage Projects

(N.B. This graph includes storage projects based on batteries, flow batteries and thermodynamic cycles with a status of ‘Contracted’, ‘Decommissioned’, ‘Offline/Under Repair’, ‘Operational’ and ‘Under Construction’)

Figure 2.2 below shows the status of the projects included in the graph above (i.e. battery, flow batteries and thermodynamic cycle energy storage in the USA, Canada, and the EU). This shows that whilst 294MW of storage is registered as ‘operational’, there is also a significant amount ‘under construction’. Figure 2.1 and Figure 2.2 exclude those projects which have been ‘announced’ but are not yet under construction – inclusion of these projects would increase the total amount by a further 138MW (from 16 projects).

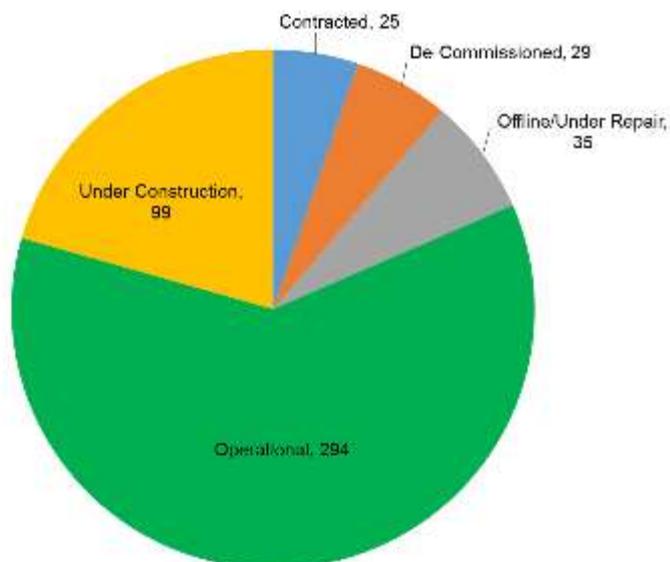


Figure 2.2: Status of EES Projects in US, Canada and the EU (September 2014)

Figure 2.3 shows the different technologies which are being deployed worldwide. This may be affected by the period of time over which EES has been installed in a given country, and the applications required. For example, early demonstrations of utility scale EES were primarily in the USA. At this early stage, Pb-Acid and NiCd were closest to market readiness and this may have influenced the dominance of these technologies.

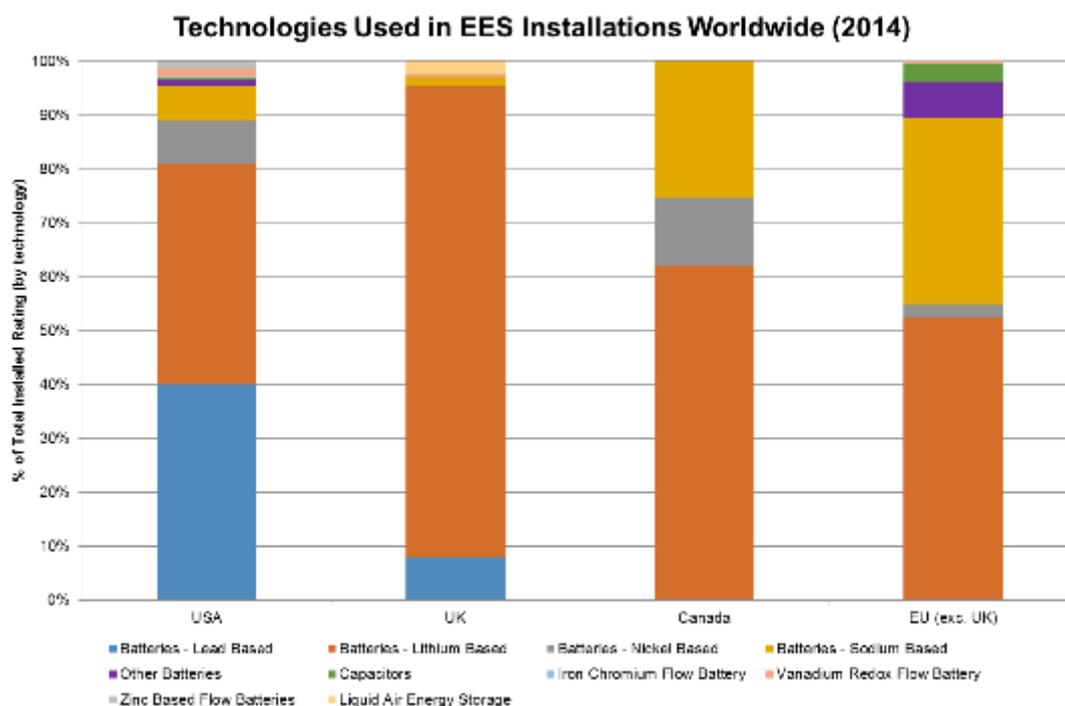


Figure 2.3: Technologies Used in EES Installations Worldwide (2014)

(N.B. This graph includes storage projects based on batteries, flow batteries and thermodynamic cycles with a status of 'Contracted', 'Decommissioned', 'Offline/Under Repair', 'Operational' and 'Under Construction'). Details of the specific electrochemistries included under each technology grouping are given in³⁰.

2.4 Deployments of Electrical Energy Storage in GB

In GB, ESOF has been established to facilitate collaboration and progress in energy storage matters, amongst network operating companies. ESOF has produced details of the various installations that make up the GB portfolio of DNO Electrical Energy Storage devices. Summary details and locations are provided in Figure 2.4. It should be noted that this diagram shows those installations which have been completed by DNOs. Other demonstrations and commercial installations are not included. Details on the functional roles of these devices are presented in Section 11.

³⁰ Batteries – Lead Based: Lead Acid, Advanced Lead Acid, Lead Carbon, Valve Regulated Lead Acid, Sealed Lead Acid, UltraBattery.

Batteries – Lithium Based: Lithium Ferrous Phosphate, Lithium-Ion, Lithium-Ion Titanate, Lithium-Ion Phosphate, Lithium-Manganese Oxide, Lithium Polymer, Lithium Cobalt Aluminium.

Batteries – Nickel Based: Nickel Cadmium, Nickel Iron, Nickel Cobalt Manganese

Batteries – Sodium Based: Sodium Sulphur, Sodium Nickel Chloride

Other Batteries: Electrochemical, Hybrid Batteries, Aqueous Hybrid Ion

Capacitors: Electrochemical Capacitors, Ultracapacitors

Zinc Based Flow Batteries: Zinc Bromine Redox Flow Batteries, Zinc Bromide, Zinc Nickel Oxide Flow Battery, Zinc Iron Flow Battery



Figure 2.4: GB DNO Deployment of Electrical Energy Storage (at 1st December 2014)

There are further energy storage installations that are not owned/operated by DNOs. A number of these are being funded via DECC's Energy Storage Technology Demonstration Competition. The projects being funded via this mechanism are:

- A distributed system totalling 0.525MWh of capacity across more than 300 sites. The consortium running this project is led by Moixa Technology Ltd. and also includes KiWi Power, Good Energy, AVC NextGen and Northern Powergrid. The principal application is to reduce peak energy demand. A number of different battery electrochemistries will be used in the project, which will involve householders across the UK³¹.
- A 105kW/1.25MWh Vanadium:Vanadium flow battery project on the Isle of Gigha, off the West Coast of Scotland. The principal application in this project is to remove constraints relating to the connection of a fourth wind turbine on the island. This consortium is being led by REDT and also involves SSEPD, EA Technology, Community Energy Scotland and Gigha Green Power Ltd³². A case study giving further details of this project is contained in Section A1.17, Appendix 1.
- A project integrating both 'new' and '2nd life' EV batteries to facilitate rapid charging of EVs and their integration with solar and wind generation. This project is being undertaken in Norfolk by the EVEREST (Electric Vehicle Embedded Renewable Energy Storage & Transmission) consortium, led by EValu8 Transport Innovations Ltd³³.
- A 5MW/15MWh "liquid air" energy storage system developed by Highview Power Storage. This system is being deployed at a Viridor landfill gas generation plant in the UK. In addition to providing energy storage, the plant will convert low grade waste heat from the landfill gas plant to power³⁴. A case study giving further details of this project is contained in Section A1.16, Appendix 1.

³¹ <http://www.moixatechnology.com/press-release/moixa-wins-share-of-decc-5m-contracts-for-energy-storage.php> Accessed 07/09/2014

³² <http://www.redtenenergy.com/news/redt-wins-%C2%A336m-decc-award-energy-storage> Accessed 07/09/2014

³³ DECC Energy Storage Technology Demonstration Competition. Phase 1 Report (Authorised Content Version, Suitable for Public Release).

³⁴ <http://www.highview-power.com/portfolio-items/pre-commercial-demonstrator-online-2015/?portfolioID=48> Accessed 07/09/2014

A number of other energy storage deployments are underway in the UK, as follows:

- A 236kW/126kWh lithium-Ion system is to be installed at the University of Manchester and connected to the local distribution network. The complete system is being supplied by Siemens (two 118kVA power converters, four 45kWh battery racks, a transformer and a control and management system). The University of Manchester is undertaking research (funded by the EPSRC) using the energy storage unit as part of a high-powered grid interface in-loop test bed. It is also investigating the use of graphene in energy storage devices to improve performance and lifetime³⁵.
- A 2 MW/1 MWh Lithium-Titanate battery system (supplied by Toshiba) is being installed at Willenhall primary substation (near Wolverhampton, West Midlands) in order to explore the advantages of grid connected energy storage. This project is being led by the University of Sheffield and is being funded by the EPSRC³⁶.
- The ETI have invested £14 million in Isentropic (a developer of thermodynamic energy storage)³⁷. Two systems will be installed as part of this project – a scaled validation system (200 kVA/600 kWh) and a field test article (1.4 MVA/5.6 MWh). A case study giving further details of this project is contained in Section A1.18, Appendix 1.

A selection of photographs of GB DNO installations are presented in Figure 2.5 to Figure 2.16.

³⁵ [http://www.siemens.com/press/en/pressrelease/2014/infrastructure-cities/low-medium-voltage/iclmv20140502.htm?content\[\]=ICLMV](http://www.siemens.com/press/en/pressrelease/2014/infrastructure-cities/low-medium-voltage/iclmv20140502.htm?content[]=ICLMV) Accessed 07/09/2014

³⁶ <http://www.sheffield.ac.uk/faculty/engineering/news/2014/giant-battery> Accessed 07/09/2014

³⁷ <http://www.eti.co.uk/eti-invest-14m-in-energy-storage-breakthrough-with-isentropic/> Accessed 07/09/2014



Figure 2.5: 2 MW, 500 kWh ESS at Kirkwall, Orkney (Source: SSEPD)



Figure 2.6: 1 MW, 6 MWh ESS at Lerwick, Shetland (Source: SSEPD)



Figure 2.7: 200 kW, 200 kWh ESS at Martham, Norfolk (Source: UK Power Networks)



Figure 2.8: 3x 25kW, 25kWh ESS at Chalvey, Slough (Source: SSEPD)



Figure 2.9: 2.5 MW, 5 MWh ESS at Darlington, Co. Durham (Source: Northern Powergrid)



Figure 2.10: 50 kW, 100 kWh ESS in Sheffield (Source: Northern Powergrid)



Figure 2.11: 100 kW, 200 kWh ESS at Darlington (Source: Northern Powergrid)



Figure 2.12: 6 MW, 10 MWh ESS at Leighton Buzzard, Bedfordshire (Source: UK Power Networks)



Figure 2.13: 1 MW, 3 MWh EES at Lerwick, Shetland (Source: SSEPD)



Figure 2.14: 2 kW, 4 kWh Domestic EES Installation as part of SolaBristol (Source: WPD)



Figure 2.15: 50 kW, 100 kWh EES Installation as part of Project FALCON (Source: WPD)



Figure 2.16: Substation containing 50 kW, 100kWh EES System as part of the CLNR project (Source: Northern Powergrid)

3 Applications of Electrical Energy Storage Systems

This section briefly describes the various ways in which EES can be used on electrical power systems, in practice. It also describes the applications which are being investigated by current trials.

As an asset that can control its power and be built at various scales, EES finds itself applicable in all the auspices of an electrical power system. Hence there is a plethora of applications that are associated with the essence of charge and discharge, but applied under various names according to the assets, users and type of operation in the relevant electrical system.

Table 3.1 maps a range of high-level applications to actors in the electricity system.

3.1 Description of Applications

Converter-connected energy storage gives the operator freedom over both real and reactive power and therefore can theoretically be applied to mitigate almost any power flow problem on electricity networks. Thus the range of possible applications for energy storage is wide. These applications are briefly described within this section and further details are given for each in Appendix 2.

- **Arbitrage:** EES can be discharged at times of high generation prices and re-charged at times of lower prices. The use of EES to increase self-consumption, for example in domestic grid-connected solar-photovoltaic (PV) storage, is a form of arbitrage made possible by the difference in value between exporting electricity to the network (at 5 p/kWh)³⁸. and buying electricity for consumption (at 14 p/kWh)³⁹
- **Portfolio balancing services:** Generators and Suppliers that are parties in the Balancing and Settlement Code can use flexible generation, demand or EES to reduce the imbalance of their positions and their exposure to imbalance charges. The same sources of flexibility can also be used to reduce their proportion of the cost of using the transmission system.
- **Deferral and avoidance of network asset reinforcement:** EES systems can defer or avoid load-related investment in networks by reducing power flow through assets so as to reduce the effective peak load and therefore the need for replacement. It can either provide a long-term solution to the asset replacement problem, i.e. until the end of the original asset's service-life, a short-term solution while preparations are being made for a long-term solution, or a short-term solution for a short-term increase in power flow.

³⁸ Ofgem, Feed-in Tariff Payment Rate Table for Photovoltaic Eligible Installations for FIT (1 April 2014 – 31 December 2014), Higher Rate.

³⁹ DECC Statistics. Annual domestic energy bills. Average variable unit costs and fixed costs for electricity for selected towns and cities in the UK. Available from: <https://www.gov.uk/government/statistical-data-sets/annual-domestic-energy-price-statistics> Accessed 12/11/2014

Table 3.1: Mapping of EES Applications to Electricity Actors

Application	DNO	TSO	Energy Supplier	Generators	Private Operators	Indicative EES Characteristics
Energy Arbitrage	x	x	✓	✓ (via Power Purchase Agreement (PPA))	✓ (via PPA)	<4 h discharge to cover peak demand periods (potentially greater in scenarios with high renewable energy penetration)
Peak Shaving or Thermal Support	✓	x (accessed via market)	x	x	✓ (via PPA & under contract to DNO)	<4 h discharge to cover peak demand periods
Voltage Support	✓	✓	x	x	✓ (under contract to DNO)	Continuous despatch of reactive power is necessary
Constraint Management	✓	x (accessed via market)	x	✓	✓ (under contract to generator, DNO or TSO)	From ½ h discharge to multiple hours, depends on constraint
System Balancing Services	x	x	✓	✓	✓ (under contract to TSO)	>2 h discharge, <3 MW requires aggregation
Portfolio Balancing Services	x	x	✓	✓	✓ (under contract to Supplier or Generator)	>1/2 h discharge
Typical EES Characteristics	50 kW to 10 MW	Defines the market in system balancing services; cannot deliver services itself	Multi-GW portfolios suggest scales of >100 MW are necessary for impact	< 4 kW (domestic) to 10s of MW for power parks and combustion-generator support	Private operators will seek to combine several applications	

- **Renewable energy constraint management:** Network assets are defined as constrained when the addition of any further generation or load would cause them to operate outside of their ratings. It is common for constraints to arise due to the connection of variable generation (e.g. wind power) to the distribution network. They form a 'bottle neck' and limit the amount of renewable generation that can be accepted onto the network. EES systems can be applied to reduce power flow at the constrained asset, thus allowing the constraint to be managed. Systems operating in this way can be linked into a wider ANM scheme to maximise connection of renewable generation. Two examples of this are contained within the project case studies – Orkney Energy Storage Park (see A1.8) and the REDT Flow Battery Demonstration Project (see A1.17).
- **Power system optimisation:** Power system optimisation comprises the fine-tuning of power flow that allows additional capacity for load or generation to be released on existing networks.
 - **Control of power flow, power factor and voltage:** The Power Conversion System (PCS) necessary within EES systems to convert from DC energy sources to AC can also enable the device to dynamically despatch reactive power in order to influence voltage and power factor. Real power (from the battery storage) can also be used to effect voltage control.
 - **Matching supply and demand on an operational (i.e. real-time) timescale:** Delivery of balancing mechanisms (i.e. to balance the second-by-second variations in supply and demand) is managed by the TSO. They are currently delivered by both the generation and demand side. EES systems can operate on either side, either charging or discharging (subject to the required rating and state-of-charge).
 - **Phase-balancing:** The best utilisation of network assets and minimisation of network losses occurs at unity power factor and an equal magnitude of current in each phase. Unbalanced current mainly originates from single-phase loads, which are a greater fraction of demand on residential and light commercial networks. The greater the single-phase current relative to power flow over all three phases, the greater the imbalance factor. EES systems with the requisite power electronics, control and common DC bus are capable of transferring power between phases, to achieve balanced phase current.
- **Power system stability:** The design of synchronous generators on the power system facilitates a natural return to a stable condition following typical disturbances. Energy storage devices with fast response can contribute by implementing a synthetic inertial response.
- **Power quality:**
 - **Mitigation of harmonic emissions:** Modern electrical appliances and heat pumps are increasingly being connected through power electronics control systems. These systems rely on digital switching which create current harmonics 'emissions' on power network, which in turn induce voltage harmonics. These emissions cause increased heating of network assets and use capacity. Power conversion equipment in EES systems (if equipped with appropriate filters and capacitive energy storage on the DC-link) can be used to implement "active filtering" for harmonics, whereby the device synthesises the harmonic currents necessary to repair the voltage waveform.
 - **Flicker reduction:** Flicker is the phenomenon of human sensitivity to the change in luminance of a source of illumination. It is carried on power networks by fluctuations in voltage magnitude that occur with periods from

sub-to multiple seconds. These changes occur due to step-changes in load or changes in network configuration (e.g. electric showers on LV networks, large industrial motors on LV and High Voltage (HV) networks). The levels of flicker which may occur in the future (e.g. due to increased use of power electronics conversion equipment and new loads such as heat pumps and EVs) is not yet clear. However, it may be possible to specify energy storage devices such that they can offer sub-cycle response to voltage fluctuations and so reduce the severity of flicker.

- **Flexible networks for low carbon technologies:** The low carbon agenda submits electricity networks to a pace of change that is much greater than historical. There are also uncertainties around the generation and technology mixes, location and magnitude. The traditional planning process is orientated towards new connections and steady growth in demand by the population. This is unsuitable for the more unpredictable changes as a result of the low carbon agenda. If new assets are installed to create additional capacity, and the expected changes do not materialise, then the new capacity would not be utilised efficiently. Newer, more flexible solutions offer a method of providing capacity where necessary via deploying solutions incrementally and at a rate appropriate to the pace of change that is being experienced. EES systems are one such solution, alongside demand-side response and generation side response via ANM schemes.
- **Mitigating the impacts of new demand and generation technologies:** Energy storage offers a solution for mitigating the potential impacts of various new demand and generation technologies (e.g. EVs, heat pumps, PV generation). For example, export from PV systems may become an issue during the summer months. Local installations of EES would allow this surplus daytime energy to be stored (thus preventing reverse power flow) and then discharged to support evening demand. This evening demand may include EV charging load.

However, a number of components of an EES have the potential to place limitations on the range of applications that can be addressed by a particular system, as follows:

- The particular energy storage device: e.g. due to the fundamental characteristics of the storage media such as the continuous and short-term rated power, hourly duration of storage or cycle-life;
- The power converter: e.g. due to its continuous and short-term ratings, whether the topology allows for inter-phase power transfer or the characteristics and ratings of the filters;
- The advantage of servicing multiple applications will be reduced if the applications are exclusive; and
- The control methods: e.g. due to ability to despatch real power in relation to thermal constraints or reactive power in relation to voltage constraints.

In practice, consideration of the application must take place prior to the specification of EES so that the chosen design and technology is suitable (see Section 7 for further details on procurement). Application considerations can drive the specification of converter components as well as the energy storage media. Harmonic filtering and phase-balancing are two applications that can be specified, that have profound implications for the design of the converter.

Section 11 (and Table 11.1 and Table 11.2 in particular) provides key details of all the network-operator-owned or contracted EES deployed in GB and the functional capability of

each. It also shows the applications addressed by each trial, and an example of the benefits which can be obtained.

3.2 Ownership Models

In GB, funding for EES pilot applications in the DNO sector has been provided predominantly from the LCN Fund. This fund was established with the express intent to stimulate distribution network innovation, such as to evaluate new methods to overcome the network challenges as GB moves to a low carbon economy.

Such EES trials have typically sought to evaluate EES in a technical sense, that is, network operators have purchased the devices in order to understand and optimise their applications, costs and benefits. These trials have purchased EES assets.

As technical learning has progressed, trials have also sought to understand and optimise commercial arrangements. One method has been to explore third-party service provision (e.g. the approach taken for the Orkney Storage Park project, see Appendix 1, Section A1.8). Another method has been to explore the provision of services for third parties from DNO-owned assets.

The “Smarter Network Storage” project⁴⁰ (SNS) is specifically investigating how to reduce the cost of EES for DNOs and has investigated different sorts of business models within the constraints of the regulatory framework. It has identified the two methods identified above as being most suitable for this purpose. It should be noted that the prevalent regulatory framework applying to a potential owner/operator of EES can strongly affect the revenue streams which can be captured, and thus the business case for deploying storage. This is explored in greater detail in Sections 12 and 13.

As can be seen from Table 3.1, third parties acting as private operators or, as identified in SNS, capacity-off take by third-parties is necessary to unlock the greatest range of possible applications and service revenues.

Further details of the various business/ownership models which can be used when deploying EES are given in Section 12.3.

⁴⁰ See <https://www.ukpowernetworks.co.uk/internet/en/community/smarter-network-storage/>, accessed 6/8/2014

4 EES Systems and Technologies

Electrical Energy Storage can be provided by a range of systems and technologies, such as:

- Electrochemical energy storage systems - principally batteries and flow batteries;
- Kinetic energy storage systems - such as flywheels;
- Thermodynamic energy storage systems - based on the Brayton cycle or cryogenic systems; and
- Potential energy storage systems - such as compressed air and pumped hydroelectric installations (e.g. Dinorwig)

These various technologies have differing capabilities in terms of their discharge time at the rated power (capacity) and system power (rating). A number of technologies are shown in the Ragone plot below, with some potential applications. It should be noted that the figures shown are intended for use as a general comparison, for conceptual purposes only. They are based on published data⁴¹ and information from the case studies provided in Appendix 1.

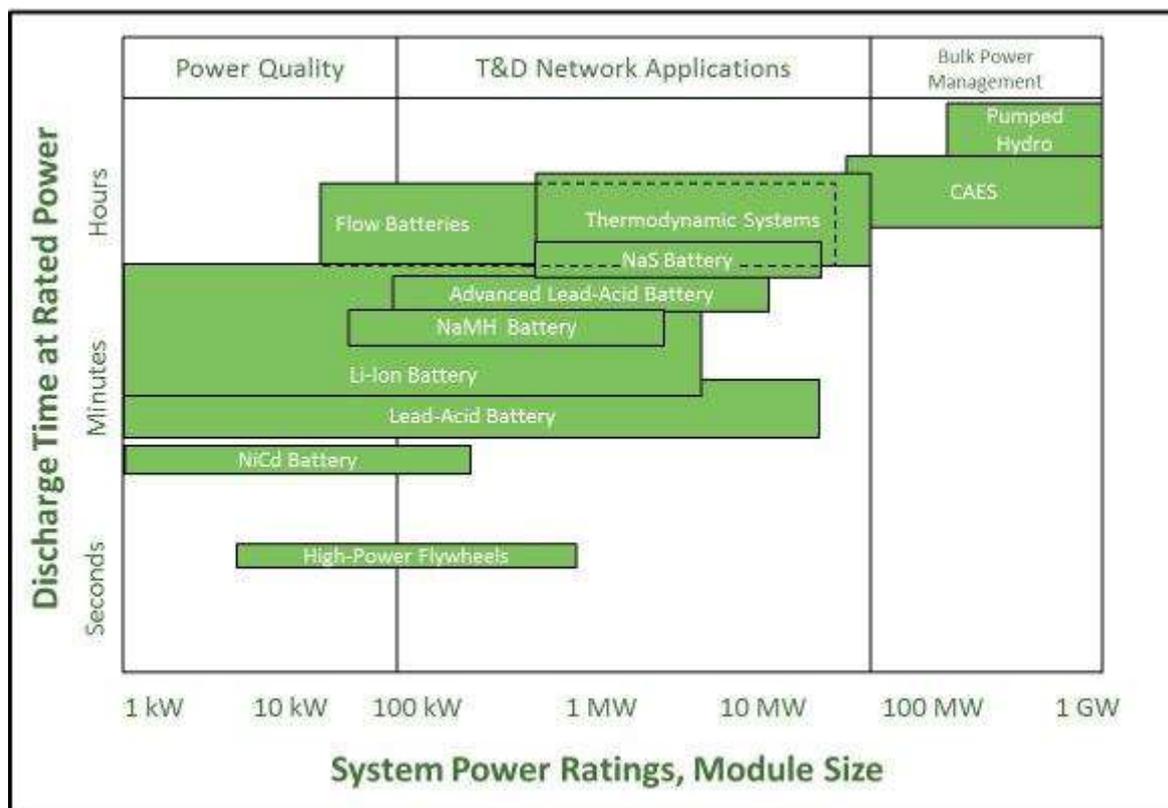


Figure 4.1: Ragone Plot of Different EES Technologies

This Guide is principally concerned with systems applicable to power distribution networks on a short/medium term time horizon. Hence, the technologies of most interest to the GPG comprise – battery energy storage, flow batteries and thermodynamic cycle systems. Each of these technology areas is described in the sub-sections below. This is complemented by further information for electrochemical systems in Appendix 3.

⁴¹ For example, that included within the DOE/EPRI 2013 Electricity Storage Handbook in Collaboration with NRECA. Available online: <http://www.sandia.gov/ess/publications/SAND2013-5131.pdf> Accessed 18/12/2014.

4.1 Battery Energy Storage Technologies

A battery is a device consisting of one or more electrochemical cells that converts stored chemical energy into electrical energy. Each cell comprises a positive (cathode) and negative (anode) electrode and an electrolyte that allows ions to flow between the electrodes. During discharge, electrical current is generated from the two electrodes and is fed into an external circuit. The electrochemical process is reversed during the charging process, where an external current is supplied back into the cell.

Batteries can be classified into two types: primary batteries (non-rechargeable) and secondary batteries (rechargeable). Only secondary batteries are considered in the context of utility scale energy storage. This section summarises the following characteristics of different battery electrochemistries:

- Technical characteristics (e.g. energy density, cycle lifetime);
- Maturity of the technology; and
- Current applications of the technology, both in the UK and elsewhere.

Short summaries are provided within this section, with further information being provided in Appendix 3. The principal electrochemistries of interest to the DNO/TO/SO sector comprise:

- **Lead Acid (Pb-Acid):** The most mature technology option, which has been used in a number of deployments worldwide. Two Pb-Acid systems have been deployed by DNOs within the UK. Pb-Acid systems are cost competitive and reliable, but suffer from limited energy density and relatively poor cycle life.
- **Nickel Cadmium (NiCd):** A further mature technology option, although with fewer deployments worldwide than for Pb-Acid systems. It has not been deployed within the UK context at a utility scale to date and its future deployment at a utility scale appears likely to be limited, e.g. due to the toxicity issues outlined below. Its advantages include a high energy density, robustness and the capability to discharge at a relatively fast rate. However, it is known to suffer from “memory effects” (decaying capacity over time when the system is not fully discharged before being recharged). There are also stringent rules outlining the use and recycling of cadmium, due to its toxicity.
- **High Temperature Sodium Based Systems:** There are a limited number of commercially available high temperature sodium based systems. Sodium based systems offer a higher energy density, an extended cycle life and high charge/discharge efficiencies. However, they can require precise thermal management.
- **Li-Ion:** Li-Ion based systems at a utility scale are one of the more recent developments in the energy storage field. There a number of varieties of Li-Ion based electrochemistries and further details are provided in A3.1.4.1, along with the features, advantages and disadvantages of each. In general, Li-Ion offers a higher energy density (when compared to other technologies), good cycle life, low maintenance requirements and relatively low self-discharge. However, costs remain relatively high and the systems must be maintained within well-defined operating limits (e.g. via a Battery Management System (BMS)) to prevent permanent cell damage or failure). There are a growing number of utility scale Li-Ion energy storage deployments worldwide. It is also being used by GB DNOs, for example by SSEPD as part of the Orkney Energy Storage Park and Chalvey projects, Northern Powergrid in their Customer Led Network Revolution project and by UK Power Networks at Hemsby and Leighton Buzzard (Smarter Network Storage).

The table on the following page summarises the indicative characteristics of each of these technologies, their advantages and disadvantages. It should be noted that these represent typical values and are intended as a general guide only. Further information and references are provided within Appendix 3. The Technology Readiness Level (TRL) is provided based on the current status of deployments within Great Britain. A definition of the TRL scale is provided in Appendix 3.

Table 4.1: Illustrative Comparison of Different Battery EES Technologies (Further information and full references are provided in Appendix 3)

	Pb-Acid	NiCd	High Temperature Sodium Based Systems	Li-Ion
Energy Density (Wh/kg)	30 – 50	40 – 60	75-250	75 – 250
Power Density (W/kg)*	75 – 300	150 – 300	90-230	150 - 315
Typical Power Rating (MW)	0.005 – 100	0.001 – 40	0.2-100	0.003 – 100
Cycle Life (cycles)	200 – 1,000	1,500 – 3,000	2,500-4,500	4,000 – 10,000
Chronological Life (yr)	5 – 20	10 – 20	5-15	5 – 15
Round- Trip Efficiency (%)	63 – 90	60 - 90	89-92	75 - 90
Technology Readiness Level (TRL)	9	9	7-9	8-9
GB DNO/TO/SO Deployments (Operational or Planned)	NINES (Shetland) Sola Bristol	None	FALCON	CLNR Chalvey LV Connected Storage Orkney Storage Park Hemsby Smarter Network Storage
Advantages	<ul style="list-style-type: none"> • Cost-competitive • Highly reliable • Well established service and support network • Multiple vendors • Established recycling route • Applicable British Standard 	<ul style="list-style-type: none"> • High energy density • Higher robustness • High rate discharge capacity • High reliability • High power at low State-of-Charge characteristics • Well established service and support network • Multiple vendors • Applicable British Standard 	<ul style="list-style-type: none"> • High energy density • High charge/discharge efficiency • Long cycle life • Good low ambient temperature performance 	<ul style="list-style-type: none"> • High energy density • Good cycle life • Low maintenance • Relatively low self-discharge • Extensive worldwide research and development programmes, increasing performance and driving down costs • Multiple vendors
Disadvantages	<ul style="list-style-type: none"> • Low energy density • Limited cycle life • Poor low temperature performance 	<ul style="list-style-type: none"> • Susceptibility to “memory effect” • Cadmium toxicity poses a hazard to the environment and human health 	<ul style="list-style-type: none"> • Absence of directly applicable standards for GB stationary applications • Limited number of vendors • Very little experience in GB context • Parasitic heating loads particularly at low utilisations 	<ul style="list-style-type: none"> • Possible restrictions on transportation • Has to be maintained within well-defined operating limits to prevent permanent cell damage or failure • Potential concerns regarding failure modes • Potential competition for raw materials with other applications

* These represent a typical value. For many technologies, short term ratings can be obtained, often at several multiples of the nominal rating.

4.2 Flow Batteries

Electrochemical flow battery systems, also known as redox flow cells, or flow cells, convert chemical energy into electrical energy (and vice versa) via a reversible electrochemical reaction between two liquid electrolyte solutions. In contrast with secondary batteries, as set out in Section 4.1, it is the electrolyte solutions themselves, which provide the energy storage medium in a flow battery. The power and energy ratings represent independent variables in a flow battery system, with the power rating determined by the active area of the cell stack and with storage capacity determined by the electrolyte quantity. It is this decoupling of power and energy ratings that provides one of the advantages of flow battery systems, in that more storage capacity can be provided for a given charge/discharge rating, by simply increasing the electrolyte volume. Flow battery systems are therefore often considered more suitable for extended storage durations of circa 10 to 15 hours duration, i.e. outside of the normal operating envelope of many battery systems, although they can equally be designed for higher power/shorter capacity operating regimes, as may be required.

This and other principal advantages for flow cell/flow battery systems include^{42,43}:

- De-coupling of power rating and energy storage capacity, allowing systems to be optimised for specific power/energy requirements;
- Potential for upward scalability, particularly in terms of energy storage capacity, via the provision of increased amount of electrolyte tankage;
- Suitability for deep discharge applications;
- Low (minimal) self-discharge characteristics;
- Potential for competitive cost bases (£/kW; £/kWh), particularly as systems are scaled up;
- Long cycle life, typically extending up to 10,000 cycles duration (projected lifetime);
- Recyclability/re-usability of electrolyte solutions, upon de-commissioning; and
- Suitability for a range of applications.

Equally however, flow cell/flow battery systems also possess some less advantageous features, including:

- Their relatively modest energy/power densities;
- The distributed nature of the systems in themselves, comprising the cell stack assemblies, electrolyte storage, pumps, valves, pipework and associated Balance-of-Plant (B-o-P); and
- Associated with the consideration above, flow cell/flow battery systems are generally less suitable for smaller scale applications.

4.2.1 Make-up, Construction and Operating Principle

A redox flow battery system is made up of a number of electrochemical cells. Each cell has two compartments, one for each electrolyte, usually physically separated by a membrane (although some systems do not require this). The electrolytes are stored in two tanks and are pumped through the cell stack across a membrane where one form of the electrolyte is electrochemically oxidised and the other is electrochemically reduced.

This creates a current that is collected by electrodes and made available to the external circuit, most usually to a PCS. The reaction is reversible, allowing the system to be charged,

⁴² Redox Flow Cells for Energy Conversion. Ponce de Leon C., Frias-Ferrer A., Gonzalez-Garcia J., Szanto D.A., and Walsh F.C. *Journal of Power Sources* 160 (2006) 716-732.

⁴³ DOE/EPRI 2013 Electricity Storage Handbook in Collaboration with NRECA. SAND2013-5131. July 2013. Available online: <http://www.sandia.gov/ess/publications/SAND2013-5131.pdf> Accessed 18/12/2014.

discharged and recharged. A simplified schematic of a redox flow battery energy storage system is shown in Figure 4.2.

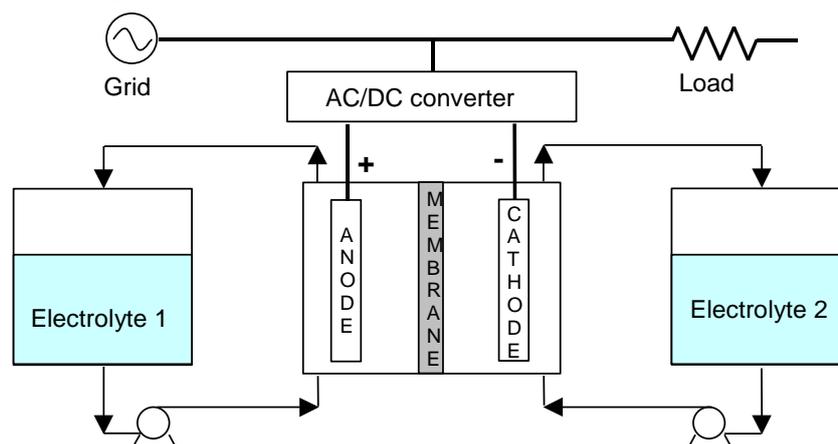


Figure 4.2: Schematic of a Redox Flow Battery Energy Storage System

The basic operating principle of all flow battery systems is therefore that of a reversible reduction/oxidation (redox) reaction between two electrochemical species. Oxidation reactions are defined as those that involve the removal of electrons from a species, whilst reduction reactions are those that involve the addition of electrons. The chemical species concerned can therefore switch between different states of charge during a reversible redox reaction, known as their oxidation states. A reversible pair of oxidation states for any particular element is known as a redox couple or half-cell, with oxidation reactions increasing the oxidation states to more positive values, whilst reduction reactions reduce the oxidation state to more negative values.

Redox flow battery systems all involve an important class of elements, known as the transition metals, for their operation. At least seven electrochemical couples are at various stages of research and development for application in flow battery energy storage systems. These combinations, and their TRL at the time of writing, (based on a global, rather than UK perspective) are shown in Table 4.2 below.

**Table 4.2: Technology Readiness Levels of Flow Battery Systems
(on a global perspective)**

Technology	TRL
Vanadium:Vanadium	9
Zinc Bromine	9
Iron Chromium	7
Bromide Polysulphide	5
Zinc Cerium	4
Vanadium Bromine	3
Soluble Lead	3

To date, the main thrust of developmental and demonstration activities have centred on the first five principal electrochemistries listed above. To date, only Vanadium:Vanadium and Zinc Bromine systems have been developed and deployed as complete integrated EES systems at any significant scale and to any significant extent (although also noting also the first network application of the iron chromium system).

At the time of writing, the US DOE International Energy Storage Database includes 66.3MW of utility flow battery storage, either installed, committed or de-commissioned in 54 projects, worldwide⁴⁴, with all but 0.4MW of this capacity being attributable to vanadium redox and

⁴⁴ DOE International Energy Storage Data Base; <http://www.energystorageexchange.org/projects> (accessed 23rd July 2014).

zinc bromine systems. Table 4.3 summarises the deployment status of such systems, as abstracted from the DOE reference data.

Table 4.3: Utility Flow Battery Installations

*(installed, committed or de-commissioned and subject to full verification)
(as abstracted from US DOE International Energy Storage Database, July 2014)*

Technology	Capacity Base (MW)	No. of Installations
Vanadium Redox	32.1	25
Zinc Bromine	33.8	26
Other	0.4	3
Totals:-	66.3	54

The polysulphide bromide and zinc cerium systems were each developed for utility scale applications, prior to their respective developmental programmes being curtailed. Active R&D programmes do however continue in relation to the other electrochemistries.

4.2.2 Technology Characteristics

A brief summary of the two former electrochemistries (Vanadium:Vanadium and Zinc Bromine) is presented below. Further details of these two electrochemistries and supplementary content in relation to the others is provided in Appendix 3, Section A3.2.

- Vanadium:Vanadium:** this system employs the V2/V3 and V4/V5 redox couples in sulphuric acid as the negative and positive electrodes respectively. The technology has been developed by a number of companies, both inside and outside the UK. One developer of the technology in the UK has received a grant from DECC to demonstrate a 105kW/1.26MWh system to be deployed on the Isle of Gigha, off the West coast of Scotland⁴⁵. Further details of this project are given within the case study (see Section A1.17, Appendix 1).
- Zinc Bromine:** The zinc bromine flow battery consists of a zinc negative electrode and a bromine positive electrode separated by a microporous separator. Solutions of zinc and a complex bromine compound are circulated through the two compartments of the cell from two separate reservoirs. This technology has been developed by various companies since the early 1970s, with a number of multi-kWh units being trialled in demonstration projects. A 100kW/150kWh zinc bromine flow battery was installed for initial testing by SSEPD at Nairn. Further details of this project are given in the project case study (see Section A1.11, Appendix 1). Table 4.4 (abstracted from the Electric Power Research Institute (EPRI) Energy Storage Technology Options White Paper⁴⁶), provides an indicative overview of their performance, in three reference applications scenarios (based on 2010 data). The data presented are based upon EPRI estimates, derived from technology assessments, discussions with vendors and utilities and feedback from operational experience.

⁴⁵ £5M boost for Energy Storage Innovation. Department of Energy and Climate Change Press Release, 4th November 2013. <https://www.gov.uk/government/news/5-million-boost-for-energy-storage-innovation> (accessed 23rd July 2014).

⁴⁶ Electrical Energy Storage Technology Options. A White Paper on Applications, Costs and Benefits. EPRI 1020676, December 2010.

Table 4.4: Summary Performance Data, for Vanadium Redox and Zinc Bromine Flow Battery Systems*(abstracted from EPRI 1020676)*

System	Application	Capacity (kWh)	Rating (kW)	Duration (hours)	% efficiency; Total cycles
Vanadium Redox	Utility T&D Grid Support	4,000 to 40,000	1,000 to 10,000	4	65-70%; (>10,000)
	Energy Management	600 to 4,000	200 to 1,200	3.3 to 3.5	65-70%; (>10,000)
	-	-	-	-	-
Zinc Bromine	Utility T&D Grid Support	5,000 to 50,000	1,000 to 10,000	5	60-65%; (>10,000)
	Energy Management	625 to 2,500	125 to 500	5	60-63%; (>10,000)
	Distributed Storage	100	50	2	60%; (>10,000)

4.3 Thermodynamic Cycle Systems

This method of storing energy relies on the use of heating and cooling of materials via particular thermodynamic cycles. Two types of thermodynamic cycle energy storage systems are being deployed within the current round of demonstration activity in the UK, as follows:

- **Liquid Air Energy Storage (LAES):** this technology is being developed by Highview Power Storage and is based on the principle of ‘charging’ the store via liquefying air which is then stored. The store is ‘discharged’ by pumping and heating the liquid to produce high pressure gas which drives a turbine to generate electricity.
- **Pumped Heat Electricity Storage (PHES):** Energy is stored thermally in two stores of material (a hot store and a cold store) via the use of reciprocating positive displacement machinery.

CAES systems also technically fall under the definition of ‘thermodynamic energy storage’ above, but are out of scope of this Guide.

The operating principle of each of these technologies, their advantages and disadvantages and current developmental status are described in the two sub-sections below.

4.3.1 Liquid Air Energy Storage

LAES is currently being developed in the UK by Highview Power Storage. This technology stores energy in the form of liquefied air. Figure 4.3 shows a representation of the Highview plant, including the sub-systems used for each stage of the process.



Figure 4.3: LAES Plant (Copyright: Highview Power Storage)

The operating (charge/store/discharge) cycle can be described as follows⁴⁷:

1. **Charging:** Electricity is used to power an air liquefier. During this process air is drawn from the surrounding environment, cleaned, compressed and cooled to sub-zero temperatures (-196°C), such that it liquefies. This decreases the volume of the air substantially, such that 700 litres of ambient air becomes 1 litre of liquid air.
2. **Store:** The liquefied air is stored at low pressures in bulk storage tanks. Standard tanks (e.g. used for bulk storage of liquid nitrogen and oxygen or liquefied natural gas (LNG)) can be used.
3. **Discharging/Power Recovery:** To discharge the store, liquid air from the tanks is pumped to high pressure. Ambient heat or stored heat from the air liquefier (or other co-located industrial processes which produce waste heat) is applied to the liquid air via heat exchangers and an intermediate heat transfer fluid evaporating and superheating the air to form a high pressure gas. The high pressure gas is used to drive a turbine and generate electricity. During this stage, very cold air is exhausted and the cold energy contained in the exhaust air is captured in a high-grade cold store, to be used to enhance the efficiency of the liquefaction process (Stage 1). Depending on the location of the plant, waste cold could also be supplied from another industrial process.

This system is based on existing industrial processes and equipment, integrated to form an EES system. This use of existing equipment offers advantages due to the maturity and reliability of the components used. LAES has the potential to offer multi-MW storage for multiple hours. It is also possible to scale capacity and rating independently. Rating is governed by the sizing of the liquefier and turbines, whereas extra capacity can be added by increasing the size of the storage tanks. Where a particular site allows, this could also allow extra capacity to be added incrementally.

A LAES system operated on the principles described above (points 1-3) provides a round-trip efficiency of around 60%. Where the plant can be integrated with other processes for waste heat/cold recovery then the efficiency is around 70%⁴⁸.

⁴⁷ Based on text from Liquid Air Energy Storage. Highview Power Storage. 2014. Available from: <http://www.highview-power.com/wp-content/uploads/Highview-Brochure-2014.pdf> Accessed 24/09/2014

⁴⁸ <http://www.highview-power.com/company/process/> Accessed 24/09/2014

The relatively high rating and duration has the potential to support a number of the applications identified in Table 3.1 for different stakeholders within the energy system (DNOs, TSO, energy suppliers and private network operators). LAES offers a slower response time when compared to other technologies such as batteries, but also provides a degree of inertia, which is an attractive feature from a SO perspective.

The process has been successfully tested and demonstrated via a 350kW/2.5MWh pilot plant, co-located at SSE Slough Heat and Power. This plant has been operational since 2011 and is due to be moved to the new Cryogenic Energy Storage Centre based at the University of Birmingham⁴⁹. A pre-commercial demonstration unit is being constructed as part of the DECC Energy Storage Technology Demonstration. This 4.5MW/15MWh system will be co-located with a Viridor landfill gas power generation plant at Pilsworth, Greater Manchester. The system will demonstrate the provision of ancillary services (see Section 12.2.2.3) and is expected to be operational in early 2015. Further details of this project are given within the project case study in Section A1.16, Appendix 1.

4.3.2 Pumped Heat Electricity Storage

PHES is being developed in the UK by Isentropic Ltd. In a PHES system energy is stored thermally (i.e. as a temperature difference between two thermal energy stores). The gravel within the hot store and cold store is respectively heated and cooled by circulating a gaseous working fluid.

A schematic showing the configuration of the system is shown below.

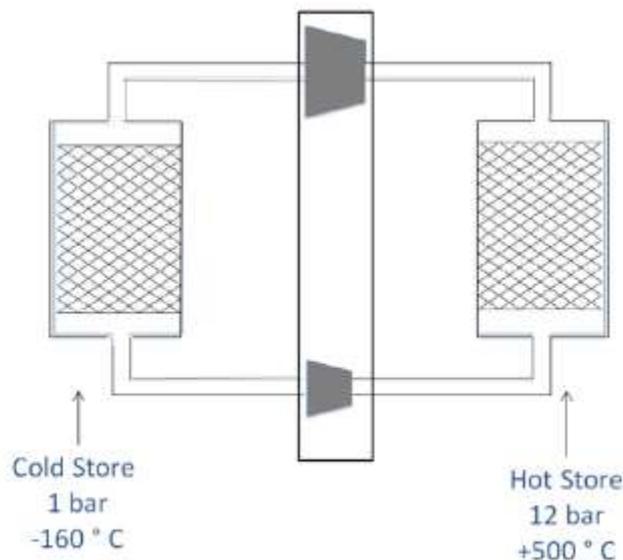


Figure 4.4: Schematic Diagram of a PHES System (Source: Isentropic Ltd.)

The operating (charge/store/discharge) cycle can be described as follows⁵⁰:

1. **Charging:** Electricity is used to power the power machinery, which operates in a similar manner to a heat pump. Gas at the top of the 'cold' store is at ambient temperature and pressure. The power machinery is used to adiabatically compress and heat the gas before it flows to the top of the 'hot' side. The heat from the gas is transferred to the gravel in the 'hot' store, increasing its temperature. It then leaves the tank at ambient temperature, but still at high pressure (12 bar). The working fluid is then expanded and cooled through the power machinery and returns to the base of

⁴⁹ <http://www.birmingham.ac.uk/news/latest/2014/07/liquid-air-energy-storage-01-07-14.aspx> Accessed 24/09/2014

⁵⁰ Based on process description in video accessed via: <http://www.isentropic.co.uk/our-phes-technology> Isentropic. Accessed 24/09/2014

the 'cold' tank, cooling the gravel in the store. As the state of charge increases (i.e. more energy is stored) a 'hot' front moves down the 'hot' store, and 'cold' front moves up the 'cold' store.

2. **Store:** The heat and cold is held in the insulated 'hot' and 'cold' stores before the energy is recovered.
3. **Discharging/Power Recovery:** In this mode of operation, the working fluid circulates through the power machinery and stores in reverse, discharging the respective stores and driving a generator connected to the power machinery.

Isentropic Ltd. claim that the system can operate with a round trip efficiency (electricity in to electricity out) in the range of 72 to 80%⁵¹. PHES is being developed in order to be competitive with other multi-MW, multiple hour storage technologies such as pumped hydro. Advantages of the system are claimed by Isentropic Ltd. as⁵²:

- Low cost;
- High round trip efficiency;
- Safety and environmentally inert, due to the materials used (steel, argon and gravel);
- No geographical constraints in locating the system (e.g. compared to pumped hydro); and
- Long chronological and cycle life.

The development of a 1.5MW/6MWh demonstration unit is being funded by the Energy Technologies Institute (ETI). The system will be deployed in the Midlands, within a WPD licence area. Further details of this project are given within the project case study in Section A1.18, Appendix 1.

⁵¹ <http://www.isentropic.co.uk/our-phes-technology> Accessed 24/09/2014

⁵² <http://www.isentropic.co.uk/> Accessed 24/09/2014

5 UK Learning Experiences to Date

To date UK Energy Storage operators have committed to commissioning over 21 grid-connected energy storage projects, with capacity exceeding 16.5 MW and 28 MWh. In addition to the energy storage installations procured by DNOs as part of LCN Fund projects, EES has been procured by a number of other parties through both private and governmental funding. These projects have facilitated the development of significant learning and expertise.

This chapter highlights UK storage installations, both planned and commissioned, and notes key learning points with linkage to later chapters in this Good Practice Guide. Figure 5.1 and Figure 5.2 summarise the geographic and network location of these installations, while Table 5.1 lists Energy Storage installations with key differentiators and lessons learnt for each.



Figure 5.1: Deployment of Storage in the UK (at 1st December 2014)

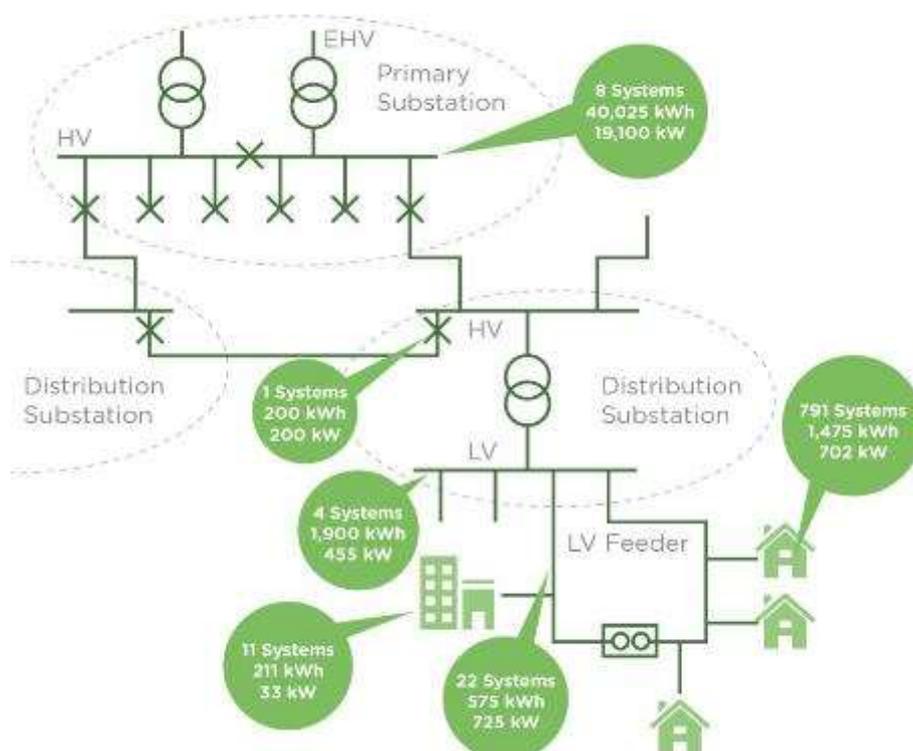


Figure 5.2: Network Connection of Proposed and Deployed Storage in the UK (DNO projects and DECC demonstrators) (at 1 December 2014)

5.1 Key Lessons Learnt

Network connected EES projects undertaken in the UK to date have allowed a number of key lessons to be learnt and these are described within the suite of project case studies. These have often been noted across several projects, this section highlights the key lessons and signposts the sections of this Good Practice Guide which are relevant to the lessons.

5.1.1 Successful Operation of EES Systems

The various deployments of EES, of different sizes and at different points on the distribution network (as shown in Figure 5.1 and Figure 5.2) have shown that the technology can be deployed as an operational network asset. These deployments have serviced various applications and the resulting network benefits are explored in greater detail in Section 11.

5.1.2 Commercial Case

Significant learning has been generated around the commercial case for energy storage, and a number of different ownership/operator models have been trialled. Within the project case studies, this includes the owner/operator model (e.g. a DNO who purchases a storage asset and then operates this solely for network applications), 3rd party ownership (e.g. whereby a DNO procures a service to fulfil the need for energy storage on their network) and DNO ownership, with operation by a 3rd party. The full evaluation of the business case for energy storage in a number of projects is ongoing and this is an area which is likely to develop further in the future. Outputs from individual projects (e.g. LCN Fund close-down reports, available via the ENA Smarter Networks Portal⁵³) will publicise these results in due course. However, interim publications from a number of LCN Fund projects are available,

⁵³ <http://www.smarternetworks.org/ProjectList.aspx?TechnologyID=7> Accessed 22/09/2014

including UK Power Networks' Smarter Network Storage⁵⁴. Links to additional sources of information are also provided within Section 15.

5.1.3 Legislation, Codes and Standards

The majority of EES installations surveyed noted a lack of applicable Legislation, Codes and Standards, with the exception of those applying to Pb-Acid battery storage systems. Safety standards which do exist are often focussed at the cell level (e.g. abuse testing of single Li-Ion cells). Compliance of cells with such standards gives some assurance over the safety features of a system. However, these standards fail to consider cell to cell propagation, or larger events which may affect multiple cells or modules

This absence of guidance forms part of the rationale for the development of this GPG. The majority of installations utilised a range of Codes and Standards in conjunction with detailed Safety Case assessments. This approach required significant effort both during project delivery and during procurement, as tender returns could not be compared against a single Standard. Section 6 of this Good Practice Guide summarises those Codes, Standards and legislative requirements which have been found to apply.

5.1.4 Maturity of the Supply Base for Network Connected Electrical Energy Storage

The supply base for network connected EES (particularly supplying to GB) has been noted to be relatively immature. This becomes apparent in a number of areas, most particularly around procurement (Section 7) where a number of projects noted difficulties with identification and assessment of suppliers of network connected EES. In addition, the relatively small number of EES installations in the UK have meant that storage operators have been required to develop Operational Procedures, Codes of Practice and Safety Procedures; often via engagement with external stakeholders and experts. Sections 9 and 10 cover relevant Hazards and the Risk Assessment process, respectively.

5.1.5 Protection

All the projects reported utilising connections compliant with ENA Engineering Recommendation G59/- or G83/-, depending on the rating of the installation. However, concerns have been raised that this approach restricts the ability of EES to contribute to the network where voltage or frequency are outside normal ranges. In addition, protection of DC circuits is relatively unusual in the GB DNO environment and learning has been noted around this issue. Learning around protection is captured within Section 8.

5.1.6 Site Selection

Despite the variation in both technology and scale of the EES installations reviewed, there is noticeable similarity in the learning reported around site selection, considered in Section 8. Primarily, this learning is around the energy density and mass of the present range of Electrical Energy Storage technologies. This can make the use of EES within existing substation or customer sites challenging in terms of footprint and ground loading. Further learning was raised around the need to note planning and safety considerations during site selection, which can ease later stages of an installation.

5.2 Summary of Energy Storage Installations

As part of the production of this Good Practice Guide, members of ESOF and other energy storage operators were invited to submit case studies summarising their experience of

⁵⁴ Smarter Network Storage Low Carbon Network Fund Progress Report June 2014, UK Power Networks, June 2014. Available: [http://www.smarternetworks.org/Files/Smarter_Network_Storage_\(SNS\)_140818161518.pdf](http://www.smarternetworks.org/Files/Smarter_Network_Storage_(SNS)_140818161518.pdf)

procuring and operating EES. The case study responses are included as Appendix 1. Table 5.1 summarises those projects which have provided input to this guide, with key differentiators and notable lessons learnt. Many of the projects included are still ongoing at the time of writing and further 'lessons learnt' may be reported at a later date, via the channels listed in Section 15.

Table 5.1: Storage Installations and Key Lessons Learnt

Project	Operator	Technology	Differentiators	Key Lessons Learnt to Date
LCN Fund Projects				
Customer-Led Network Revolution	Northern Powergrid	Lithium Ion Iron Nanophosphate	Multiple storage devices of different sizes interacting with multiple technologies as part of a large Smart Grid trial	<p>There are very few standards for battery and PCS devices that can be quoted in the specification.</p> <p>Existing installation base of large scale batteries is not yet global and testing, legislation, operational practice and distribution and transmission codes of practice and safety rules are not well defined to the manufacturers and designers.</p> <p>Build the relationship with those who will operate the device as early as possible. Involve them in the safety procedure discussions.</p>
LV Connected Batteries	SSEPD	Lithium Ion (Nickel Manganese Cobalt)	<p>Part of Zero Carbon Homes Project</p> <p>Constraint mitigation for both demand and embedded generation</p>	<p>Taking a product specifically built for the US market and modifying it for the UK is likely to result in issues with integration etc. The main difficulties in this installation were with the communications side e.g. the link to the SCADA system / remote access.</p> <p>Remote access is key to supporting the project and should be arranged prior to installation</p> <p>Completing a full safety case for a new project is costly and takes a great deal of time / resource. This is not feasible going forward for every new project; there needs to be more responsibility on the system supplier to provide an adequate assurance the system is safe. This may involve input from the suppliers of the various sub-systems within the installation, where the supplier is a system integrator.</p>
Orkney Energy Storage Park	SSEPD	Lithium Ion (Nickel Manganese Cobalt)	<p>First MW scale grid supporting battery in the UK</p> <p>First service contract trialled for constraint management</p> <p>First load to be controlled by an Active Network Management (ANM) scheme in the UK</p>	<p>Few overarching codes and standards apply to Li-Ion systems. This means that a far more in-depth safety case is required to demonstrate compliance.</p> <p>G59/- has implications for non-stable networks</p> <p>Engage with the local emergency services early and consistently. Ensure that people attending meetings are suitably senior to understand the overall application</p>

Project	Operator	Technology	Differentiators	Key Lessons Learnt to Date
1MW Battery, Shetland	SSEPD	Sodium Sulphur	First MW scale grid supporting battery procurement UK	<p>Majority of regulations covering battery systems are aimed at specific technologies, but do not exclude others.</p> <p>No codes and standards which are directly applicable/relevant to this technology.</p> <p>Importance of stakeholder engagement, when using permitted development (not a full consultation planning process)</p> <p>How isolation will be achieved and safety locks applied, is an important design consideration.</p>
1MW Battery, Shetland	SSEPD	Valve Regulated Lead Acid	<p>First VRLA grid supporting battery in the UK</p> <p>Largest VRLA battery in Europe</p>	<p>Codes and standards for Pb-Acid battery systems are mature and robust; this is a significant advantage in building a safety case and proving compliance. These codes and standards are described within Section 6 of this Guide.</p> <p>In comparison to the NaS battery, installation time was significantly longer. However, as the method utilised off-site construction and was highly repetitive, the process was simpler.</p> <p>It was concluded that the Pb-Acid batteries used are “articles” under REACH regulations and do not constitute “dangerous substances” under COMAH.</p>
SoLA BRISTOL	WPD	Lead Acid (gel electrolyte)	<p>Batteries installed in customer properties</p> <p>Storage installed in conjunction with PV and DC circuits</p> <p>Batteries “shared” between DNO and customer</p>	<p>Refresher training courses required due to time delays between installs and the innovative nature of the installations i.e. not your usual every day work.</p> <p>Boarding of lofts and lifting of batteries needs to be completed as a separate task in case of delays.</p> <p>Customers have bespoke lighting that cannot be converted to DC.</p>

Project	Operator	Technology	Differentiators	Key Lessons Learnt to Date
FALCON	WPD	Sodium Nickel Chloride	First UK installation of this battery technology	<p>Most codes are US-based and few manufacturers offer certification to UK specific codes.</p> <p>Density of energy in current battery energy storage technologies is not compatible with the available space in many existing distribution substations.</p> <p>Site selection can significantly help to reduce hazards</p> <p>Protection of the equipment via G59/- is essential and overlooked by US suppliers.</p> <p>Using BAU procedures to disconnect the equipment allows any authorised staff member to remove the device from the network and leave any fault-finding to more suitably qualified staff.</p>
Hemsby	UKPN	Lithium-Ion	First Electrical Energy Storage device connected to a distribution network ⁵⁵	<p>There are very few standards for battery and PCS devices that can be quoted in the specification.</p> <p>As the technology is still immature careful coordination with Procurement has to be maintained.</p> <p>Still unclear whether it is better to choose a battery supplier who subcontracts a PCS supplier or vice versa or an integrator who subcontracts both major components.</p> <p>Protection co-ordination of the DC side can be challenging. DC rated fuses were required to protect the DC cables.</p> <p>Only connect the installation to the network when the contractor has completed all cold commissioning. Once connected it becomes part of the network and bound by DSR and DNO safety procedures.</p>

⁵⁵ Under prevalent Ofgem regulatory regime. The former Manweb company deployed a 40 kVA/80 kWh Pb-Acid system for load levelling purposes in Wrexham, in the late 1980s.

Project	Operator	Technology	Differentiators	Key Lessons Learnt to Date
Smarter Network Storage	UKPN	Lithium-Ion	<p>First battery to be incorporated in the TSO portfolio of balancing plant</p> <p>Focus on commercial and regulatory considerations</p>	<p>An Achilles search was substituted with intensive internal market search as it was deemed that Achilles did not have a robust or up to date view of the relevant market for grid-scale energy storage systems and lacks many appropriate categories for such a solution.</p> <p>Securing planning consents required a significant amount of additional time, engagement and cost than anticipated. Pre-application guidance from the council was invaluable in early identification of the key areas to address.</p> <p>The public consultation exercise highlighted that the nature of the technology was of relatively little concern to local residents.</p> <p>Additional site safety inductions were needed once batteries were present on site due to the residual stored energy, despite not being connected to the network.</p> <p>The application of some standard charges as part of The Electricity Supplier Obligations could lead to disadvantages for storage operators, and double counting of industry charges – in particular the Climate Change Levy (CCL) and Contracts for Difference and Feed in Tariffs.</p>
DECC Funded Demonstrator Projects				
REDT – Gigha Flow Battery	REDT	Vanadium Redox Flow Battery	<p>Grid-scale flow battery demonstration</p> <p>De-constraining of renewable generation capacity</p>	<p>Essential to consult all relevant parties at the earliest opportunity. The need to implement changes after the commencement of a project costs time and money.</p> <p>All the advice and co-operation provided has been of considerable assistance in the thorough planning and execution of the project.</p> <p>VRFB energy storage technology is relatively unknown so it has been necessary to inform and educate all organisations consulted before relevant risks could be properly assessed. Again, such consultations very early in the project programme have proven to be invaluable.</p>

Project	Operator	Technology	Differentiators	Key Lessons Learnt to Date
Highview Liquid Air Energy Storage System	Highview Power Storage	Liquid Air Energy Storage	<p>Thermodynamic Storage technology</p> <p>Integration with waste to energy generation to increase efficiency</p> <p>Bidding into capacity markets and simulation of “firming” of variable renewable generation</p>	To be released as project progresses
ETI Assisted Projects				
Distribution Scale Energy Storage	WPD	Isentropic® Pumped Heat Energy Storage	Pumped Heat Energy Storage Technology Demonstration	<p>Pressure vessels are a well-established technology with a number of associated relevant codes and standards. However it is not an area often encountered by a DNO.</p> <p>The relevant codes and standards from the chemical industry are probably the most appropriate to PHES.</p> <p>It is possible for a custom design to be under-written by a number of bodies to reduce risk.</p>

6 Codes, Standards and Legislative Requirements

6.1 Introduction

This section outlines the codes, standards and legislative requirements which impact on the installation and operation of EES systems. It reflects the position of the relevant codes, standards and legislation at the time of writing. This sub-section outlines the codes, standards and legislation which may be relevant to different technologies/sub-systems. The remaining sub-sections provide detailed information in relation to a number of codes, standards etc.

The majority of this section is also relevant for stakeholders installing EES systems within their own site/premises or private networks. An inventory of safety related Codes and Standards for EES systems has also been produced for the USA and published by Pacific Northwest National Laboratory⁵⁶. Although not directly relevant to the UK context it describes a number of codes and standards which are relevant to both individual components/sub-systems within an EES unit and installations as a whole. This publication is also accompanied by a companion document which provides an overview of Codes, Standards and Regulations developments and deployments in the USA⁵⁷. A summary of the Codes, Standards and Regulations and their applicability to the different EES technologies is given in Table 6.1. Note that Table 6.1 provides an overview based on the case studies in Appendix 1 and should not be used as a substitute for full consideration of all relevant codes, standards and regulations.

Table 6.1: Applicability of Legislation, Codes and Standards to Different EES Technologies

Legislation/ Code/ Standard	EES Technology					
	Li-Ion	Pb-Acid	NiCd	High Temperature Sodium Flow Batteries	Thermo-dynamic Systems	
Applicability to EES Site						
Health and Safety at Work etc. Act 1974	✓✓	✓✓	✓✓	✓✓	✓✓	✓✓
The Planning (Control of Major Accident Hazards) Regulations 1999	✓	✓	✓	✓	✓	✓
Construction (Design and Management) Regulations 2007	✓✓	✓✓	✓✓	✓✓	✓✓	✓
Management of Health and Safety at Work Regulations 1999 and amendments	✓✓	✓✓	✓✓	✓✓	✓✓	✓✓
Local Authority Planning Permission	✓✓	✓✓	✓✓	✓✓	✓✓	✓
Hazardous Substances Consent					✓	✓
Integrated Pollution Prevention and Control	✓	✓	✓	✓	✓	✓
						EES Technology

⁵⁶Available from: http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-23618.pdf Accessed 22/09/2014

⁵⁷ Available from: http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-23578.pdf Accessed 24/09/2014

Legislation/ Code/ Standard	Li-Ion	Pb-Acid	NiCd	High Temperature Sodium Flow Batteries	Thermo-dynamic Systems
Applicability to EES System					
ENA Engineering Recommendation G5/- Managing Harmonics	✓✓	✓✓	✓✓	✓✓	✓✓
EN 50272-2 Safety Requirements for Secondary Batteries and Battery Installations	✓	✓✓	✓✓	✓	✓
Electrical Equipment (Safety) Regulations 1994	✓✓	✓✓	✓✓	✓✓	✓✓
Wiring Regulations (BS 7671:2008(2011))	✓✓	✓✓	✓✓	✓✓	✓✓
Electricity at Work Regulations 1989	✓✓	✓✓	✓✓	✓✓	✓✓
Dangerous Substances and Explosive Atmospheres Regulations 2002	✓	✓	✓		✓
Low Voltage Equipment Directive (EU Directive 2006/95/EC)	✓✓	✓✓	✓✓	✓✓	✓✓
Simple Pressure Vessels Directive (EU Directive 2009/105/EC)					✓
Pressure Equipment Directive (EU Directive 97/23/EC)					✓
EMC Directive (EU Directive 2004/108/EC)	✓✓	✓✓	✓✓	✓✓	✓✓
Machinery Directive (EU Directive 2006/42/EC)					✓✓
IEC 61000-4-2; Electrostatic Discharge Immunity Tests	✓✓	✓✓	✓✓	✓✓	✓✓
ANSI C57.12.28. Pad Mounted Equipment Enclosure Integrity	✓	✓	✓	✓	✓
IEEE P2030.3- Standard for Test Procedures for Electric Energy Storage Equipment and Systems for Electric Power Systems Applications	✓	✓	✓	✓	✓
ANSI/IEEE C2-1997 National Electrical Safety Code	✓	✓	✓	✓	✓
Applicability to Storage Medium					
Control of Substances Hazardous to Health Regulations 2002		✓			✓✓
Chemicals (Hazard Information and Packaging for Supply) Regulations 2009		✓			✓✓
Classification, Labelling and Packaging of Substances and Mixtures Regulations 2009		✓			✓✓
Registration, Evaluation, Authorisation and Restriction of Chemicals Regulations 2008					✓
Batteries and Accumulators Directive (SI 2008 No. 2164)	✓✓	✓✓	✓✓	✓✓	✓✓
Waste Batteries and Accumulators Directive (SI 2009 No. 890)	✓✓	✓✓	✓✓	✓✓	✓✓
The Carriage of Dangerous Goods and Use of Transportable Pressure Equipment Regulations 2009 (SI 2009 No. 1348)	✓✓	✓	✓	✓	✓✓
British Standard BS EN 62281:2013 - Safety of Primary and Secondary Lithium Cells and Batteries during Transport	✓✓				
P1679.2 - Guide for the Characterization and Evaluation of Sodium-Based Batteries in Stationary Applications				✓	
IEC 60896-22- Stationary lead acid batteries- Part 22: Valve regulated types- requirements		✓✓			
UL1642- Standard for Safety. Lithium Batteries	✓				

Key: ✓✓: Directly Applicable, ✓: Indirectly Applicable (i.e. a non-EU/UK standard, or a related standard with some overlap), ✓: May apply, subject to the details of the installation

Legislation/ Code/ Standard	EES Technology					
	Li-Ion	Pb-Acid	NiCd	High Temperature Sodium	Flow Batteries	Thermo-dynamic Systems
Applicability to Network Integration						
ENA ER G59/-: Recommendations for the Connection of Generating Plant to Distribution Systems	✓	✓	✓	✓	✓	✓
ENA ER G83/-: Recommendations for the Connection of Generating Plant to Distribution Systems	✓	✓	✓	✓	✓	✓
UL 1741: Inverters, Converters, Controllers and Interconnection System Equipment for Use with Distributed Energy Resources	✓	✓	✓	✓	✓	✓
IEEE 1547-2003. Standard for Interconnecting Distributed Resources with Electric Power Systems	✓	✓	✓	✓	✓	✓
IEEE P1547.1. Standard test procedures for equipment interconnecting distributed resources with electric power systems	✓	✓	✓	✓	✓	✓
Applicability to Balance of Plant						
International Convention for Safe Containers	✓	✓	✓	✓	✓	✓
Standards in relation to fire suppression systems (See Table 6.2)	✓	✓	✓	✓	✓	✓

Key: ✓✓: Directly Applicable, ✓: Indirectly Applicable (i.e. a non-EU/UK standard, or a related standard with some overlap), ✓: May apply, subject to the details of the installation

The Codes, Standards and Legislative requirements landscape which has the potential to impact on storage systems' implementation and operations embraces a wide range of facets and responsible organisations, including, but not limited to:

- Key enabling and overriding legislation, specifically the Health and Safety at Work etc. Act, 1974⁵⁸ (Statute/Health and Safety Executive (HSE));
- Specific Statutory Instruments (SIs), e.g. Batteries & Accumulators/Waste Batteries and Accumulators Regulations 2008⁵⁹ (Statute);
- Specific Standards, e.g. BS50272-2 for Stationary Lead Acid and NiCd Battery Systems (BSI);
- European "Essential Requirements" Directives, as enshrined into UK Legislation (Statute/HSE & Local Authorities));
- Regulations specific to the DNO/TO/SO sector, e.g. Electricity Safety, Quality and Continuity Regulations 2002 (ESQCR)⁶⁰ (Statute/HSE);
- Guidance Notes (HSE and other);
- Engineering Recommendations (ENA);
- Planning and Consenting (Environment Agency/Scottish Environment Protection Agency (SEPA));
- Planning Regulations (Local Authority); and

⁵⁸ <http://www.legislation.gov.uk/ukpga/1974/37> Accessed 17/02/2014

⁵⁹ The Batteries and Accumulators (Placing on the Market) Regulations 2008. Statutory Instrument 2008 No. 2164. Available from: http://www.legislation.gov.uk/uksi/2008/2164/pdfs/uksi_20082164_en.pdf Accessed 17/02/2014

⁶⁰ Statutory Instrument 2002 No. 2665. Available from: http://www.legislation.gov.uk/uksi/2002/2665/pdfs/uksi_20022665_en.pdf Accessed 17/02/2014

- Overseas Codes, Standards and Test Regimes (numerous background and supporting material, e.g. from UN, IEEE, Underwriters Laboratories, Sandia National Laboratories, Japanese Electric Vehicle Association (JEVA) etc.)

The key piece of legislation for the management of Health and Safety in the UK is the Health and Safety at Work, etc. Act, of 1974, (“the Health and Safety at Work Act”) which serves as the key “enabling” legislation for the creation of specific further pieces of legislation. In general terms, the underlying rationale as contained within the Health and Safety at Work Act is that those who are responsible for creating a risk must also control that risk. The Health and Safety at Work Act sets out, in its Section 2, the general duties of Employers to their Employees. These include, as far as is reasonably practicable, ensuring the health, safety and welfare at work of employees and the provision and maintenance of plant and systems that are safe and without risks to health.

The Management of Health and Safety at Work Regulations 1999 (and as amended 2006) (the Management Regulations) generally make more explicit what employers are required to do to manage health and safety under the Health and Safety at Work Act. Like the Health and Safety at Work Act, the Management Regulations apply to every work activity.

The main requirement on employers is to carry out Risk Assessments, as appropriate. Employers with five or more employees need to record the significant findings of such Risk Assessments.

In the context of employers operating EES they will be responsible for the preparation of such Risk Assessments, as required to cover the operation of the system(s) including their commissioning, normal operation and any other associated circumstances, including their de-commissioning and removal from service. The issue of Risk Assessments for EES systems is covered in more detail in Section 10.

Codes and standards can apply to various parts of the installation (e.g. the whole site, only specific sub-systems such as the PCS or only specific types of system). They can also be related to purely technical matters, the safe operation of the system, or mitigating potential environmental hazards. A summary of the codes, standards and legislative requirements which are described here and those which are relevant to the case studies in Appendix 1 is provided in Table 6.2 and Table 6.3. Table 6.2 lists those standards which are directly applicable in the GB context, while Table 6.3 relates to relevant standards from overseas, which although not a legal requirement can provide guidance in the absence of coverage from a UK or European context.

The use of Standards by a system manufacturer or designer is voluntary. However, if followed in full it can confer presumption of conformity with one or more essential health and safety requirements, provided that the system is within scope of the standard and that the standard supports the relevant product safety Directive without qualification. In some circumstances the designer/manufacturer can show compliance with the ‘essential requirements’ (of the Directives) in the Technical File (see Section 6.4) by another equally effective method, so the level of risk reduction is at least as good as if the standard had been used.

Table 6.2: Summary of Codes, Standards and Legislative Requirements (Directly Applicable in the UK Context)

Applies to:	Purpose:	Relevant Codes/Standards/Legislative Requirements
Site	Technical	N/A
	Safety	Construction (Design and Management) Regulations 2007 (Section 6.3.4) The Planning (Control of Major Accident Hazards) Regulations 1999 (Section 6.5.2) ⁶¹ Hazardous Substances Consent (Section 6.5.3) OHSAS 18001 Workplace Health and Safety Health and Safety at Work etc. Act 1974 and Management of Health and Safety at Work Regulations 1999 and amendments. (see Section 6.1)
	Other (e.g. Environmental)	Local Authority Planning Permission (permitted development or full planning) (Section 6.5.1) Integrated Pollution Prevention and Control (EU Directive 2008/1/EC) (Environmental) (Section 6.5.4)
Whole EES System	Technical	Electromagnetic Compatibility Regulations 2006 ⁶² (Sections 6.3 and 6.4) ENA Engineering Recommendation G5/4-1 (October 2005). Managing Harmonics
	Safety	BS EN 50272-2:2001: Safety Requirements for Secondary Batteries and Battery Installations- Stationary Batteries (Pb-Acid and Nickel Cadmium systems) (Section 6.2.2) Electrical Design and Safety (Section 6.3.2) via: <ul style="list-style-type: none"> • Electrical Equipment (Safety) Regulations 1994 • The Low Voltage Directive (EU Directive 2006/95/EC) • Wiring Regulations (BS 7671:2008(2011)) Electricity at Work Regulations 1989 (Section 6.3.2) Dangerous Substances and Explosive Atmospheres Regulations 2002 (Section 6.3.3 and Appendix 4, Section A4.5.5) CE Marking and Relevant Directives (Section 6.4): <ul style="list-style-type: none"> • Low Voltage Equipment Directive (EU Directive 2006/95/EC) • Simple Pressure Vessels Directive (EU Directive 2009/105/EC) • Pressure Equipment Directive (EU Directive 97/23/EC) • EMC (EU Directive 2004/108/EC) • Machinery Directive (EU Directive 2006/42/EC)
	Other (e.g. Environmental)	Engineering Recommendation G59/-: Recommendations for the Connection of Generating Plant to the Distribution Systems of Licensed Distribution Network Operators. (Section 6.6)
S	Technical	

⁶¹ Equivalent Scottish regulations apply as The Planning (Control of Major–Accident Hazards) (Scotland) Regulations 2009

⁶² Guidance notes available from: <http://www.berr.gov.uk/files/file47539.pdf> Accessed 17/02/2014

Applies to:	Purpose:	Relevant Codes/Standards/Legislative Requirements
Storage Medium	Safety	Using Electric Storage Batteries Safely (HSE Guidance) (Section 6.2.3) Control of Substances Hazardous to Health Regulations 2002 (Section 6.3.3 and Appendix 4, Section A4.5.1) Chemicals (Hazard Information and Packaging for Supply) Regulations 2009 (Section 6.3.3 and Appendix 4, Section A4.5.2) Classification, Labelling and Packaging of Substances and Mixtures Regulations 2009 (Section 6.3.3 and Appendix 4, Section A4.5.1) Registration, Evaluation, Authorisation and Restriction of Chemicals Regulations 2008. (Section 6.3.3 and Appendix 4, Section A4.5.3)
	Other (e.g. Environmental and Transport)	The Batteries and Accumulators and Waste Batteries and Accumulators Directives (Section 6.2.1) The UN Recommendation on the Transport of Dangerous Goods, Manual of Tests and Criteria. 5 th Revised Edition. Section 38.3. (Applies to transport of Li-Ion systems, as Class 9 dangerous goods.) British Standard BS EN 62281:2013 - Safety of Primary and Secondary Lithium Cells and Batteries during Transport. August 2013. (Section 6.2.4.1) The Carriage of Dangerous Goods and Use of Transportable Pressure Equipment Regulations 2009
Grid Integration (PCS and Control System)	Technical	
	Safety	
	Other (e.g. Environmental)	
Balance of Plant	Technical	
	Safety	International Convention for Safe Containers Standards in relation to fire suppression systems: <ul style="list-style-type: none"> • BS EN 15004-1:2008- Fixed fire fighting systems. Gas extinguishing systems. Design, installation and maintenance • BS 6266:2011: Fire Protection for Electronic Equipment Installations. Code of Practice. • BS 7273: Code of practice for the operation of fire protection measures. Actuation of release mechanisms for doors. • BS 5839-1:2002+A2:2008: Fire detection and fire alarm systems for buildings. Code of practice for design, installation, commissioning and maintenance of systems in non-domestic premises.
	Other (e.g. Environmental)	

Table 6.3: Overseas Codes and Standards Providing Guidance for GB EES Deployments – identified in project case studies

Applies to:		Purpose:	Relevant Codes/Standards/Legislative Requirements
Site		Technical	N/A
		Safety	
		Other (e.g. Environmental)	
Whole EES System		Technical	IEC 61000-4-2; Electrostatic Discharge Immunity Tests ANSI C57.12.28. Pad Mounted Equipment Enclosure Integrity IEEE P2030.3- Standard for Test Procedures for Electric Energy Storage Equipment and Systems for Electric Power Systems Applications (draft under development in the USA). ⁶³ (Section 6.6)
		Safety	ANSI/IEEE C2-1997 National Electrical Safety Code
		Other (e.g. Environmental)	
Sub-Systems	Storage Medium	Technical	
		Safety	
		Other (e.g. Environmental)	P1679.2 - Guide for the Characterization and Evaluation of Sodium-Based Batteries in Stationary Applications (Section 6.6) IEC 60896-22- Stationary lead acid batteries- Part 22: Valve regulated types- requirements (Section 6.6) UL1642- Standard for Safety. Lithium Batteries. (Section 6.6)
	Grid Integration (PCS and Control System)	Technical	UL 1741: Inverters, Converters, Controllers and Interconnection System Equipment for Use with Distributed Energy Resources IEEE 1547-2003. Standard for Interconnecting Distributed Resources with Electric Power Systems ⁶⁴ . IEEE P1547.1. Standard test procedures for equipment interconnecting distributed resources with electric power systems
		Safety	
		Other (e.g. Environmental)	
	Balance of Plant	Technical	
		Safety	
		Other (e.g. Environmental)	

N.B. An empty row in the table above indicates that no relevant standards were outlined within the project case studies, rather than an absence of standards.

⁶³ <http://standards.ieee.org/develop/project/2030.3.html>

⁶⁴ <http://standards.ieee.org/findstds/standard/1547-2003.html>

6.2 Battery Energy Storage System Specific Codes, Standards and Guidance

There is a relative absence of codes, standards, codes-of-practice and guidance relating specifically to stationary EES systems for power utility applications, particularly those for the EU or UK. Those which do exist and which are directly applicable are described in this section. There are a greater number of codes and standards which apply more generally to made-up systems and products (including EES). These are described in Sections 6.3, 6.4, 6.5 and 6.6, with further details contained in Appendix 4.

6.2.1 The Batteries and Accumulators and Waste Batteries and Accumulators Directives

The Batteries and Accumulators and Waste Batteries and Accumulators Directive (2006/66/EC) aims to improve the environmental performance of batteries and accumulators and minimise the impact waste batteries and accumulators have on the environment⁶⁵. Further details of the legislation are provided in Appendix A4.1. The main requirements of the Directives, of relevance to the providers of EES systems, are to:

- Formally register as a producer of batteries/accumulators (on the National Packaging Waste Database via the Department for Business, Innovation and Skills (BIS));
- Appropriately label their batteries/accumulators, e.g. via application of the crossed-out “wheeled bin” symbol;



Figure 6.1: Labelling Requirements of Batteries and Accumulators and Waste Batteries and Accumulators Directive⁶⁶

- Comply with take back obligations; and
- Ensure waste batteries/accumulators are responsibly treated.

6.2.2 BS EN 50272-2:2001 Safety Requirements for Secondary Batteries and Battery Installations – Part 2: Stationary Batteries

BS EN 50272-2:2001⁶⁷ represents the official English Language Version of the European Standard EN 50272-2 and addresses the safety requirements to protect from hazards generated by the electricity, the electrolyte and the explosive gases when using secondary batteries. It also covers additional measures to maintain the functional safety of batteries and battery installations.

The Standard applies to stationary secondary battery and battery installations with a maximum voltage of 1,500 V DC (nominal) and states “*It covers Lead Acid and NiCd*”

⁶⁵ In UK legislation as: Statutory Instrument 2008 No.2164: The Batteries and Accumulators (Placing on the Market) Regulations 2008 and Statutory Instrument 2009 No.890: The Waste Batteries and Accumulators Regulations 2009.

⁶⁶ Annex II of DIRECTIVE 2006/66/EC. Available from:

http://www.bmu.de/files/pdfs/allgemein/application/pdf/richtlinie_batterien_eng.pdf Accessed 24/03/12.

⁶⁷ Further guidance in relation to the legal status of Standards is available via the HSE: <http://www.hse.gov.uk/work-equipment-machinery/standard.htm> Accessed 20/01/2014

batteries". However, it does not explicitly exclude other electrochemistries. It can nevertheless provide useful guidance which can be applied to systems based on other electrochemistries (e.g. Li-Ion). The standard addresses the following aspects in relation to battery safety:

- Protection against electric shock;
- Disconnection and separation;
- Prevention of short circuits and protection from other effects of electric current;
- Provisions against explosion hazards;
- Provision against electrolyte hazard;
- Accommodation and housing;
- Charge current requirements;
- Identification labels, warning notices and instructions for use, installation and maintenance;
- Transportation, storage, disposal and environmental aspects; and
- Inspection and monitoring.

It should be noted that some of these sections are written for hazards specific to Pb-Acid and NiCd systems alone (e.g. provision against explosion hazards from hydrogen). However, other sections provide useful guidance for other electrochemistries.

6.2.3 Using Electric Storage Batteries Safely, HSE, INDG139(rev1), 05/06

The Health and Safety Executive (HSE) Publication HSE, INDG139(rev1)⁶⁸ is written as a general "good practice" document, principally for the benefit of supervisors, technicians and safety personnel working with batteries in applications such as motor vehicle repair, IT and telecommunications, stand-by generation and electric vehicles. It is written principally around the hazards associated with Pb-Acid and alkaline batteries but nevertheless does highlight some generic safety issues, applicable to utility scale EES systems of other electrochemistries.

6.2.4 Transport of Batteries and Energy Storage Systems

6.2.4.1 Overview

The construction and commissioning of an EES system may involve the transport of "dangerous goods" to site, with such "dangerous goods" being defined as chemicals, mixtures of substances, manufactured products or articles which can pose a risk to people, animals or the environment if not properly handled in use or in transport⁶⁹. In many cases, this responsibility may be vested in the prime contractor/system vendor and, as such, would fall outside the responsibility of the end user, who has ordered such equipment.

An emerging scenario, is that of an end user having to routinely transport various EES components, sub-assemblies and materials, to support the operation of multiple EES systems, in service. At least some of these components, sub-assemblies and materials may invoke the dangerous goods classification, for example:

- Li-Ion battery monoblocs and/or cells;
- Battery acid (e.g. H₂SO₄); and
- Redox flow battery electrolyte solutions.

⁶⁸ Available from: <http://www.hse.gov.uk/pubns/indg139.pdf> Accessed 21/10/2013

⁶⁹ What are dangerous goods? DfT web-site: <http://www.dft.gov.uk/vca/dangerousgoods/what-are-dangerous-g.asp> (accessed 25th July 2014).

Within the UK, the Dangerous Goods Office of the Department for Transport's Vehicle Certification Agency (VCA) is the relevant UK authority for the certification of packaging and intermediate bulk containers used for the transport of dangerous goods, in accordance with national and international regulations. The VCA's remit applies to considerations in relation to "dangerous in transit", as opposed to "dangerous in use". The latter category is addressed via the design and construction of the equipment itself and the classification, labelling and packaging of the chemicals concerned.

The regulations in relation to the transport of dangerous goods are harmonized with the Model Regulations, published by United Nations Economic and Social Council's Committee of Experts on the Transport of Dangerous Goods⁷⁰. Here, each Dangerous Substance is assigned a unique number and is assigned to a 'Class', depending on the nature of the danger it presents. There are nine Classes, some of which also contain sub-divisions, as follows:

- Class 1: Explosives;
- Class 2: Gases;
- Class 3: Flammable liquids;
- Class 4: Flammable solids; substances liable to spontaneous combustion; substances which, on contact with water, emit flammable gases;
- Class 5: Oxidizing substances and organic peroxides;
- Class 6: Toxic and infectious substances;
- Class 7: Radioactive material;
- Class 8: Corrosive substances; and
- Class 9: Miscellaneous dangerous substances and articles, including environmentally hazardous substances.

Class 9 (Miscellaneous dangerous substances and articles) includes lithium and Li-Ion cells and batteries.

The relevant testing requirements in relation to the transport of Li-Ion batteries are described in the "UN38.3" document "Recommendations on the Transport of Dangerous Goods Manual of Tests and Criteria"⁷¹. British Standard BS EN 62281:2013, (Safety of Primary and Secondary Lithium Cells and Batteries during Transport") applies to batteries containing lithium in any chemical form (lithium metal, lithium alloy or Li-Ion). It also applies to lithium polymer cells and batteries. Its scope is to specify test methods and requirements for primary and secondary lithium cells and batteries to ensure their safety during transport (other than for recycling and disposal). Abuse tests are specified which mirror those contained within the UN38.3 Regulations, described above. The British Standard also provides guidance in relation to the packaging and labelling which should be applied to lithium batteries during transport.

6.2.4.2 Implications for Operators

The overall regulations, which cover the full nine classes of dangerous goods are complex; see, for example, the detailed guidance available from the HSE web-site⁷². The relevant Statutory Instrument which covers the Transport of Dangerous Goods is SI 2009 No.1348

⁷⁰ UN Model Regulations. UN Recommendations on the Transport of Dangerous Goods - Model Regulations Nature, Purpose and Significance of the Recommendations. Available from:- <http://www.unece.org/?id=3598> (accessed 25th July 2014).

⁷¹ UN Manual of Tests and Criteria. Fifth revised edition. Section 38.3. Lithium Metal and Lithium Ion Batteries. http://www.unece.org/trans/danger/publi/manual/rev5/manrev5-files_e.html (accessed 1st August 2014)

⁷² Carriage of Dangerous Goods. HSE. Available from <http://www.hse.gov.uk/cdg/> (accessed 25th July 2014).

“The Carriage of Dangerous Goods and Use of Transportable Pressure Equipment Regulations 2009⁷³ (“CDG 2009”). These implement the “Accord européen relatif au transport international des marchandises dangereuses par route” (ADR), with the main duties covered by Regulation 5. Further details of the specific implications of CDG Regulations on the transport of Li-Ion batteries are given in Appendix 4, Section A4.2.

In the short to medium term, one scenario likely to be encountered by GB EES operators, deploying multiple EES systems, is that of their holding a stock of (battery) cells/monoblocs and these being subject to road transport, in the context of field personnel replacing unserviceable cells/monoblocs in network connected EES installations. However, it should be noted that a number of exemptions exist which may be applicable for transport of replacement cells, including those for cells of rating less than 20 Wh and batteries of less than 100 Wh⁷⁴.

6.3 Design and Construction Codes and Standards

A number of codes and standards apply more generally to the design and construction of a wide range of made-up products (i.e. not specific to EES systems). These govern various facets of the design and specific hazards, such as mechanical or electrical aspects. Designers/manufacturers of products have a responsibility to ensure their products meet minimum European requirements for safety and health when first placed on the market⁷⁵. The relevant pieces of legislation are outlined in the sections below.

6.3.1 Mechanical Design and Safety

Within the context of the present GPG, the regulations in relation to mechanical design and safety are likely to be applicable to:

- Those EES systems which include various assemblies and moving parts, e.g. thermodynamic and kinetic energy storage systems; and
- Specific jigs and tools, which may comprise one or more inter-linked moving parts, e.g. battery handling equipment.

The design and construction of machinery is primarily covered by “The Supply of Machinery (Safety) Regulations 2008”⁷⁶, as amended by the “Supply of Machinery (Safety) (Amendment) Regulations 2011”. These regulations (otherwise known as the Machinery Regulations) implement the Machinery Directive (2006/42/EC) in the UK.

The definition of “machinery” under the regulations is broad and covers:

- An assembly, fitted with or intended to be fitted with a drive system other than directly applied human or animal effort, consisting of linked parts or components, at least one of which moves, and which are joined together for a specific application;
- An assembly referred to in the first indent (above), missing only the components to connect it on site or to sources of energy and motion;

⁷³ SI1348 2009. The Carriage of Dangerous Goods and Use of Transportable Pressure Equipment Regulations 2009. Available from <http://www.legislation.gov.uk/ukxi/2009/1348/contents/made> (accessed 1st August 2014).

⁷⁴ European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR) <http://www.unece.org/trans/danger/publi/adr/adr2013/13contentse.html> (accessed 13 November 2014)

⁷⁵ <http://www.hse.gov.uk/work-equipment-machinery/manufacturer.htm> Accessed 16/01/2014

⁷⁶ The Supply of Machinery (Safety) Regulations 2008. SI 2008 No.1597, available from:- <http://www.legislation.gov.uk/ukxi/2008/1597/made> (accessed 31st July 2014).

- An assembly referred to in the first and second indents (above), ready to be installed and able to function as it stands only if mounted on a means of transport, or installed in a building or a structure;
- Assemblies of machinery referred to in the first, second and third indents (above) or partly completed machinery (also a defined term, see below) which, in order to achieve the same end, are arranged and controlled so that they function as an integral whole; and
- An assembly of linked parts or components, at least one of which moves and which are joined together, intended for lifting loads and whose only power source is directly applied human effort.

Furthermore, the Regulations also apply to certain interchangeable equipment, safety components (described as components), lifting accessories, chains, ropes and webbing, removable mechanical transmission devices and partly completed machinery. A number of specific exceptions also apply, including those for various electrical and electronic products, insofar as these are covered by the (European) Directive 2006/95/EC (i.e. the Low Voltage Directive (LVD)). The Machinery Directive is mutually exclusive with the LVD (as described in Sections 6.3.2 and 6.4), so that either one or the other will apply, but never both. Annex 1 of the Machinery Directive contains requirements for electrical safety which mirrors those of the Low Voltage Directive, with the net effect that the electrical safety requirements of the two directives are identical.

The broad requirements of the regulations are that all machinery:

- Is designed and constructed to be safe, meeting the essential health and safety requirements listed in the regulations;
- Is CE marked;
- Is supplied with instructions in English; and
- Has a Declaration of Conformity.

Those procuring, or operating EES systems should therefore ensure adherence to the relevant parts of the legislation, for example through ensuring products are appropriately CE Marked, with an accompanying Declaration of Conformity. Further guidance on the Machinery Regulations and their application is contained in the Department for Business Innovation & Skills' notes on the subject⁷⁷.

Conformity with the Machinery Directive is the responsibility of the "manufacturer" and is covered in greater detail in Section 6.4.

6.3.2 Electrical Design and Safety

Electrical design and safety is covered by a number of pieces of legislation, as listed in Appendix A4.4. This includes the Electrical Equipment (Safety) Regulations 1994, which implements the Low Voltage Directive⁷⁸. This covers low-voltage equipment with an input or output voltage of between 50 and 1000V AC and 75-1500V DC.

Within the legislation there is an express requirement to satisfy "essential requirements" in terms of the Low Voltage Directive and the Electromagnetic Compatibility (EMC) Directive,

⁷⁷ Machinery. Guidance Notes on the UK Regulations. Department for Business, Innovation & Skills, September 2009. Available from:- <http://www.berr.gov.uk/files/file52968.pdf> (accessed 25th July 2014).

⁷⁸ Guidance is available via the Department for Business, Innovation and Skills. <http://www.bis.gov.uk/files/file38623.pdf> Accessed 16/01/2014

before the product can be placed on the market. The over-riding obligation on system suppliers is to supply “safe” equipment. Further details of the CE Marking process are given in Section 6.4.

EES systems within a GB DNO/TO/SO environment represent a somewhat atypical electrical safety hazard due to presence of high voltage DC power sources. Appropriate operational safety procedures and precautions must be developed and applied. Such precautions include the locking off, discharge and testing to dead of equipment, before maintenance on it can commence. The earthing of terminals may also be necessary for certain circuits.

The electric shock hazard from EES systems is addressed in further detail in Section 9.1.1.

The precautions necessary to avoid danger from electrical systems, equipment and apparatus are entailed in the Electricity at Work Regulations 1989. The onus of these regulations is to assess the activities that use electricity and to define all foreseeable risks. All electrical equipment must therefore be designed, constructed, installed and tested to meet the technical requirements of the Electricity at Work Regulations, the Low Voltage Directive (or to Annex 1 of the Machinery Directive) and the Electromagnetic Compatibility (EMC) Directive. In addition, wiring should conform to BS 7671:2001 which incorporates the Institution of Engineering and Technology (IET) Wiring Regulations.

From the point of view of an operator of energy storage, the Health and Safety at Work Act and the Electricity at Work Regulations defines “persons on whom duties are imposed”, which includes a responsibility on the part of the employer to comply with the provisions of the Electricity at Work Act 1989⁷⁹.

6.3.3 Chemical Design and Safety

A chemicals inventory is inherent to any electro-chemical energy storage medium. However, the form of the chemical inventory and the degree of handling associated with it will vary, according to the technologies and systems involved.

For example, a number of battery energy storage systems are made up from an inter-connected series of hermetically sealed cells, with no handling of the free electrolyte involved. On the other hand, flooded Pb-Acid cells may involve handling of the free electrolyte during maintenance activities. Hence, the relevance and applicability of specific chemical safety considerations will depend on the make-up and operation of the systems concerned. There are a number of potentially relevant pieces of legislation, as listed on the following page. Further details in relation to each piece of legislation are given in Appendix 4, Section A4.5.

- **The Control of Substances Hazardous to Health (COSHH) Regulations 2002:** This imposes a duty on employers to control substances that are hazardous to health, and compliance is achieved via the performance of a COSHH Assessment. COSHH Regulations are applicable to substances which are classified as very toxic, toxic, harmful, corrosive or irritant as listed as part of the Classification, Labelling and Packaging (CLP) of Substances Regulations 2009.
- **The Chemicals (Hazard Information and Packaging for Supply) (CHIP) Regulations 2009 (also known as CHIP4):** Addresses the marketing of dangerous substances and preparation and requires suppliers to determine if the chemicals they supply are ‘dangerous’, in what way, and to provide information to their customers via

⁷⁹ Legislation available from: <http://www.legislation.gov.uk/ukxi/1989/635/contents/made> Accessed 16/01/2014.

warning labels. The CHIP Regulations will be completely replaced by the CLP Regulations with effect from 1st June 2015.

- **The Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) Regulations 2008:** These regulations form the system for controlling chemicals in Europe and can affect importers of chemicals into the EU. It is the responsibility of the manufacturer/supplier to register and comply with the REACH regulations.
- **The Restriction of Hazardous Substances Directive (2002/95/EC) (RoHS):** This Directive took effect from 1st July 2006 and restricts (with exceptions) the use of six hazardous materials in the manufacture of various types of electronic and electrical equipment. It relates to the use of lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls and polybrominated diphenyl ether. RoHS 2 (an update to the original Directive) took effect from 2nd January 2013.
- **DSEAR (Dangerous Substances and Explosive Atmosphere) Regulations 2002:** These regulations require employers to assess the risk of fires and explosions from “dangerous substances in the workplace” and eliminate or reduce such risks as far as is reasonably practicable. Flammable and explosive gases, such as hydrogen fall under the DSEAR Regulations.
- **ATEX Equipment Directive (derived from the French title of the EC Directive, “Appareils destinés à être utilisés en ATmosphères EXplosibles”):** This Directive sets out the selection of electrical equipment for ‘zones’ (e.g. ‘Zone 1 – Hazardous Area’, as defined by the DSEAR Regulations). The explosion risk from a particular system, and any requirement for compliance with DSEAR or ATEX should be assessed on a case-by-case basis.

6.3.4 Pressure Systems

Regulations in relation to pressure systems are potentially applicable to a sub-set of EES systems. Within the scope of the present GPG this includes flow batteries and certain thermodynamic cycle systems. Additional regulations may be relevant for other technologies such as CAES or hydrogen systems, but are beyond the scope of this Guide. However, where a fire suppression system is employed, it is likely the pressurised system would be within the scope of these Regulations. The potentially applicable regulations here comprise:

- **The Pressure Equipment Regulations (PER) (SI 1999/2001, as amended by SI 2002/1267):** The PER address the design, manufacture and conformity of pressure systems and apply to pressure equipment and assemblies of pressure equipment with a maximum allowable pressure of greater than 0.5 bar;
- **The Simple Pressure Vessels (Safety) Regulations 1991 (SPV):** applicable to simple pressure vessels containing air or nitrogen at a gauge pressure of between 0.5 and 30 bar; and
- **The Pressure Systems Safety Regulations 2000 (PSSR):** which address usage aspects and aim to prevent serious injury from the hazard of stored energy as a result of the failure of a pressure system or one of its component parts.

Further and more detailed guidance on the use and application of these regulations is provided in Appendix 4, Section A4.6.

6.3.5 Civil Engineering/ Construction Considerations

Civil engineering issues are generally well understood by turnkey contractors, with common issues occurring for most sites. Applicable regulations are as summarised in Appendix A4.7.

The main issues will be for the health and safety of construction employees, and subsequently site operators. For construction, the Construction (Design and Management) (CDM) Regulations 2007 regulate the health and safety management systems on site until the site is handed over to the customer. The general requirements under CDM regulations are summarised within this section.

Construction projects are either defined as “notifiable” or “non-notifiable”. A project becomes notifiable if the construction phase is likely to last more than 30 days, or 500 person days of construction work. This applies only to actual working days, rather than the overall construction phase duration. There are a number of specific roles defined under the CDM regulations, as follows:

- **Designers:** the designer is strategically placed to significantly influence health and safety throughout the lifecycle of the project. Close working relationships with the Client, CDM Co-ordinator and Contractors prior to and during the site works is of immense value particularly on design and build projects. Designers must:
 - Take reasonable steps to ensure that clients are aware of their duties under CDM before starting design work;
 - Prepare designs with adequate regard to health and safety, and to the information supplied by the client;
 - Provide adequate information in or with the design; or
 - Co-operate with the CDM Co-ordinator (if applicable) and with any other designers so that each of them can comply with their duties under the Regulations. This includes providing any information for the health and safety file.
- **Client:** the organisation or individual for whom a construction project is carried out (e.g. the owner of the storage, such as a DNO). These responsibilities are therefore particularly key for operators of storage. The client must ensure:
 - Designers, contractors and others are competent (i.e. by appointing competent parties) and adequately resourced;
 - Reasonable management arrangements are in place throughout the project;
 - They allow sufficient time for each stage of the project;
 - They give notice to contractors of minimum time for planning and preparation;
 - They co-operate with others, and co-ordinate work with others;
 - Ensure adequate arrangements have been made for suitable welfare from the start; and
 - Relevant information is provided to all who need it.
- **Contractors:** contractors have a responsibility to ensure clients are aware of their duties under CDM, plan, manage and monitor their own work on site (including ensuring the competence of their employees) and co-operate and co-ordinate their work with others involved in the project;
- **CDM Co-ordinator (mandatory for notifiable projects):** the main role and responsibility of a CDM co-ordinator is ensuring that all those who carry out design work on a project, collaborate and pay adequate attention to the need to reduce risk wherever possible, and that the correct advice is provided to the client;
- **Principal Contractor (mandatory for notifiable projects):** the distinctive and key duty of principal contractors is the effective management of health and safety during the construction phase of a project.

An 'Approved Code of Practice' accompanies the CDM Regulations which provides practical guidance on complying with the duties set out in the Regulations⁸⁰. The existing portfolio of storage projects are all classified as notifiable under remit of the CDM regulations. Only those with a larger civil engineering component (e.g. considerable site work such as the construction of a new purpose built structure) have required notification to the HSE.

6.4 CE Marking

CE marking must be applied to any product subject to one or more New Approach Directives, placed on the European market and put into service, save where specific directives require otherwise. European Commission guidance is available as the "Blue Guide"⁸¹ and lists directives where CE marking is applicable and also provides other relevant definitions and information. The relevant Essential Requirements are set out in the annexes of the directives and include all that is necessary to achieve the objective of the directive(s). Products may only be placed on the market and put into service, if they are in compliance with the Essential Requirements.

The presence of a CE mark together with a Declaration of Conformity is a declaration of the manufacturer's intention to comply with the essential requirements as set out within the directives. CE marking indicates that the manufacturer has compiled a Technical File, providing evidence that the product meets all the appropriate provisions of the relevant legislation implementing certain European directives (e.g. those Directives described above). CE marking does not automatically guarantee compliance, as matters of product safety and final interpretation about whether products meet essential requirements may only be decided by the courts.

The New Approach Directives listed in the Blue Guide are defined as those that provide for CE marking and include:

- Low Voltage Equipment;
- Simple Pressure Vessels;
- Pressure Equipment;
- Electromagnetic Compatibility; and
- Machinery.

A summary of each of these directives is provided in Appendix A4.7.

The over-riding rationale of the CE marking directives relates to the free circulation of goods within the European Union markets. As such, CE marking gives companies easier access into the European market to sell their products without adaptation or re-checking. However, CE marking does not exempt manufacturers from compliance with applicable local codes, standards or legislation.

The principles of CE marking apply equally to imported products, as to those products manufactured within the European market. In this case, it is the responsibility of the authorised representative or the importer/person placing the product on the market to ensure that the product is correctly CE-marked.

The Machinery Directive is mutually exclusive with the Low Voltage Directive, so that either one or the other will apply but never both. Annex 1 of the Machinery Directive contains

⁸⁰ Available from: <http://www.hse.gov.uk/pubns/priced/l144.pdf> Accessed 17/02/2014

⁸¹ Guide to the Implementation of Directives Based on the New Approach and the Global Approach. European Commission, 2000.

requirements for electrical safety which mirrors those of the Low Voltage Directive, with the net effect that the electrical safety requirements of the two directives are identical. However, it should be noted that a number of items of HV equipment, including switchgear and transformers, are explicitly excluded from the Machinery Directive.

In the context of utility scale electrical energy storage based on battery systems (i.e. excluding thermodynamic or flow battery systems), the Directives which are likely to be applicable are:

- **Low Voltage Directive:** Applies to most electrical equipment that is designed for use with an input or output voltage of between 50 and 1,000 volts (AC) and between 75 and 1,500 volts (DC). It requires that electrical equipment must be constructed in accordance with good engineering practice so that it does not endanger the safety of people, domestic animals or property.
- **Electromagnetic Compatibility (EMC):** Applies to almost all electrical and electronic appliances, equipment and apparatus. It requires that the equipment does not generate electromagnetic disturbances and that it is immune from disturbances from other nearby equipment.

6.4.1 Responsibilities

It is the manufacturer of the product, whether established within or outwith of the European Union, who is ultimately responsible for the conformity of the product with the provisions of the relevant directive(s) and affixing the CE marking. A manufacturer is defined as any entity who is responsible for designing and manufacturing a product with a view to placing it on the (European) market under their own name. The manufacturer may appoint an authorised representative, established within the European Union, to act on their behalf. Further details of the routes to CE Marking which may be pursued by a manufacturer are given in Appendix 4 (Section A4.8.2).

A product is deemed to be placed on the (European) market when it is made available for the first time. This is considered to take place when a product is transferred from the stage of manufacture with the intention of distribution or use on the Community market. Such transfer can be for payment or free of charge, or based on any type of legal instrument.

The owner of an EES system which falls under the auspices of the various Directives relevant to CE Marking should receive a copy of the Declaration of Conformity from the system supplier. The product should also be appropriately marked with the CE Mark. Ensuring that the product conforms with the relevant Directives and that the Technical File is in place is the responsibility of the manufacturer or their authorised representative. The presence of a CE Mark (and therefore compliance with the relevant Directives) provides operators of energy storage systems with a basic level of assurance of the safety of the system, in relation to the requirements of specific applicable directives. It does not, however, guarantee the overall safety of the system.

6.5 Licensing and Consenting

There are a number of licensing and consenting issues which may arise due to the installation of energy storage. This includes those in relation to Local Authority planning requirements and safety/environmental concerns. This section first addresses the approach which can be taken by those installing storage in relation to Local Authority planning permission. It then addresses three specific pieces of legislation in relation to safety/environmental controls.

6.5.1 Local Authority Planning

Well established local authority planning procedures are in place that apply to all new developments, major changes to existing buildings or when the use of a building will change (e.g. installation of an EES within an existing building). The planning system for England and Wales is set out in the Town and Country Planning Act 1990 (as amended). The main planning law for Scotland is The Town and Country Planning Act (Scotland) 1997 Chapter 8 as amended by The Planning etc. (Scotland) Act 2006⁸². Those deploying EES may be subject to two potential planning mechanisms:

- Full Planning Consent; and
- Permitted Development (available to DNOs, as described in Section 6.5.1.1).

In the case of any proposal a two stage test is applied to determine the type of consent required: Is the proposal defined as “development” and if it is, then “is it permitted development?” Only if a development cannot be considered “permitted” is a full planning submission required. Applications are made to the relevant Local Planning Authority (LPA), who is generally the local borough or district council. LPAs are generally receptive to pre-application discussion in order to clarify whether a proposal will require planning permission, and the probability of such permission being granted⁸³. The mechanisms for planning approval used by the case studies in Appendix 1 are set out in Table 6.4.

6.5.1.1 Permitted Development

Electricity undertakings, such as licensed distribution operators are permitted to make developments on their own property under a General Development Order, under the Electricity Act 1989.

The use of permitted development rules is most relevant to licensed DNOs and is unlikely to apply to non-DNO EES operators. Furthermore, where use of permitted development is intended, additional considerations include: Local development regulations; the definition of operational land; and the requirement to demonstrate that the installation is necessary to support the distribution network. This consideration is likely to become most relevant where an EES system is utilised both for electricity market applications and for distribution network support.

For England and Wales, The Town and Country Planning (General Permitted Development) Order 1995⁸⁴ sets out a number of categories of development which may take place as ‘permitted development’ – i.e. without a fully planning submission. For Scotland these are set out in the Town and Country Planning (General permitted Development) (Scotland) Order 1992⁸⁵. The types of development which may be classed as ‘permitted’ are set out within Schedule 2 of the regulations. Full details of the developments allowed, and those which are not permitted, are given in the regulations. Developments which are allowed in relation to electricity undertakings are set out as follows:

“Development by statutory undertakers for the generation, transmission or supply of electricity for the purposes of their undertaking consisting of:

⁸² <http://www.scotland.gov.uk/Topics/Built-Environment/planning/publications/legislation> Accessed 25/02/2014

⁸³ Smarter Network Storage- Design and Planning Considerations for Large-Scale Distribution-Connected Energy Storage (SNS 1.2). UK Power Networks. Available from: http://www.ukpowernetworks.co.uk/internet/en/community/documents/SNS1.2_SDRG_9.1_Design_and_Planning_Considerations_Report_v2.0.pdf Accessed 06/01/2014

⁸⁴ Available from: <http://www.legislation.gov.uk/uk/si/1995/418/schedule/2/made> Accessed 29/11/2013

⁸⁵ <http://www.scotland.gov.uk/Topics/Built-Environment/planning/National-Planning-Policy/themes/PermittedDevelopment> Accessed 25/02/2014

- (a) the installation or replacement in, on, over or under land of an electric line and the construction of shafts and tunnels and the installation or replacement of feeder or service pillars or transforming or switching stations or chambers reasonably necessary in connection with an electric line;
- (b) the installation or replacement of any telecommunications line which connects any part of an electric line to any electrical plant or building, and the installation or replacement of any support for any such line;
- (c) the sinking of boreholes to ascertain the nature of the subsoil and the installation of any plant or machinery reasonably necessary in connection with such boreholes;
- (d) the extension or alteration of buildings on operational land;
- (e) the erection on operational land of the undertaking or a building solely for the protection of plant or machinery;
- (f) any other development carried out in, on, over or under the operational land of the undertaking.”

Points (d) to (f) of the above are most likely to be of relevance to the installation of EES on DNO land, as this may involve the erection of housings for storage on currently operational land (e.g. at a substation). ‘Street furniture’ style installations may fall under point (a) as they represent a similar activity as the installation of a service pillar.

6.5.1.2 Full Planning Application

There are a number of types of planning permission, as follows:

- **Full planning permission:** granting permission for all aspects of the proposed development, possibly subject to various conditions.
- **Outline planning permission:** This may be used when an applicant is seeking “agreement in principle” to a proposed development, without being committed to a particular form of design or layout. It cannot be granted for a proposed change in the use of land or buildings.
- **Approval of reserved matters:** seeking permission for those aspects that were not dealt with in an outline planning permission, or those which were ‘reserved’ by a planning condition in an earlier grant of full planning permission.
- **Renewal of planning permission:** planning permission can be granted with a time limitation. An application for the renewal of planning permission would then be submitted if this time period had elapsed. Such applications are usually granted, providing there has not been a significant change in the relevant material considerations affecting the development.
- **Removal or alteration of a planning condition:** conditions may be imposed on a grant of planning permission only if they are required to make an unacceptable development acceptable (i.e. without compliance with the condition, the application would not be granted). A developer can apply to “vary” the condition applied.

The timescales for a decision, for each of the application types above, is set by the Government and can vary between 4 and 16 weeks (full or outline planning permission involving an environmental statement). Councils are permitted to agree with the developers for an extension, although both parties must agree to this. After the timescale set out by the Government has elapsed, a developer can appeal to the Secretary of State for “non-determination” of an application.

Planning conditions can be attached to the granting of permission, for example in relation to the timescales in which the development must be started, agreement of colour or finish of

external materials to be agreed with the LPA. These conditions generally relate to items within the site boundary. “Grampian conditions” are those which relate to matters outside of the boundary, such as improvement of the local highway. A planning condition of this type may stipulate that on-site development may only proceed once the conditions set outside of the development have been satisfied (e.g. the highway improvements are complete). In addition, a developer could be required to enter into a Section 106 agreement (named after the relevant section of the Town and Country Planning Act). These agreements can require a monetary contribution for particular off-site developments to be made to the LPA before building work on site commences. However, these contributions (in common with all planning conditions) can only be applied where they are necessary to make an otherwise unacceptable development, acceptable.

6.5.1.3 Lessons Learnt from Current Storage Deployments

The current round of DNO led and DECC supported Energy Storage demonstration projects have addressed the subject of securing planning permission in a number of ways, as summarised in this sub-section. Further details are provided within the project case studies in Appendix 1.

Table 6.4: Approaches to Planning Permission in Existing Storage Deployments

Deployment	Relevant LPA	Approach Taken
Northern Powergrid- Rise Carr (2.5MVA, 5MWh)	Darlington Borough Council	Permitted development schedule (in coordination with county Durham authorities and Darlington Borough Council) via existing Northern Powergrid wayleave.
Northern Powergrid- High Northgate (100kVA, 200kWh)	Darlington Borough Council	Permitted development schedule in coordination with county Durham authorities and Darlington Borough Council.
Northern Powergrid- Wooler Ramsey (100kVA, 200kWh)	Northumberland County Council	Permitted development schedule in coordination with Northumberland authorities and Northumberland County Council.
Northern Powergrid- Harrowgate Hill (50kVA, 100kWh)	Darlington Borough Council	Permitted development schedule in coordination with Darlington authorities and Darlington Borough Council.
Northern Powergrid- Maltby (50kVA, 100kWh)	Rotherham Metropolitan Borough Council	Permitted development and five year wayleave schedule in coordination with South Yorkshire council authorities.
Northern Powergrid- Wooler St. Mary (50kVA, 100kWh)	Northumberland County Council	Permitted development schedule in coordination with Northumberland authorities and Northumberland County Council via Northern Powergrid.
SSEPD- Orkney Energy Storage Park	Orkney Islands Council	A full planning application was submitted to the local council by the storage supplier. The local council then stated that the project could progress as permitted development; as the storage was to be installed at the power station site and the supplier was SSE Generation.
SSEPD- Chalvey	Slough Borough Council	Agreed as permitted development following detailed discussions and submission of drawings to the council. However, there was some debate as to whether storage for the purposes of research and development is considered “critical infrastructure” and therefore eligible for permitted development.

Deployment	Relevant LPA	Approach Taken
SSEPD- Shetland (NaS and Pb-Acid)	Shetland Islands Council	All of the equipment was located within a dedicated building, on the existing Lerwick Power Station site. SSEPD were able to construct the building under permitted development. Stakeholder engagement was seen as important for this project, when progressing under permitted development route.
UK Power Networks- Hemsby	Great Yarmouth Borough Council	Planning permission granted with conditions. Conditions relate to the temporary duration of the installation (8 years, although with the possibility of applying to extend the duration) and the external appearance of the installation.
UK Power Networks- Smarter Network Storage	Central Bedfordshire Council	Planning permission granted following full planning submission with a total of 15 planning conditions. Obtaining permission involved multiple site investigations and alternative site scenario analysis, full design of the external appearance and consultation with local residents. It was important to establish why the installation needed to be in that specific location. The installation is within a flood zone and therefore it was necessary to establish it as “essential infrastructure” to comply with the National Planning Policy Framework. The process was lengthier than had been anticipated, showing the importance of early consultation with the LPA when considering sites for storage, in order to gain an understanding of the specific nuances and local issues which were present. It was also important to incorporate the feedback received from consultation responses from local residents. ⁸⁶
WPD- Falcon	Milton Keynes Council	Permitted development.
WPD- SolaBristol	N/A	Planning permission not required, as installation is within customers’ property.
REDT - Gigha Flow Battery Demonstration	Argyll and Bute Council	Planning permission for the installation of the Vanadium Redox Flow Battery (VRFB) was granted for the length of the demonstration project (through to end March 2016). Discussions are underway with the local Planning Officer regarding the possibility of, eventually, making the site permanent rather than temporary. This may involve the replacement of the fence around the containerised compound with a simple agricultural building.
Highview – LAES Demonstration	Bury Council	A planning application was due to be filed in September 2014. However, no issues were experienced in obtaining planning permission for the pilot plant from Slough Borough Council.

The table above shows the results from approaches by individual storage owner/operators (DNOs and demonstration consortia) to the relevant LPA for each installation. Clear guidance from Government regarding the treatment of EES in the planning system is not currently in place.

It can be seen from Table 6.4 that the majority of the existing deployments of EES in the UK by DNOs have been undertaken as ‘permitted development’, with deployments by other parties subject to a full planning application. Where EES systems are to be installed on existing substation sites (i.e. ‘operational’ land) it is likely that the use of ‘permitted

⁸⁶ Further details are provided within the Smarter Network Storage ‘Design and Planning Considerations for large-scale distribution-connected energy storage’ report. Available from: [http://innovation.ukpowernetworks.co.uk/innovation/en/Projects/tier-2-projects/Smarter-Network-Storage-\(SNS\)/Project-Documents/SNS1.2_SDRC+9.1+-+Design+%26+Planning+Considerations+Report_v1.0.pdf](http://innovation.ukpowernetworks.co.uk/innovation/en/Projects/tier-2-projects/Smarter-Network-Storage-(SNS)/Project-Documents/SNS1.2_SDRC+9.1+-+Design+%26+Planning+Considerations+Report_v1.0.pdf) Accessed 04/12/2013

development' can continue. EES installations will be treated in the same manner as secondary substations under ESQCR. It may however be necessary for some elements of the development to be agreed with the LPA. These may include the visual impact of the changes. If an EES system was to be installed on 'non-operational' land (e.g. by a DNO where a new site was required due to limited space available on 'operational' land, or by a 3rd party developer who did have access to 'permitted development' status) then it is more likely that full planning permission would be necessary. Street furniture style deployments of EES by DNOs can be installed under the normal arrangements applied to other types of street furniture (e.g. LV pillars).

6.5.2 COMAH Regulations

The Planning (Control of Major Accident Hazards (COMAH)) Regulations 1999 are most likely to be relevant to large scale flow battery installations, but may have the potential to impact on larger battery energy storage installations.

The COMAH Regulations came into force on 1 April 1999. Their main aim is to prevent and mitigate the effects of those major accidents involving dangerous substances, such as chlorine, liquefied petroleum gas, explosives and arsenic pentoxide which can cause serious damage/harm to people and/or the environment. The COMAH Regulations treat risks to the environment as seriously as those to people. The Regulations were amended 30 June 2005 to reflect changes to Seveso II Directive.

The Competent Authority for the purposes of COMAH comprises three organizations, namely the HSE, the Environment Agency (EA) - for England and Wales and the Scottish Environment Protection Agency (SEPA). These three organisations are responsible for the enforcement of the Regulations.

'Dangerous Substances', as defined by COMAH, are as set out in Schedule 1 of the Regulations⁸⁷. This includes a list of specific chemicals (Part 2 of Schedule 1) and chemicals which fall under certain 'categories' (Part 3 of Schedule 1), listed below:

- Very Toxic
- Toxic
- Oxidizing
- Explosive (different upper and lower thresholds depending on the nature of the substance)
- Any classification not listed in combination with risk phrases R14 ("reacts violently with water") and R29 ("in contact with water, liberates toxic gas")
- Flammable
- Highly Flammable
- Extremely Flammable
- Dangerous for the Environment (risk phrases R50 and R51/53)

The Regulations define qualifying limits, or thresholds, referred to as Lower Tier and Top Tier. These limits vary substantially according to the substance concerned and are listed within Schedule 1 of the Regulations⁸⁸. Any site exceeding the Lower Tier threshold is required to comply with the Regulations; for those sites which exceed the Top Tier threshold, there are additional compliance requirements. There are also aggregation rules that invoke the Regulations, even if individual inventories are below threshold values.

⁸⁷ Available from: <http://www.legislation.gov.uk/ukxi/1999/981/schedule/1/made> Accessed 05/03/2014

⁸⁸ Available from: <http://www.legislation.gov.uk/ukxi/1999/981/schedule/1/made> Accessed 12/11/2014

Further detailed information is available via an HSE Guidance Document⁸⁹.

6.5.3 Hazardous Substances Consent

A Hazardous Substances consent must be obtained under the Planning (Control of Major-Accident Hazards) Regulations 1999 if any of the substances listed in Schedule 1 of the regulations are present at or above the threshold quantity. This list is more extensive than the list of dangerous substances covered by the COMAH Regulations and with Schedule 1 Part A defining a range of “Named Substances” and with Part B addressing “Categories of Substances and Preparations Not Specifically Named in Part A”.

6.5.4 Pollution Prevention and Control

The Integrated Pollution Prevention and Control (IPPC) Directive aims to minimise pollution from various industrial activities throughout the European Union⁹⁰. The regulations are only likely to impinge on EES installations located on those sites which already come within the PPC regulations. This could include installations by network operators or generators co-located with power stations with a thermal output of greater than 50MW, or ‘customer-side of the meter’ storage deployed on industrial sites. For the majority of DNO installations, located on solely DNO sites, developments will not be subject to PPC regulations.

Operators of certain industrial installations that are covered by the Directive are required to obtain an environmental permit from the designated authority in the relevant country (e.g. Environment Agency or SEPA in Great Britain). If an EES system was to be installed on an existing industrial site (e.g. co-located at a power station) the site may already have an IPPC permit. IPPC permits set out the maximum permissible annual emissions of various substances from a site and reporting requirements.

A site which only contained an EES system (and associated substation) of the scale described in this Good Practice Guide would not fall under the IPPC regulations. However, sites which already have an IPPC permit and are subject to “substantial changes” are required to submit either a “notification of a change” or an “application to vary conditions”. These are referred to in Regulations 12 and 13 respectively. A notification of change is “appropriate when amendments to the permit are not required to implement the change but where such change has consequences for the environment”. In contrast, a variation (Regulation 13) is required when “a proposed change would require an amendment to the PPC permit”. The requirements for agreement regarding a notification of change (under Regulation 12) are less onerous than those under Regulation 13.

The IPPC directive has been relevant to two of the current deployments of EES in Great Britain: The Trial of the Orkney Energy Storage Park and the installation on Shetland as part of the Northern Isles New Energy Solutions (NINES) project. As part of the project on Shetland an EES system was installed at Lerwick Power Station (rating of 67MW⁹¹). The process can be described as follows:

- SSEPD made SEPA aware of the proposed installation and the nature of the technology via their regular discussions regarding the power station;
- A Regulation 12 “notification of a change” document was prepared which described the technology and set out the rationale behind the assertion that the EES system

⁸⁹ Available from: <http://www.hse.gov.uk/pubns/priced/l111.pdf> Accessed 26/09/2014

⁹⁰ Further guidance is available from the Department for the Environment, Food and Rural Affairs.

<http://www.defra.gov.uk/industrial-emissions/eu-international/ippc/> Accessed 06/01/2014.

⁹¹ <http://www.ssepd.co.uk/WorkArea/DownloadAsset.aspx?id=3834> Accessed 25/11/2014

would not have any impact on any of the emissions regulated by the IPPC permit (e.g. NO_x emissions, waste water etc.); and

- SEPA accepted this rationale.

6.6 Other Standards

Notwithstanding the coverage of the more general product design and construction standards provided in Section 6.3 and 6.4, it is worth noting the dearth of codes and standards which are directly applicable to stationary EES systems. BS EN 50272-2:2001 represents an exception here and this standard is described within Section 6.2.2.

Manufacturers and suppliers therefore regularly cite various non-UK codes, standards and test methods in order to help reinforce the argument for the safety of their systems. This is particularly the case for non Pb-Acid systems. These can relate to either the core storage technology or the PCS. A selection of the codes for various core storage technologies are summarised below.

- **International Standard (IEC) 60896 Stationary Lead Acid Batteries:** There are two main parts to this standard - 21 and 22 - which describe the methods of test and provide further details of the purpose of each test respectively. The standard applies to “all stationary lead-acid cells and monobloc batteries of the valve regulated type for float charge application, in a static location and incorporated into stationary equipment or installed in battery rooms for use in telecom, uninterruptible power supply, utility switching, emergency power or similar applications”⁹².
- **UL (Underwriters Laboratories) 1642 Standard for Safety for Lithium Batteries:** This standard is designed for primary and secondary batteries containing small amounts of lithium (less than 5 grams of metallic lithium) but states that “A battery containing more than 5 grams of lithium is judged on the basis of compliance with the requirements in this standard, insofar as they are applicable, and further examination and test to determine whether the battery is acceptable for its intended uses.”⁹³ It defines a number of abuse tests which batteries should be able to withstand (short-circuit, abnormal charging, crush, vibration, heating etc.) and the marking that should be applied to the battery⁹⁴.
- **P1679.2 Guide for the Characterization and Evaluation of Sodium-Based Batteries in Stationary Applications:** This standard is under development by the IEEE Standards Association and is based on IEEE 1679-2010.

There is currently a paucity of standards relating to performance and abuse tests for battery modules (i.e. multiple cells) or whole EES systems (i.e. multiple modules). This is particularly true for standards originating the EU, with those described above being developed in the USA. Compliance of cells with standards such as those described above gives some assurance over the safety features of a system (e.g. the ability of particular cells to withstand fault conditions such as overcharging). However, they fail to consider cell to cell propagation, or larger events which may affect multiple cells or modules. Further abuse testing by manufacturers may provide some assurance of the behaviour of the system during these more widespread events, but a standard set of tests is not currently available.

In addition to the test/performance standards for the core storage technology, there are also a number of standards which relate to the PCS. A number of these are listed within Table 6.2. This includes IEEE P2030.3 – Standard for Test Procedures for Electric Energy

⁹² http://webstore.iec.ch/preview/info_iec60896-21%7Bed1.0%7Den_d.pdf Accessed 06/01/2014.

⁹³ <http://ulstandardsinfonyet.ul.com/scopes/scopesnew.asp?fn=1642.html> Accessed 06/01/2014.

⁹⁴ <http://ulstandardsinfonyet.ul.com/tocs/tocs.asp?doc=s&fn=1642.toc> Accessed 06/01/2014.

Storage Equipment and Systems for Electric Power Systems Applications, which is currently under development in the USA. This standard will form part of a series of Smart Grid standards and will establish test procedures for EES equipment and systems for “electric power systems applications”⁹⁵. As this standard is still under development, it not yet clear what effect it may have on the functionality of devices manufactured in the USA, and how this could benefit (or otherwise) technology deployments in the UK.

In the context of the UK, within the current deployments of storage, systems have been connected which comply Engineering Recommendation G59/- (Recommendations for the Connection of Generating Plant to the Distribution System of Licensed Distribution Network Operators). The guidance within G59/- is designed to facilitate the connection of generating plant (or storage when discharging) whilst maintain the integrity of the distribution network, both in terms of safety and supply quality. It describes the methods by which generating plant should be connected to the distribution network and the way in which they should behave under certain conditions (increase/decrease in voltage or frequency or loss of mains supply).

The current deployments of EES technology by DNOs and others connected to the distribution network (as shown in Figure 2.4) generally represent the first installation of a particular EES unit (as a combination of a storage unit and inverter). DNOs have therefore subjected the units to site commissioning tests to confirm their compliance with the requirements of G59/-. The purpose of this protection is both to protect the device from the network, and vice-versa. Compliance with G59/- is the current ‘default’ position for the connection of EES systems to the distribution network. However, GB DNOs are currently gaining a considerable amount of knowledge of the ways in which energy storage should operate and the ways in which to maximise its benefits to distribution networks, via a number of trials. The most beneficial behaviour of units under certain conditions (under or over voltage/frequency) is an area for further discussion.

6.7 Current Developments

At the time of writing (October 2014), the International Electrotechnical Committee (IEC) had established a new Technical Committee (TC 120) to address EES systems⁹⁶. TC 120 was established in 2013 specifically to provide a systems approach for EES, with the objective “to plan, integrate, control and manage EES systems beyond mechanical and thermal storage domains”. Its scope is intended to embrace electrochemical, electrical, mechanical, thermal and chemical energy storage, with five Working Groups (WGs) established, to address:

- Terminology (WG1);
- Unit Parameters and Testing Methods (WG2);
- Planning and Installation (WG3);
- Environmental Issues (WG4); and
- Safety Considerations (WG5).

A further, ad-hoc WG (AHG1) addresses ‘Systems Aspects and Gap Analysis’. Seventeen countries (as of 25 November 2014) are participating in IEC TC 120 and with it being likely that the UK will participate, via the auspices of the BSI.

⁹⁵ http://grouper.ieee.org/groups/scc21/2030.3a/2030.3_index.html Accessed 07/01/2014

⁹⁶ http://www.iec.ch/dyn/www/f?p=103:7:0:::FSP_ORG_ID:9463 Accessed 22/09/2014

6.8 Potential Future Developments of Codes, Standards and Regulations

The sections above have identified codes, standards and legislation which are either directly applicable to utility scale EES equipment and installations, or which have the potential to impact upon them. Utility scale EES is still a relatively immature technology in the UK and has been deployed under a number of trials (e.g. LCN Fund activity). The development of codes, standards and regulations takes place over a period of multiple years, partly driven by developments in technology. Through the deployment of EES under the various projects described in Appendix 1, and discussion during ESOF meetings, a number of current 'gaps' within codes, standards and regulations have been identified, including:

- Planning guidance (or an addendum to existing planning guidance for T&D networks) from Department of Communities and Local Government in relation to the treatment of EES installations. Development of such guidance would assist individual LPAs, where an application for an EES site may be the first submitted in that locality.
- Standards for abuse testing of modules/full-scale systems, relevant to stationary, utility scale installations. Existing standards generally involve the testing of individual cells, or are designed for testing of batteries for use in EVs. The provision of abuse testing data at a module/system level assists in the development of a rigorous safety case for EES installations (see Sections 9 and 10). However, whilst abuse testing to a particular standard is beneficial, it should be noted that this does not predict the behaviour of the system under different scenarios (e.g. exposure to a longer, more intense fire, or different types of impact).
- Standards for stationary EES installations, such as the current BS EN 50272-2:2001, could extend to other electrochemistries (i.e. beyond Pb-Acid and NiCd systems).
- The development of consistent treatment of EES installations under ESQCR. The current approach used by DNOs when deploying energy storage as part of trials has been to treat EES installations as a secondary substation site. The way in which energy storage should be integrated within 'business as usual' operational/safety guidance is an area which is being progressed by DNOs within their current trial activities. Further details of the integration of storage with DNO policies are given in Section 10.
- Explicit inclusion of the EES installations in the UK electricity market regulations, including the various incentive schemes aimed at reducing carbon emissions. See Section 12 for details of current EES installations' interaction with the UK electricity market.

7 Procurement

This Guide considers the knowledge developed from deployments of EES by GB DNOs and by the current round of DECC supported Energy Storage Demonstration projects. In the case of the DECC supported Demonstration projects, the consortia delivering the projects are generally installing their own storage equipment, possibly with external suppliers providing sub-systems such as the PCS. This section therefore focuses on the knowledge of procuring energy storage, as developed by DNOs through the various deployments set out in Section 2 and as shown in Figure 2.4.

The experience base in procuring this relatively novel technology is limited but growing with around 16.5 MW/28 MWh storage procured by GB DNOs at the time of writing. However, DNOs (and the TO/SO) have well-established procurement processes for purchasing other, more 'standard' pieces of equipment. Such processes have generally been used when purchasing energy storage.

The process followed by DNOs in procuring energy storage is summarised by the following flow diagram. A similar process is also likely to be followed by other potential owners of energy storage.



Figure 7.1: Procurement Process

This section first describes the EU Directives which DNOs/the TO/SO must comply with when procuring equipment, before describing each stage of the procurement process (see Figure 7.1) and the lessons learnt in relation to energy storage.

7.1 EU Procurement Directives

Procurement activities which are being undertaken by central and local government and other monopoly industries such as utilities are subject to a series of European Directives. The aim of these Directives is to open up the EU's public procurement market to competition, to prevent "buy national" (or "buy local") policies and to promote the free movement of goods and services. They also aim to ensure that government or monopoly companies (such as distribution and transmission network operators) obtain best value through their procurement processes, in order to pass this onto their customers.

In the UK there are two sets of Regulations; those covering England, Wales and Northern Ireland and a separate set of regulations covering Scotland. These Regulations interpret and implement the Utilities Directive into UK legislation. They essentially mandate

contracting entities to adapt their contract award procedures to the framework set out in the Directive.

Under the Utilities Contracts Regulations 2006, from the 1st January 2014 the following thresholds apply over which the Regulations must be applied (save where an exemption applies)⁹⁷:

- £345,028 (€414,000) for goods or services
- £4,322,012 (€5,186,000) for works

Implementation of energy storage schemes may touch upon all 3 categories of goods, services and works. Ordinarily the majority of the purchase will be in the goods category and the threshold for goods should therefore be applied in determining whether the Regulations do or do not apply.

Given the relatively immature status of this market and desire to obtain innovative solutions, DNOs may be able to rely on the Research & Development exemption under the Regulations. This allows DNOs to rapidly trial technology where it may be difficult to develop a specification or performance criteria given the low TRL of the product. The growing experience within the sector of procuring and operating EES systems (particularly those based on battery technologies) means that it is unlikely that such an exemption would apply. Specific criteria apply to this exemption and procurement advice should be sought before proceeding with this option to ensure compliance.

7.2 Specification, PQQ and Performance Criteria Development

The first stage of the procurement process involves the development of specifications, a pre-qualification questionnaire (PQQ) and performance criteria for the system. A specification is typically developed, detailing exactly what is required from system suppliers. A PQQ is a list of questions designed to screen potential suppliers against some basic criteria. In parallel, performance/evaluation criteria are required in order to assess the responses to the specification received.

The specification takes into account the functionality and reliability/availability required from the device, and other items such as the physical constraints of the installation site (available footprint, height etc.). There are a wide variety of aspects which could be included within the specification for an EES device. However, due to the relatively immature nature of the market, it is worth considering including some degree of flexibility in the requirements. This would allow credible suppliers who may not meet the full specification to be included. Aspects considered within specifications typically include:

- **A description of the project:** the key outcomes required and the anticipated scope of supply (e.g. whether a full turnkey solution is required);
- **Network connection:** Where and how the devices are to be connected to the distribution network, including protection, earthing and metering requirements;
- **Technology:** maturity of technology required, rating of the inverter (kW and kVAR, type of inverter (e.g. 4 quadrant)), capacity of storage (kWh), three phase or single phase units, lifetime of the system (both chronological and number of cycles) and the level of degradation in performance that is acceptable during this lifetime;
- **Physical requirements:** maximum dimensions, Ingress Protection (IP) rating of the housings, installation requirements (e.g. modular or single containerised system), operating temperatures and humidity;

⁹⁷ <http://www.oiec.com/Thresholds.aspx> Accessed 17/01/2014

- **Functionality requirements:** frequency, speed of response, round trip efficiency, self-discharge rates, ability to increase rating or capacity, serviceability (e.g. any requirement for storage of critical components, number of suppliers available etc.), ability to transfer energy between phases, scheduling options (e.g. scheduled charge/discharge, or reaction to a fixed limit for voltage or current) and operational regimes, including the types of response which the system may provide (e.g. the requirements for providing reserve services to National Grid);
- **Reliability and Availability:** an EES system may be required to operate at crucial times – for example, providing additional capacity to a network in ‘n-1’ conditions (see Section 12.2.2.2). Significant contractual penalties may also be placed on an EES owner/operator if they fail to deliver a contracted service (e.g. to the Capacity Market, see Section 12.2.2.4). It may therefore be necessary to specify the reliability or availability of the system which is required as part of the specification;
- **Control requirements:** communication channels and protocols to be used (e.g. requirements to communicate with existing DNO control systems or Active Network Management (ANM) schemes), alarms to be communicated to other systems and data and cyber security; and
- **Safety and Environment:** maximum noise level when in operation, codes and standards to be complied with (see Section 4.2) and requirements for any envisaged safety systems (e.g. non-lethal fire suppressant to be used, with a requirement to disable this and ‘lock-off’ before entering the building).

Evaluation criteria have been developed by those procuring EES systems in order to compare the tender responses received against the particular priorities of a project. These must be agreed in advance of the tendering exercise⁹⁸. In rare circumstances, where necessary, these criteria can be changed during the tendering phase but all bidders must be advised of any such change. It is also likely that this would require an extension to the time period given to bidders to complete their tender return. The evaluation criteria used by GB DNOs have included:

- Safety, health and environmental factors;
- TRL/Maturity of a product;
- Cost effectiveness;
- Deployment track record (overseas or UK specific);
- Efficiency/lifetime;
- Technical product quality;
- Financial background of supplier; and
- Ability to meet project timescales.

A pre-qualification questionnaire (or e-qualification) stage should be implemented (when completing a regulated procurement process) in order to screen potential suppliers against a shorter list of requirements. This can be advantageous for filtering a large number of potential suppliers which may include those who are not suitable and also limits the initial commitment required from suppliers. The level of detail requested from potential suppliers can vary, but could include a series of questions to address matters such as:

- The scope of supply which could be offered (e.g. full turnkey installation including civil works, ability to deliver maintenance and training);
- Lead time for delivery, installation and commissioning;
- Ability to comply with all relevant UK codes and standards;
- Relevant reference installations (e.g. installations of a similar size or work with similar organisations); and

⁹⁸ Clauses 30 (3), (4) and (5) of the Utilities Contract Regulations 2006 (Consolidated).

- Standard questions regarding organisational and financial standing.

Performance criteria and weightings can also be used to screen the responses received from the PQQ stage.

7.3 Issue of Pre-Qualification Questionnaire and Specification

The PQQ and specification are then published, in order for potential suppliers to respond. The most commonly used supplier management and supply chain solution by GB DNOs is provided by a private company, 'Achilles'⁹⁹. This system is used to advertise tenders (product specification documents) amongst a community of manufacturers in relevant industries. 'Achilles' is used by the DNOs and TO/SO for the majority of their equipment procurement activities.

Suppliers wishing to use 'Achilles' register under a series of categories which are relevant to the products or services they provide. EES is currently a relatively novel technology and does not have a dedicated code within the system. GB DNOs have therefore advertised tenders under a number of potentially applicable codes, such as:

- 1.8.10 Primary Cells, Batteries and Chargers;
- 1.8.21 Control & Instrumentation Systems & Spares (excluding Nuclear); and
- 1.9.99 Other Electrical Protection Equipment.

The use of multiple codes is required due to the relatively complex nature of storage systems and the multiple types of supplier which may provide them. The different parts of energy storage systems and their current status are illustrated by the figure on the following page.

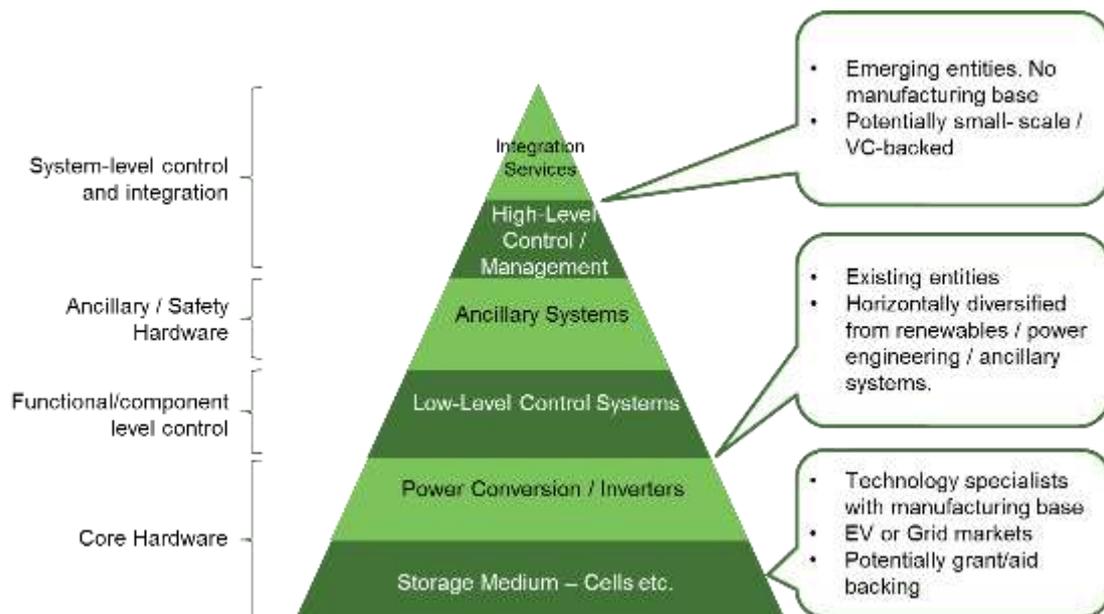


Figure 7.2: Components of Energy Storage Systems¹⁰⁰

A number of 'Achilles' codes would be relevant to the various organisations on the pyramid shown in Figure 7.2. For example, providers of the core storage medium may be registered

⁹⁹ <http://www.achilles.com/en> Accessed 17/01/2014

¹⁰⁰ Energy Storage Workshop Presentation at LCNF Conference 2013. Presentation by Nick Heyward, UK Power Networks. 13th November 2013. Presentation available to watch online via: <http://tv.theiet.org/channels/news/18139.cfm> Accessed 17/12/2013.

under 1.8.10, whilst system integrators or PCS suppliers may be registered under 1.8.21. The use of multiple codes increases the number of potential suppliers which receive notification of the tender. It would be advantageous for a single code within 'Achilles' to be available which encompassed all parts of utility scale energy storage and to which all relevant suppliers were registered.

Due to the relative immaturity of the market, a number of GB DNOs have supplemented the use of 'Achilles' with a further market search. This ensures that other potential vendors are aware of the tender, can register with Achilles and take part in the procurement process. This is currently necessary due to the relatively immature nature of the market (e.g. involvement of suppliers who have previously not supplied to GB DNOs) and its evolving nature. There are a number of different ways in which the system could be procured, due to its various main components, as follows:

- Procurement from a battery supplier who then sub-contracts for the PCS;
- Procurement from a PCS supplier who then sub-contracts for the core storage technology; and
- Procurement from a systems integrator who subcontracts both major components.

It is not yet clear whether there are particular advantages/disadvantages in each of these routes and which, if any, will become the "standard" route in the future.

7.4 Evaluation of PQQ Responses and Issue of Invitation to Tender

The PQQ responses should then be screened against the set criteria. This stage is a 'first pass' high level screening designed to show the suitability of potential suppliers, and is generally a qualitative assessment, with minimal detail requested from respondents. Following the screening of PQQ responses, the successful suppliers are then invited to provide much more detailed information, via an Invitation to Tender (ITT).

The tender exercises to date have shown a relatively sharp 'cliff edge' in the number of potential suppliers, as demonstrated by Figure 7.3 below.

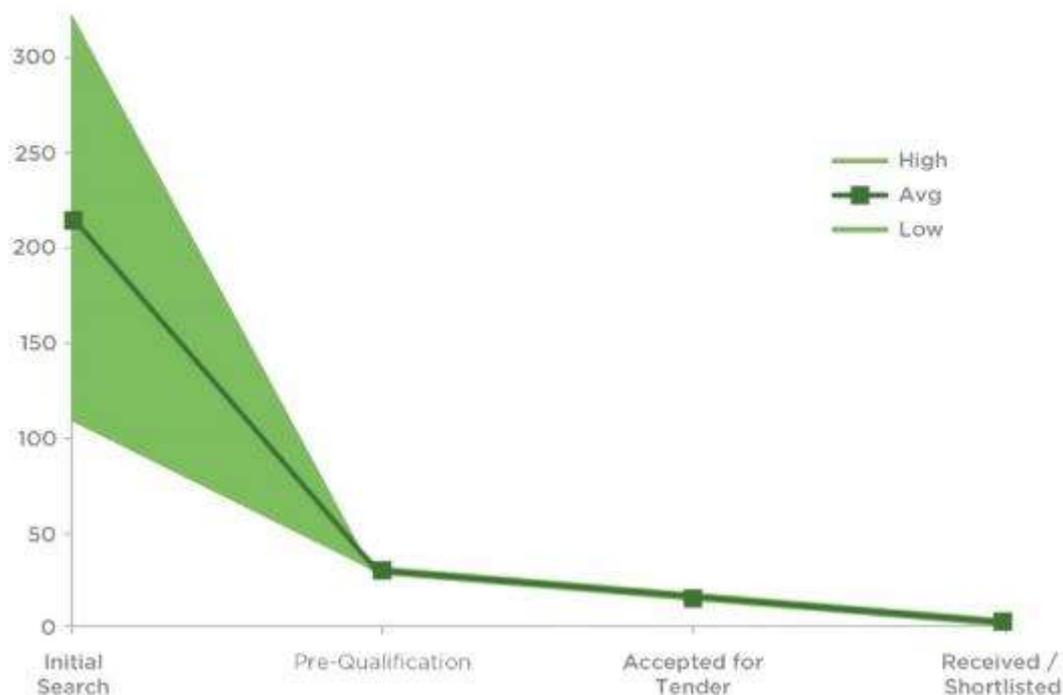


Figure 7.3: Number of Potential Suppliers during Procurement Stages¹⁰⁰

Figure 7.3 shows the number of potential suppliers in the procurement process at the end of each stage. An initial search of a supplier management and supply chain solution such as ‘Achilles’ and the addition of other potential suppliers leads to a large number of results. Around 15% of these companies will then complete the PQQ and a sub-set of these (around 10% of the original total) are then accepted to submit a full tender.

From the initial 200+ potential suppliers it is likely that only three to five would submit a tender response or be shortlisted for a given project. This demonstrates the lack of supplier choice currently in the UK market, particularly when requirements such as technology maturity and prior experience of deploying storage in the UK are taken into account.

7.5 Evaluation of Tender Responses against Specifications and Performance Criteria

Following the receipt of responses to the PQQ and the issue of an ITT, bidders will then submit full tender returns. A process of assessment is then required to evaluate the responses received. This is carried out against the evaluation criteria defined at the outset of the procurement process, including the project budget (likely to have been set in conjunction with some preliminary cost:benefit analysis, see Sections 12 and 13).

One of the criteria which can be used in the evaluation of a tender is the expected lifetime of the EES system. This is generally linked to a defined number of cycles which the system can undergo before its capacity is reduced to 80% of its nominal value. The rate at which the capacity will reduce is influenced by a number of factors including the choice of technology, depth and rate of discharge and environmental conditions (e.g. operation at an elevated temperature can decrease the lifetime of the system). A standard definition of the charge/discharge regime used does not currently exist, making comparison between manufacturers more difficult. If such a definition were to be developed it is likely that a number of different ‘standard’ regimes would need to be included to encompass different applications for EES.

7.6 Selection of Supplier and Contract Agreement

Following the tender evaluation process, a preferred supplier will be selected. Contract terms will then require agreement between the two parties. A variety of commercial terms have been suggested which may be advantageous when procuring large-scale energy storage systems. These are shown in Table 7.1.

Table 7.1: Potential Contractual Provisions for Large Scale EES¹⁰⁰

Contractual Provision Secured	Rationale
Staged payments	Incentivise delivery and commissioning on schedule; mitigate against default
Performance bond	Incentivise performance and mitigate against default (e.g. by including minimum system efficiency as a contractual limit)
Delay compensation	Mitigate against construction/storage related costs for delays
Parental company guarantees	Mitigate default or non-delivery of supplier & sub-suppliers
Warranty periods and protection for warranty payments	Incentivise manufacturing quality, mitigate against defaults
Public and product liability insurances in excess of contract	Cover for catastrophic failures impacting network or public assets
Professional/design indemnity in excess of contract value	Cover for design failures impacting network security, damages to network or public assets
Availability performance Key Performance Indicators (KPIs)	Incentivise high system availability
Sell-back option	Mitigate for significant changes to network security requirements; lack of performance

7.7 Acceptance Tests

A series of factory and site acceptance tests (FAT and SAT) have been employed as part of the procurement and installation of energy storage by GB DNOs and details are given in Table 7.2 below. It is worth noting that for larger systems, the individual sub-assemblies (e.g. the core storage unit, PCS) will only ever physically come together at the installation site, limiting the amount of factory acceptance testing which can be undertaken. This is particularly true when component suppliers are geographically distributed. Notwithstanding this, manufacturers should carefully consider the extent of the testing which can be completed on individual components/sub-assemblies prior to arrival at site. Such testing has the potential to reduce the probability of any issues only coming to light once at site.

Table 7.2: Acceptance Tests by DNOs¹⁰¹

Project	Acceptance Tests
FALCON (WPD)	FAT for device limits and operation. SAT for full operation of equipment. 5 days full commissioning testing per device once connected to the live network.
SolaBristol (WPD)	FAT attended by WPD. As part of the FAT the complete system was tested. This included the storage unit, DC loads and a variable DC power supply to mimic PV generation. However, the variable DC power supply proved not to be representative of a PV panel. Site commissioning tests as per G59/-.
CLNR, all sites (Northern Powergrid)	FAT on entire systems completed by A123 and Dynapower (battery and inverter suppliers). Northern Powergrid witnessed A123 major component testing. Cold commissioning to prove functionality. Northern Powergrid carried out interface and G59/- protection commissioning tests. After final connection to distribution network hot commissioning tests were completed including charge and discharge onto network via primary source.
Hemsby (UK Power Networks)	FAT on control system and other individual components. Type test certificates were made available for off the shelf components. Cold commissioning to prove functionality. After final connections to 11kV network, hot commissioning testing the device at rating (i.e. after full charge 200kW discharge for one hour, recharge and short time discharge at 600kW). Several weeks of commissioning tests after snagging.
Smarter Network Storage (UK PN)	Test Strategy included 8 separate stages for the full end-to-end system: <ul style="list-style-type: none"> • System (Unit) Testing • Attendance at Factory Acceptance Tests • Site Acceptance Tests • System Integration Tests • User Acceptance Tests • Non-Functional Tests • Operational Acceptance Tests • Cut-Over Process Test
Orkney (SSEPD)	This was a third party owned system and so testing was the responsibility of the system operator (Scottish and Southern Energy Generation). DNO tests under G59/- and to commission system to ANM control.
Chalvey (SSEPD)	SSEPD attended the Factory Acceptance tests and requested additional tests beyond manufacturer standard. The purpose of the FAT testing was to: <ul style="list-style-type: none"> • View and inspect the units to be installed • Witness manufacturers testing and engage with staff • Request own tests • Obtain efficiency figures • Observe the control interface Site acceptance testing completed under G59/- (islanded network) Manufacturer's site acceptance testing (islanded network) Site safety/operational testing completed. Multiple charge/discharge cycles run to establish efficiency.
Shetland-NaS (SSEPD)	Factory acceptance tests/Factory visits were completed for both the PCS and the battery The battery visit provided useful information on how the modules were manufactured, but in the absence of defined standards, it was difficult to conduct acceptance tests, The PCS completed a rigorous test schedule.
Shetland-Pb-Acid (SSEPD)	No FAT was conducted for the cells, due to the 'mass production' nature of the manufacturing.

There have been a number of 'lessons learnt' as result of the acceptance tests carried out in EES deployments to date, as follows:

- There is a lack of a standard calculation for round trip efficiency. Efficiency can be measured at a number of points (e.g. energy in and out of the battery (DC only) or

¹⁰¹ Details provided by DNOs via project case studies. See Appendix 1.

energy in and out of the whole EES system (AC i.e. including losses in the PCS). In addition, 'reference cycles' are defined differently by manufacturers and then used to calculate the round trip efficiency of the unit. A standard definition or increased clarity in the figures provided by manufacturers (e.g. details of the charge/discharge cycle employed and points of measurement) would provide greater clarity for those procuring energy storage;

- There is a difficulty in defining and performing acceptance tests for new technology. Standards do not currently exist in this area;
- It is important to ensure that factory acceptance tests accurately replicate the conditions that will be experienced on site. The FAT for one trial used a variable DC power supply to mimic the changing output from PV generation for the purposes of testing the response of the EES system. However, this did not accurately reflect the speed at which the output of the PV system could change (e.g. due to cloud cover);
- All distribution network connected systems are currently tested to ensure compliance with G59/-. This sets out the response of the unit to under or over voltage and frequency and loss of mains. The preferred protection settings for distribution network connected storage are still being defined by GB DNOs and this will be developed further through the on-going activities of ESOF; and
- Acceptance tests need to be carefully designed in order to prove the required functionalities.

7.8 Warranty and After-Sales Support

The majority of the energy storage deployed to date represents a "first" of some kind. For example, "the first distribution network connected storage"¹⁰² (Hemsby, UK Power Networks), or the first of one particular system or technology (e.g. first Nickel Metal Hydride system in the UK, FALCON, WPD). The experience base of operators of EES (such as personnel within DNOs) of operating, maintaining and (where necessary) troubleshooting energy storage is also still developing. The after-sales support and warranty provided by manufacturers is therefore important. It is more likely that there will be a greater degree of interaction between the EES owner/operator and the technology supplier during the period following initial commissioning than for more technologically mature equipment.

A warranty has been provided for all the storage projects operated by DNOs described in the case studies (see Appendix 1). These vary in length, but typically cover the lifetime of the project (3-5 years). In addition to the warranty, maintenance, inspection and troubleshooting support has also been provided. Many manufacturers have the option of accessing the storage devices remotely following commissioning. This can be used for the purposes of checking system performance and providing support to the DNO in operating the system, and troubleshooting. Whilst this has proved beneficial in some cases, it can also raise a number of commissioning issues in relation to the communication channels required (see Appendix 1, Section A1.7).

¹⁰² In recent times. A 40kVA/80kWh Pb-Acid system was installed by Manweb in Wrexham in 1990.

8 Installation

Within the current round of storage deployments, each installation has been in some way unique - there have been no repeated installations of the same technology; every site has needed a bespoke approach. However, each installation follows a similar process from site selection, through various stages of installation activities, to commissioning and handover to operational teams. This section aims to summarise the issues to be considered during the installation process and the lessons learnt from current deployments. The installation process is summarised by Figure 8.1 below.

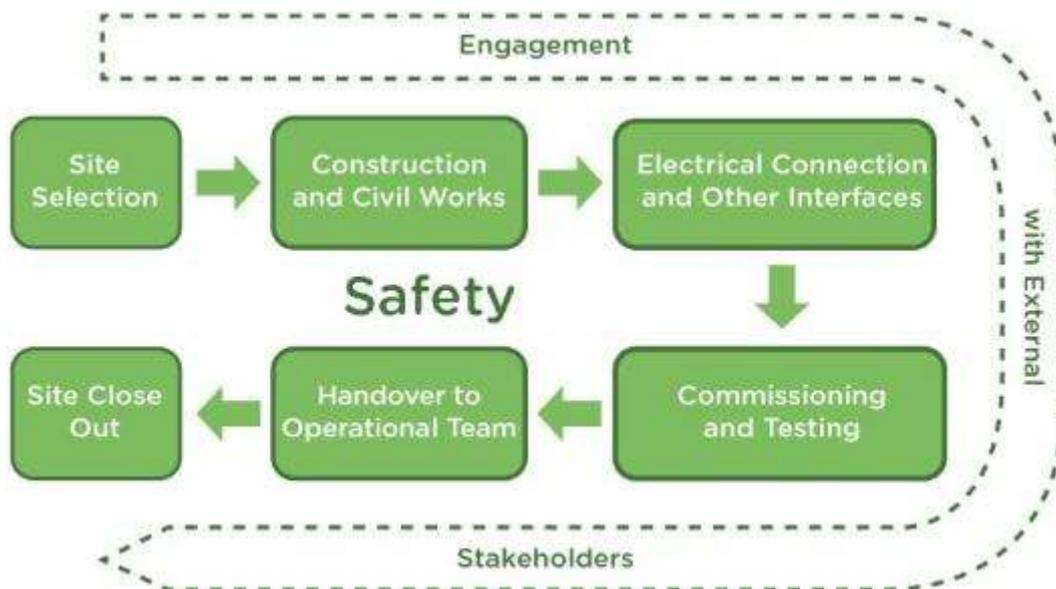


Figure 8.1: Installation Process

This section first considers the regulations which govern many of the processes involved from the design phase, through to installation and commissioning (the CDM Regulations). Each of the stages of installation as shown in Figure 8.1 is then discussed in turn.

8.1 The Construction (Design and Management) Regulations

The Construction (Design and Management) Regulations¹⁰³ (CDM) apply to the activities carried out from the design phase, through the fitting-out of accommodation, installation and commissioning of the system. Projects carried out to-date have not always met the criteria necessary to make formal notification to the HSE (the designated body to which notifications are made) necessary – which triggers the need to maintain a Health-and-Safety file, formally appoint a competent Principal Contractor and CDM Co-ordinator¹⁰⁴.

The process to be followed generally includes, but is not limited to, the parties and duties presented in Table 8.1 below, some of which are summaries of CDM duties. For large systems, the process has encompassed calendar durations of more than one year.

¹⁰³ UK Statutory Instrument 2007 No. 320, The Construction (Design and Management) Regulations 2007

¹⁰⁴ HSE, Construction (Design and Management) Regulations 2007, Approved Code of Practice, 2013

Table 8.1: Site Processes¹⁰⁵

	Client (i.e. the organisation commissioning construction work, e.g. the DNO)	Approved Contractors	Energy Storage System (ESS) Supplier / Designer
Before Construction	<p>Carry out Operational Risk Assessment (ORA) to ensure risks relevant to the specific site can be managed (see Section 10). Prepare pre-construction information. Ensure designers and contractors are competent.</p>	<p>Demonstrate competence. Take design roles as appropriate.</p>	<p>Advise Client on specific hazards of the ESS technology, mitigations employed and residual risks. Provide Client with assurance of effectiveness of design measures.</p>
During Construction	<p>Put reasonable management arrangements in place. Potentially provide assistance understanding UK Health and Safety legislation, especially if the ESS Supplier is from outside the UK. May assign own engineering staff to manage connection and protection. Manages residual design risks during the operational phase.</p>	<p>Contracted to the Manufacturer or Client and forming the Principal Contractor under CDM. Usually responsible for the site preparation, fitting-out and/or assembly of ESS modules. May be assigned to carry out network connection and protection to Client instructions. May install and test fire and/or chemical protection systems and alarms.</p>	<p>Takes the role of a Designer under CDM. Responsible for the safety aspects of the design – “Design Risk Assessment”, supply of the ESS, commissioning and training. Transfers residual design risks to the CDM Co-ordinator to be managed. May be a foreign entity, with limited prior knowledge of UK Health and Safety legislation.</p>
Prior to Site Live	<p>Witness tests of emergency systems e.g. gas/fire alarms. Witness commissioning tests.</p>	<p>Provide support during commissioning tests.</p>	<p>Demonstrate G59/- compliant protection. Demonstrate emergency procedures and systems, safe shutdown etc. Demonstrate operation to limits of operating envelope. Provide service contract and support to negotiated terms. Pass construction-phase Health and Safety file to Client. Keep Client apprised of any safety-related matters occurring within the class of technology.</p>
After Site Live	<p>Formally accept ESS into asset base and apply safety rules. Advise appropriate authorities. Maintain process for periodic substation inspection. Review Health and Safety procedures.</p>	<p>Provide Health and Safety information and any additional operating and maintenance procedures.</p>	<p>Provide training material for ESS safety and operating procedures. Provide service contract and support to agreed terms. Accept return of used batteries under the Waste Batteries and Accumulators Directive (see Section 6.2.1). Pass construction-phase Health and Safety file to Client. Keep Client apprised of any safety-related matters occurring within the class of technology.</p>

¹⁰⁵ Developed based on guidance contained in: HSE, Construction (Design and Management) Regulations 2007, Approved Code of Practice, 2013

8.2 Site Selection

Installations of EES are driven by a particular need. Within the current round of deployments described in Appendix 1 these needs are a mixture of solving particular network constraints or proving the performance and impact of systems, as part of R&D activity. Outside of R&D projects (i.e. the deployment of storage as BaU activity) the 'needs' to be addressed by EES installations could also be described by the 'Applications' described in Section 3 and Appendix 2.

An assessment will be required to determine the suitability of potential site(s) for deploying EES. Depending upon the application/need to be addressed, and the organisation deploying EES (e.g. DNO with multiple sites/substations, or generator/industrial customer with a single site) this may relate to the viability of a single site, or may be a comparison of multiple potential locations. The degree to which applications are location specific varies – for example, EES may be required in a particular network location in order to solve a particular network constraint, whilst energy arbitrage is not similarly constrained. The table below shows those applications (based on those identified in Table 3.1) which are location specific (or otherwise). It should be noted that if a particular EES system is serving a location specific application (e.g. DNO constraint management) this may restrict their availability for other uses at particular times.

Table 8.2: Applications and Location Specificity

Application	Location Specific?	Comments
Energy Arbitrage	N	Location may be limited by availability/cost of connection to DNO network. Some elements of import/export charging vary according to time of day and licence area under Distribution Use of System (DUoS) charges.
Peak Shaving/Thermal Support	Y	It may be possible to locate storage on multiple affected circuits to provide an effective solution – but geographical and network characteristics will limit the number of potential locations.
Voltage Support	Y	
Constraint Management	Y	Management of DNO network constraints: It may be possible to locate storage on multiple affected circuits to provide an effective solution – but geographical and network characteristics will limit the number of potential locations. Management of generation/import constraints (e.g. for a renewable generator or private operator): Will be limited to co-locating EES with site affected by network constraint (e.g. generation asset or site with constrained import connection).
System Balancing Services	N	System balancing services (Short Term Operating Reserve (STOR) and Frequency Response) are not constrained by location. Location may be limited by availability/cost of connection to DNO network.
Portfolio Balancing Services	N	Could be located at any site owned by the relevant supplier or generator.

As well as the ability to satisfy the application identified, there a number of issues to be considered when selecting a suitable site for installing energy storage, including:

- **Space available (both footprint and height):** For example, as a rough guide to the space requirements of an ESS, a 40ft ISO container¹⁰⁶ with maximum payload of 25t could contain 2.5 MWh at an energy density of 100 Wh/kg (see Table 4.1). A separate container is usually necessary for the PCS. In the context of DNOs installing EES storage, due to size, it cannot often be incorporated within the bounds of existing substations. It may be necessary to purchase land (where available) to install energy storage, but this should be considered as part of the cost:benefit calculation.
- **The presence of risks from the surrounding environment:** risks could include the potential for flood, or adjacent chemical/fuel storage. However, within the case studies in Appendix 1, a number of projects have mitigated against the potential for flooding by constructing EES facilities on raised plinths. If the site in question is currently subject to COMAH¹⁰⁷ regulations (see Section 4.2), how proximity of an EES system would affect the Major Accident Prevention Policy should be considered.
- **Availability of a network connection:** for owners/operators of EES outside of the DNO environment, an EES facility would require a connection agreement with the relevant DNO. The cost and lead-time for this connection will vary according to the current spare capacity at a given location and this could influence the choice of site. Early engagement with the DNO is to be encouraged.
- **Noise:** there is a potential for noise from EES installations – either from auxiliary systems such as Heating, Ventilation and Air Conditioning equipment, the PCS or transformers, or the core storage technology/mechanisms. The characteristics of this noise (e.g. pitch, times it is present) may be different to existing noise sources and so have the potential to impact upon adjacent properties. The level of noise which may be generated must be assessed relative to the background level. For example, within current DNO trials the same units have been installed in two locations (one relatively noisy and urban and the other quiet and rural). Noise was an issue in the rural location, but not in the noisier environment. It is possible to install mitigation measures such as sound insulation within the fabric of the building.
- **Potential impact of residual design risks:** As part of the Risk Assessment process (see further details in Section 10) a number of residual risks may remain (although the probability of the hazard occurring and its severity can be reduced). The acceptability of these risks in a given location should be considered.
- **Access routes:** access will be required during the construction/installation phase – e.g. cranes accessing site to lift sub-systems into place. This will require suitable access routes. Any planning application associated with an installation would also consider the potential impact on traffic routes if additional vehicles will visit the site due to the installation of energy storage.
- **Planning permission availability:** depending upon the owner installing the EES system, either a full planning submission or an application for ‘permitted development’ is likely to be required. The likelihood of a successful application may influence the choice of site. The acceptance of the local community (e.g. if the proposed site is in a particularly sensitive location due to the nature of the landscape etc.) should also be considered here. Further details of the planning process and issues to be considered are given in Section 6.5.1.
- **Availability of required auxiliary services:** depending upon the technology to be used, various auxiliary services may be required such as water connections, secure communication links to wider network schemes (e.g. ANM), or a secondary electricity

¹⁰⁶Hapag-Lloyd, Container Specification, ISO Size Type Code 42U6, Group Communication 01/2010

¹⁰⁷HSE, Understanding COMAH: A guide for new entrants, 11/2013

supply for critical systems. Further details on additional site interfaces are given in Section 8.4.

- **Co-location with other systems:** the ability to co-locate an EES system with other installations may be advantageous and so should be considered when selecting a site. Examples of this within the case studies include the ability to deploy battery energy storage within an existing ANM scheme, and a LAES plant co-located with another industrial process providing waste heat, thus improving the round trip efficiency of the system.

Following considerations of the issues above, EES systems have been sited at existing substations, at new purpose-designed substations, existing power-station sites and close to specific loads.

8.3 Construction/Civil Works

As for substation assets, EES devices require the site to be prepared for installation via a series of construction/civil engineering tasks. These preparation tasks scale roughly in proportion to the rating of the ESS. The varying size/installation complexity of EES systems installed to date is illustrated by the Figures below.



Figure 8.2: 6MW/10MWh EES System (UKPN)
- Installed in a purpose built building



Figure 8.3: 2MW/500kWh EES System (SSEPD)
- Containerised



Figure 8.4: 50kW/100kWh EES Installation (Northern Powergrid)
- Installed within an existing substation



Figure 8.5: 2kW/4kWh Residential EES System (WPD)
- Installed within domestic loft spaces

An example of the installation activities required for one containerised 2.5MW/5MWh system, installed by Northern Powergrid is available to view online¹⁰⁸.

¹⁰⁸ <http://www.youtube.com/watch?v=AzuWYkxaCr0>. CLNR Youtube Channel. Energy Storage Installation Time Lapse Footage. Accessed 29/09/2014

Construction/civil works have generally been undertaken by specialist contractors (for both DNO and demonstrator projects). The activities involved in this stage may include:

- **Assessment of survey / design information:**
 - Survey of ground conditions etc. leading to foundation designs;
 - Access for large/heavy vehicles/delivery Method Statements, including adjacent space for cranes if required;
 - Environmental concerns (flora/fauna/floods/environmental protection from specific risks of technology etc.) and mitigation methods;
 - Buried services investigation in construction area, cables/equipment may need to be moved to make space for ESS installation;
 - Where relevant, design internal walls considering environmental conditions for various subsystems (e.g. where batteries and PCS operate most efficiently at different temperatures);
 - Review design to confirm it is suitable; and
 - Procure materials / contractors.
- **Civil construction:**
 - Clear site, erect safety/security fencing and set up access and welfare facilities;
 - Prepare foundations, drainage, auxiliary services (e.g. connection to water main if required) and cable trenches– piling or excavation for basements as required;
 - Construct plinths, bunds, buildings, flood protection measures, and internal compartments (e.g. within existing substation buildings) as required for specific EES system/layout used; and
 - Install permanent site security measures (as required).

8.4 Electrical Connection and Other Interfaces

Following the completion of civil engineering works to prepare the site (or alongside this work), an electrical connection is required. To date, EES systems within the UK have been connected to the LV distribution network, at secondary substations (typically 11kV/LV transformers), at primary substations (typically 33kV/11kV transformers) and at existing power station sites, as shown in Figure 8.6 on the following page. An interposing transformer is often necessary to match the AC output of the PCS to the relevant network connection voltage.

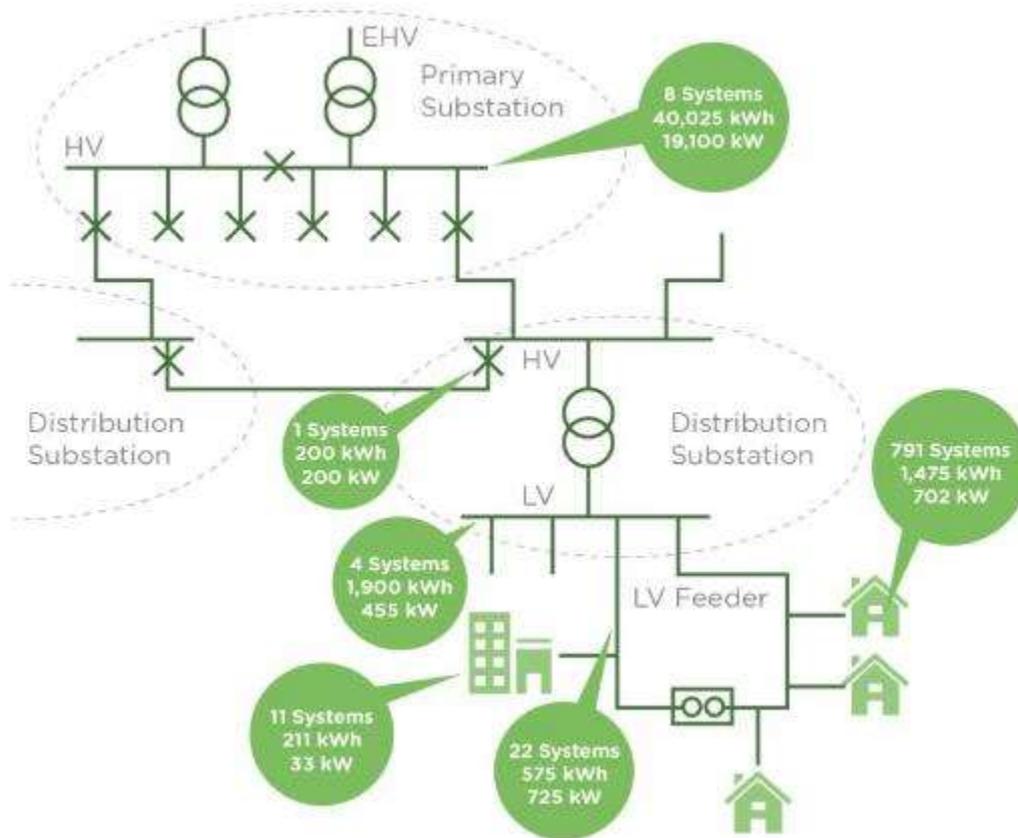


Figure 8.6: Network Connection of Proposed and Deployed Storage in the UK (DNO projects and DECC demonstrators) (at 1 December 2014)

The typical tasks required in relation to the electrical connection are shown below.

- Install HV or LV network connection equipment as required (network outages may be required);
- Install auxiliary power supplies as required;
- Install appropriate protection relays (see Section 8.4.1) as required;
- Install telecoms equipment (SCADA, real-time control, etc.) additional wired or wireless connections may be required;
- Install HV/LV or isolation transformers if required;
- Install metering as required;
- Install EES equipment;
- Install interconnecting cables with appropriate physical and electrical protection; and
- Ensure all equipment is appropriately earthed.

It should be noted that DC cabling/interconnection will normally be required between the various modules that make up a complete EES system (e.g. one or more battery modules and separate PCS modules). Such DC systems may have specific isolation procedures that differ from typical DNO practices.

In addition to the connection to distribution network, additional interfaces may be required such as:

- **A link to a despatch control-system:** in the current portfolio of DNO activities, this connection has generally required a specific SCADA or ANM Remote Terminal Unit (RTU) to be provided and supplied from a Uninterruptible Power System (UPS) or backup battery;
- **Hard-wired alarms and diagnostics:** within early-stage deployments of EES (e.g. where a first of a kind system is being deployed as part of an R&D project) alarms and advanced diagnostics have generally been made accessible to the EES supplier, for the purposes of monitoring the warranty and providing condition-based maintenance. A secure remote connection is required to facilitate this access;
- **Fire and/or chemical alarms and systems:** projects to date have included various gas detection systems, as well as smoke detection and fire suppressants; and
- **Heating, Ventilation and Air Conditioning system connections:** these systems can be used as part of routine operation in order to maintain the optimum battery environment, or in particular situations (e.g. fans to disperse any hydrogen generated from a Pb-Acid installation, linked to a gas detection system).

For some owners/operators of EES these devices may represent only a small, and relatively novel, part of their asset base. The number of operational staff who may be called to an EES site to investigate or perform fault isolation procedures may be large (e.g. a large team of field engineers). These faults/incidents may or may not involve the core storage technology. To facilitate fast, effective and safe resolution, they should be presented with interfaces and procedures similar to those on non-EES sites.

8.4.1 Protection

Network protection measures need to be installed as part of any EES system. The purpose of this protection is both to protect the device from the network (e.g. from high or low voltages) and vice-versa. Protection considerations for connections to GB DNO networks are addressed via a number of Engineering Recommendations.

The relevant Engineering Recommendation is dependent upon the rating of the device in question, or the total installed rating of multiple devices within a premise. Residential/small commercial systems are likely to be governed by Engineering Recommendation G83¹⁰⁹. This Engineering Recommendation applies to single systems rated up to and including 16A per phase, single or multi-phase, 230/400V AC, and multiple units within the limit which are deployed under a planned programme of work. Where multiple systems are deployed within a particular premise then the total combined rating must be within the specified limits, otherwise G59/- applies. The protection requirements for larger, utility scale systems (i.e. the vast majority deployed by DNOs) are set out in Engineering Recommendation G59¹¹⁰. G59/- applies to all generating plant (“any source of electrical energy, irrespective of the prime mover and generating unit type”) which are outside of the scope of G83/-.

G59/- specifies the protection required for all sources of electrical energy, irrespective of the prime mover or generating unit type. This clearly applies to EES as it is an energy source. Some of the settings specified in previous versions of G59 have been noted to cause “nuisance tripping” during network disturbances, something that is clearly undesirable for EES devices (and other generators) that are relied upon to support the demand on the network. Changes have been made in G59/3-1¹¹¹ to resolve this. However, if problems arise in the future the ENA will assess the issue and revise the Engineering Recommendations accordingly.

¹⁰⁹ Energy Networks Association. Engineering Recommendation G83/- – Recommendations for the connection of small-scale embedded generators (up to and including 16A per phase) in parallel with public low-voltage distribution networks.

¹¹⁰ Energy Networks Association, Engineering Recommendation G59, Issue 3-1. August 2014.

¹¹¹ <http://www.energynetworks.org/electricity/engineering/distributed-generation/distributed-generation.html>

G59/- protection can either be integral to the EES PCS or a standalone protection relay that activates a circuit-breaker. If the relay is standalone, then it can be set according to DNO requirements and proved using primary or secondary injection test sets; that is, the protective function can be proved separately to the operation of the ESS device itself, requiring only low-power instruments. A DNO normally chooses to witness such tests.

8.5 Commissioning and Testing

Following the completion of construction activities the EES will undergo a period of commissioning and testing to gain confidence in its operation. These tests may involve both 'cold' (i.e. prior to connection to the distribution network) and 'hot' tests. Potential testing stages are shown below:

- Cold commission new/modified equipment (or witness manufacture commissioning if appropriate);
- Commission new/modified IT systems if appropriate;
- Energise and hot commission new/modified equipment, ensuring it all operates correctly; and
- Ensure all new/modified equipment is integrated together and with existing systems before sign-off.

Further details of the Site Acceptance Tests employed in the various DNO projects are included in the project case studies (see Appendix 1) and listed in Section 7.7.

8.6 Handover to Operational Team

Where an EES system is being deployed in a 'business as usual' situation (i.e. outside of an exclusively R&D project) responsibility for the safe operation and maintenance of the asset will be transferred to an operational team. In some cases the original equipment supplier may retain responsibility for maintaining the equipment as part of a service agreement. This is likely to involve some liaison with operational teams (e.g. gaining access, disconnection from the network). Transferring responsibility for the system to operational teams is likely to involve the development of suitable procedures and Risk Assessments, and the training of staff. These issues are considered further in Sections 10.3.1 and 10.3.4 respectively.

8.7 Site Close Out

Following the completion of installation and commissioning activities a number of tasks in relation to site close-out are likely to be required, as detailed below:

- Remove construction site facilities and 'make good' site (e.g. landscape disturbed ground);
- Ensure all drawings and documentation are up to date; and
- Update site Health & Safety File (as per CDM Regulations (2007)).

8.8 Engagement with External Stakeholders

Throughout the installation process it is likely to be necessary to liaise with a range of external stakeholders, including:

- **Local authorities/councils:** this engagement may be required in relation to obtaining planning permission/confirming deployment under ‘permitted development’ rules (see Section 6.5.1) or obtaining the necessary wayleaves. Local authorities/councils have also been involved in relation to emergency planning.
- **Emergency services:** emergency services have generally been alerted to the presence of EES at various sites, both via engagement during the installation phase and via signs at sites. This engagement has generally involved a discussion of the various hazards present at the site and the actions which would be taken in an emergency. Further details are given in Section 10.3.3.
- **Environment Agency (SEPA in Scotland):** this engagement can be in relation to specific environmental hazards from a particular technology (e.g. flow battery electrolyte) or hazards from the environment which could impact upon the EES (e.g. flooding). Further details in relation to environmental permits are given in Section 6.5.
- **Distribution Network Operator:** a connection agreement is required in order to connect EES to the distribution network. Early engagement with the DNO is recommended to ensure that sufficient capacity is available in the proposed location. In locations where constraints exist it may be possible to arrange a flexible connection with the relevant DNO.
- **Local community:** this includes engagement with community groups, local businesses and residents. Potential issues to consider are the access required to the site, particular hazards in relation to neighbouring properties/businesses, ensuring the safety/security of the site and concerns of local residents about the proposed development (e.g. in relation to visual impact, noise or the safety of the system). The level of engagement required is likely to depend on the size of system and nature of the location (e.g. within a residential area, a remote, sparsely populated rural location, or an existing industrial estate). Engagement with the local community may be required as part of the planning permission process. Various methods have been used to engage with the community including specific consultation meetings, visits to local resident groups/parish councils, infographics on construction sites, mailshots and visits to local schools (particularly to highlight electrical safety aspects).

8.9 Lessons Learnt

Many lessons learnt from installation have been incorporated into the previous Sections. Specific lessons that have not been included above are:

- The siting of EES in domestic premises, especially in loft areas, is difficult due to restricted loft access, the need for specialist lifting equipment and the time necessary to board lofts;
- Smoke detectors should be kept clean. A ‘false alarm’ (due to dust) from a smoke detector caused the activation of a fire suppressant system (mitigated by use of two detectors in series);
- Ensure that the auxiliary loads (battery heating, ventilation and air conditioning and control systems) is not disproportionate to the battery size, eroding the battery benefit;
- Maximise the amount of system testing completed prior to the installation of the system. This allows system integration issues to be resolved prior to installation work. The ability to do this may be limited by the size of the units, or sub-systems being supplied from different entities/locations;
- Where a DNO is implementing an EES system, it should only be connected to the network after completion of commissioning. Once connected it becomes part of the

- network and is bound by DNO safety procedures – needing a Senior Authorised Person (SAP) to authorise and release equipment for inspection; and
- Where a large quantity of goods are to be brought out of lorry mounted containers (at one height) and offloaded into a building (at another height due to flood protection) a temporary interim loading bay may be required to enable the process to be completed quickly and efficiently.

9 Hazards, Failure Modes and Effects

This section sets out the hazards which may be presented by EES systems. The nature of each hazard and its source is described, along with an indication of potential mitigation and control measures. It has been informed by the work undertaken by the DNO sector, within the projects described in Appendix 1 and other published background information. The DNO/TSO sector has an excellent safety record in deploying and operating existing pieces of distribution/transmission equipment, and is naturally conservative. In common with other equipment on their networks, the sector has devoted considerable efforts to the evaluation of all possible failure modes/hazards and how these can be mitigated. Sections 9 and 10 describe the possible hazards, how these have been mitigated against and other risk management procedures which have been implemented.

It is worth noting that HSE statistics state that “every year, at least 25 people are seriously injured when using batteries at work”¹¹². Whilst it is likely that these injuries relate to non-utility sector battery installations/applications (e.g. in automotive repair) a number of hazards are common between the two scenarios.

Within this section hazards are separated into:

- Generic hazards, broadly applicable across a range of EES technologies; and
- Technology specific, i.e. applicable to a particular storage technology (e.g. the phenomenon of thermal runaway in Li-Ion batteries, or hydrogen gassing from Pb-Acid batteries).

The coverage of technology specific hazards here is limited those technologies within the scope of the GPG – i.e. battery storage systems, redox flow battery systems and thermodynamic systems.

9.1 Generic Issues

9.1.1 Electric Shock

The risk of electric shock and the potential consequences of electric shock are well known within the power utility sector. Those operating electrical switchgear/plant (e.g. DNOs and TO/SOs) have developed a variety of procedures for working with established equipment (e.g. AC switchgear, transformers) in order to carry out testing and maintenance. These procedures involve reducing the requirement for ‘live working’, ensuring that multiple points of isolation are in place between any source of electricity and the area being worked on and the issuing of Permits to Work.

However, EES systems represent a new and unfamiliar class of technology in the sector, as many such systems (particularly electrochemical systems) operate (as least partly) on DC electricity. The very nature of the electrochemical storage systems, in particular, means that they cannot be ‘switched off’ and, if connected, can continue to supply electricity for long periods of time. Even at very low states of charge their DC voltages can still be lethal (e.g. circa 90% of voltage at 10% State of Charge (SoC)).

Electric shock occurs upon the contact of a body part with a source of electricity that causes a sufficient current through the skin, muscles or hair. The level of harm resulting from an electric shock depends on a number of factors including:

¹¹² HSE Publication “Using Electric Storage Batteries Safely”. Available from: <http://www.hse.gov.uk/pubns/indg139.pdf>
Accessed 17/01/2014.

- **Current:** a greater current is more likely to cause significant harm (or be lethal);
- **Duration:** a shock with a longer duration is more likely to be lethal. In the case of contact with a battery, if the muscles contract and cause the person to hold onto the source of the shock then a current could flow for a long period of time;
- **Pathway:** if current flows through the heart muscle, it is more likely to be lethal; and
- **High voltage (above around 600V):** a higher voltage (for a fixed resistance) will result in a greater current and therefore a higher risk of death or serious injury. In addition, higher voltages may cause dielectric breakdown at the skin, lowering its resistance, causing higher currents to flow.

Electric shock can result in burns (due to the heat generated), ventricular fibrillation (caused the current disturbing the rhythm of the heart muscles), neurological effects and hazards from arc flash (thermal burns etc.). An electric shock from AC current causes a series of muscle contractions depending on its frequency. However, DC electric shock will result in a single contraction of the muscles, and so a greater potential for the body to 'lock-on' to the source of the current.

As an example, the block diagram below shows a generic make-up of a BESS. Multiple cells (e.g. with an output of a small number (e.g. less than 5) volts DC) connect together to form a module. Multiple modules can be connected together to form the complete battery. The output from the whole BESS for larger systems is generally multiple hundreds of volts DC. The battery system is then connected to the PCS, converted to AC, before being connected to the distribution network (e.g. at 415 V or 11 kV) via a transformer.

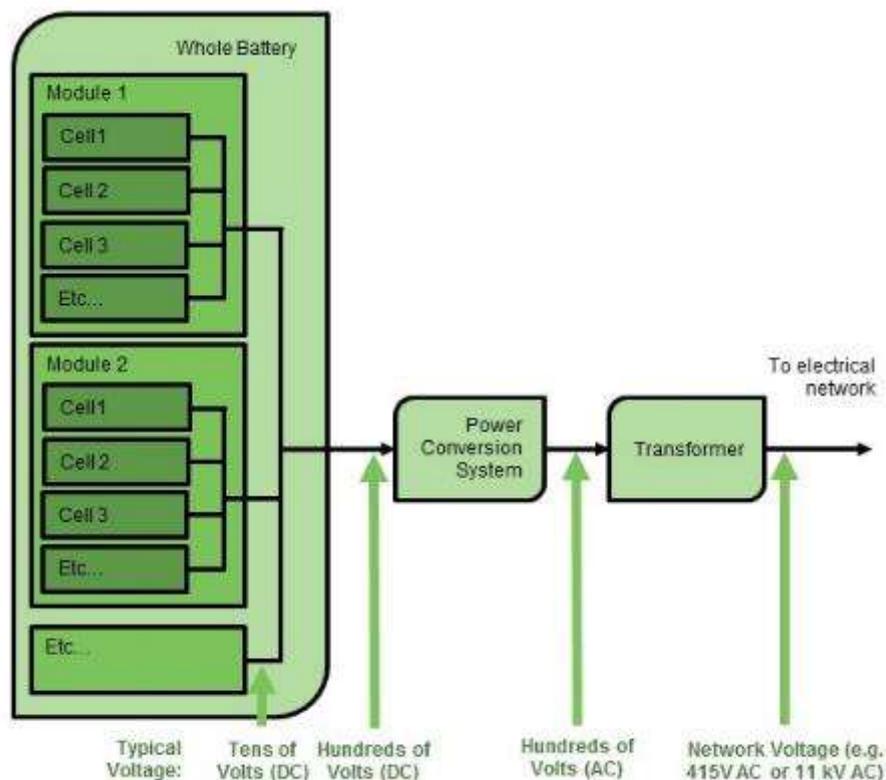


Figure 9.1: Block Diagram of EES with Approximate Voltages

Within the DNO sector, safe working procedures have been developed over the course of many years, albeit focussed on more 'typical' hazards from distribution equipment. These

are set out within the ENA Model Safety Rules, and could provide useful guidance for others deploying EES¹¹³. Individual DNOs also work within their own Distribution Safety Rules.

A variety of mitigation and control measures can be employed to guard against the hazards from DC electric shock. These include:

- The capability to isolate individual parts of the core storage technology, such as to mitigate against the DC electric shock hazard (e.g. 4 x 125 V DC instead of 500 V DC). This could be achieved via the use of circuit breakers at various points within the system. Isolating the DC source is also important to allow any maintenance activities to take place in relation to the AC components (e.g. the PCS). Such maintenance would also require isolation of the system from the distribution network to which it is connected;
- Shielding of components: this can be used to place a physical barrier between anyone accessing the interior of a unit (e.g. opening a door on a rack) and any points where they may be exposed to the potential for electric shock;
- The provision of training to staff that may need to access the units to carry out inspection or maintenance;
- Restriction of access to the compound or building containing the energy storage system to authorised personnel;
- Appropriate warning signs, particularly those which signal the potential for DC electric shock. This should be placed on the storage units themselves and at the entrance to compounds or buildings containing energy storage;
- The removal of metallic articles (e.g. watches, jewellery) by personnel¹¹⁴ that may be working in the vicinity of the battery; and
- Wearing of appropriate personal protective equipment (PPE) such as insulating gloves and the use of appropriate tools (e.g. those with insulated handles).

Ensuring that a system is designed such as to mitigate the potential for electric shock is part of the requirements of the Low Voltage Directive (see Section 6.3.2) and compliance with this gives a basic level of assurance to the purchaser.

9.1.2 Storage Management and Control Systems

Storage Management and Control Systems (SMCSs) are an integral part of EES systems. For example, in a Battery Energy Storage System, a Battery Management System (BMS) will be employed to monitor cells and control the conditions to which cells are exposed. Typically SMCSs monitor the voltage and temperature of individual cells and act to prevent overcharge or overdischarge. Similar considerations will apply in flow battery storage systems and, likewise, in thermodynamic systems, where the SMCS will monitor and control various critical temperatures, pressures, actuator states etc. The SMCS can also raise system alarms if any of the monitored parameters exceed the limits set by the system manufacturer, preventing further damage. The importance of SMCSs in ensuring the safe operation of the system is such that they should include a “fail-safe” design (i.e. a failure of the SMCS prevents operation of the EES system) and potentially redundancy.

The SMCS typically integrates with the overall control system for the EES system. Signals from the SMCS are received by the control system for the EES system and can then communicate relevant signals to the storage operator’s control system (e.g. via a SCADA system). In addition to this link to a software-based control system, the provision of hard-wired alarms can also be valuable. This provides visibility of system faults in the event of a

¹¹³ ENA Safety Health and Environment Committee. Model Distribution Safety Rules.

http://www.independentpowernetworks.co.uk/docs/040_IPNL_Safety_Rules/020_ENA_Distribution_Safety_Rules.pdf

¹¹⁴ See Section 7.2 of BS EN 50272-2:2001 (described in Section 6.2.2 of this guide).

communications failure or loss of power. The level of detail in the signals reported to the storage operator's control system requires some consideration during system design. It is important that critical information is transferred, but it may be more appropriate for some information to remain within the storage device control system. This detailed information can then be interrogated by trained personnel in order to carry out the necessary actions.

9.1.3 Fire, Fire Containment and Suppression

Operators of distribution/transmission equipment (e.g. DNOs, Private Network Operators (PNOs), the TO/SO) and the emergency services are familiar with the potential hazards from fires emanating from electrical switchgear and other traditional equipment. Well established procedures are in place for eliminating/reducing the hazard; additionally, appropriate fire-fighting measures have been developed, over many decades. This section considers the different types of fire which may involve an EES system, their differences to fires involving other electrical equipment and mitigation measures which may be applied.

There are a number of potential causes of a fire involving an EES system, as follows:

- **A fire emanating from the core storage technology:** For example, in a battery energy storage system, the potential for a true 'battery fire' (i.e. one which is fed by the cell inventory) is dependent on the electrochemistry in question. A battery fire could emanate either from causal defects/events within the battery itself or from an extraneous source (e.g. a defective wiring loom). The risks from particular technologies are discussed in Section 9.2;
- **A fire emanating from another part of the EES system (e.g. the PCS or associated transformer):** These are likely to be more familiar to both storage operators and the emergency services, but nevertheless could still constitute a significant hazard, with the potential to spread to the core storage technology (depending on the physical layout of the system and flammability of the materials involved);
- **A fire from the surrounding area (e.g. a building fire):** A fire which originates from outside the EES system may also be a credible scenario. These could include situations such as a building fire, or a malicious fire in an outside substation containing energy storage. Such a fire could then spread to the EES system, depending on the spread of the fire, flammability of the system and the speed of emergency response; and
- **A fire due to external impact:** For smaller scale EES systems, installed as street furniture, another credible scenario is that of vehicular impact and a resultant hydrocarbon fire (due to the vehicle's fuel).

EES systems present some atypical hazards in the context of fire-fighting, when compared to more mature distribution network equipment. These hazards are summarised as follows:

- It may not be possible to reduce the electromotive force (EMF) from the system to zero during fire-fighting. Although the EES can be disconnected from the distribution network (e.g. via the opening of circuit breakers) it may not be possible to fully discharge the EES system which can still present an electric shock hazard (see Section 9.1.1). This has the potential to present a hazard to emergency services attending any incident. This should be addressed via engagement with the relevant Fire and Rescue Service to fully describe the system and the nature of the hazard. The potential for the system to remain live for some time following an incident

(multiple hours/tens of hours) should also be considered, with the supplier providing necessary expertise;

- The chemical inventory of EES systems can present particular hazards during a fire (either directly from the combustion process, or due to the application of unsuitable extinguishment materials); and
- Specific extinguishment material may be required, depending on any chemicals inventory, in the storage technology concerned. For example, a Class D (dry powder) extinguisher should be used on fire involving flammable metals such as sodium¹¹⁵. In all cases, due to the electric shock hazard present, the use of water based extinguishment presents particular risks.

A number of mitigation measures can be employed to reduce the likelihood of fire occurring, reduce the severity of any fire, and prevent harm to the public, the emergency services or storage owner/operator personnel. These are summarised as follows:

- **The development of fire containment guidance, with support from the system manufacturer:** All owners, landlords or occupiers of business/non-domestic premises in the UK have a legal responsibility for fire safety (i.e. they are the 'responsible person') and have a number of duties, as follows¹¹⁶:
 - To carry out a fire risk assessment of the premises and review it regularly (e.g. this could be a building containing an EES installation);
 - To tell staff or their representatives about the risks identified (e.g. as part of induction or training activities, or with appropriate notices);
 - To put in place, and maintain, appropriate fire safety measures;
 - To plan for an emergency (e.g. liaising with the local Fire and Rescue Service); and
 - Provide staff information, fire safety instruction and training.

System suppliers should provide guidance specific to their system detailing both the mitigation measures against fire and the actions to be taken in the event of a fire.

Where equipment originates from outside the UK, this guidance should take account of the requirements of the particular storage owner/operator (e.g. GB DNOs/TO/SO) and the legislative landscape in which they operate. Within the project case studies, one project included a fire engineering report which provided a quantified fire engineering assessment. This type of assessment can provide an estimate of the effect of a fire on surrounding areas and buildings. The development of any fire fighting/containment strategy should inform the inclusion of the risk of fire within the overall Risk Assessment for the EES system (see Section 10). This is an area requiring further development (e.g. via research and development activity) if EES is to become a significant component part of the electricity system.

- **Use of smoke detectors and closed-circuit television (CCTV) linked to the control room:** Detectors provide an early warning of any incident. The addition of CCTV can assist in monitoring sites remotely in the event of an incident. A number of the current deployments of storage by GB DNOs have used multiple smoke detectors, with an alarm trigger requiring a signal from multiple detectors. This is in order to prevent 'false alarms' which could then trigger other events such the discharge of a fire suppression system. EES systems can be housed in a number of different ways: inside a substation building (e.g. the FALCON project); within purpose built buildings (e.g. Shetland); or within shipping containers (e.g. Orkney and Rise

¹¹⁵ <http://www.ch.cam.ac.uk/safety/fire-safety-types-extinguisher> Accessed 08/01/2014.

¹¹⁶ Fire Safety in the Workplace. UK Government. [Online]. Available from: <https://www.gov.uk/workplace-fire-safety-your-responsibilities> Accessed 07/11/2014

Carr). Suitable audible and visual warnings should be included within smoke and fire detection systems to ensure those inside and outside the container or building are aware of any incident.

- **Fire containment or suppression systems:** Typical operation of these systems involves the reduction of the oxygen content within the EES system enclosure in order to limit the potential for combustion to occur. A number of different suppression chemicals can be employed. While the use of a suppression system can mitigate the hazard from fire (i.e. by quickly extinguishing a fire before it is allowed to spread) it can in turn introduce other hazards, specifically from asphyxiation. The hazards present from the suppression medium depend upon its chemical content and the mechanism of fire suppression. The chemicals used in many of the trials described in this Guide are 'life supporting' – i.e. they reduce the oxygen concentration to a point where the fire is suppressed, but sufficient oxygen remains to support life. Nevertheless, these installations employ measures to prevent discharge of the suppression system while personnel are within the container/building. Where suppression systems are used which present an asphyxiation hazard it is important that procedures are developed to prevent accidental discharge of the suppression system and to ensure the system cannot discharge when personnel are within the area affected. In addition to a procedure to prevent operation when personnel are present, the suppression systems used within current deployments of energy storage include an audible warning prior to discharging the system. It should be noted that the majority of suppression systems can discharge once, before requiring maintenance/re-filling. In the case of re-ignition of a fire, the suppression system would therefore not be available. A number of British Standards exist in relation to the fire containment and suppression systems and these are listed in Table 6.2. However, it is worth noting that the by-products of certain types of catastrophic failure (e.g. a Li-Ion thermal runaway) can undergo combustion, even at low oxygen concentrations. At present, there are no specific UK standards for the application of fire suppression systems to battery energy storage. The use of various types of extinguishment materials for Li-Ion battery fires is discussed within research published by the Fire Protection Research Foundation (USA)¹¹⁷.
- **Engagement with the Fire and Rescue Services:** The relevant Fire and Rescue service, and other parties such as the emergency services and local councils, should be engaged early in the development of fire-fighting/containment procedures. This reduces the potential risks in the event of a fire as the Fire and Rescue Service will have a greater awareness of the system, any atypical hazards present and the fire-fighting/containment guidance provided by the manufacturer.
- **Security measures:** Appropriate physical security measures (e.g. high fencing) may limit the potential for unauthorised access to compounds containing energy storage and so for malicious actions leading to fire. GB DNOs are regarding energy storage sites in the same manner as other substations and so installing security measures in accordance with the Electricity Safety Quality and Continuity Regulations. The installation of high fencing/other security measures also increases the physical security of the site.
- **Provision of on-site guidance for the Fire and Rescue service in the event of any incident:** A number of sites have been registered with the local fire authority, including the relevant Material Safety Data Sheets (MSDS)¹¹⁸. This registration

¹¹⁷ Lithium-Ion Batteries Hazard and Use Assessment (Chapter 6). July 2011. Available online from: <http://www.nfpa.org/~media/Files/Research/Research%20Foundation/Research%20Foundation%20reports/Hazardous%20materials/lithiumionbatterieshazard.pdf> Accessed 17/01/2014.

¹¹⁸ For example, see SSEPD Chalvey project case study (Appendix 1).

system alerts the Fire and Rescue Service to the particular hazards at the site should they be called to attend an incident. Signage can be provided at the entrance to sites, with an example for Chalvey (SSEPD site) shown below.



Figure 9.2: Example Fire Fighting Guidance Sign (Photograph by EA Technology)

- Routine site inspections: Site inspections and good housekeeping procedures should be followed in order to prevent build-up of any other materials which could contribute to a fire.

9.1.4 Explosion

The thorough engineering design and manufacture of EES systems (both the core storage technology and the associated PCS) has the result that the probability of an explosive failure should be “as low as is reasonably practicable”. Nevertheless, the consequences of an event are such that it should be considered as part of the development of a safety case for EES installations.

An explosion may relate either to an uncontained catastrophic failure of a pressure vessel or pressure system or, alternatively, from the ignition of a flammable (explosive) gas mixture, that may have accumulated as a consequence of the failure of one or more sub-systems (e.g. part of the core storage technology such as a battery module, or the PCS).

Mitigation of the former possibility is principally addressed via the appropriate design, manufacture, operation and inspection of the relevant pressure systems and pressure vessels, e.g. as described in Section 6.3.4. This Section addresses the scenario, of the ignition of a flammable (explosive) gas mixture that may have accumulated as a consequence of the failure of one or more sub-systems. In general terms, such an explosion risk may relate either to that of deflagration or detonation, with the latter being particularly undesirable.

The make-up of the system in question determines the chemicals present and therefore whether an explosion is a credible failure mode. A fire or explosion can occur when a fuel (in this case, a combustible gas or vapour) and oxygen exist in certain proportions, along with an ignition source, such as spark or flame. The proportion of gas/vapour to oxygen required depends on the combustible gas or vapour in question. The Lower Explosive Limit

(LEL) is the minimum concentration at which combustion in air will be supported¹¹⁹. Likewise, the Upper Explosive Limit (UEL) is the highest concentration of a gas/vapour in air which is capable of producing a flash or fire in the presence of an ignition source.

In the context of the technologies considered in this GPG, an explosive failure could result from the release of the following reagents:

- Hydrogen:** A number of electrochemical storage technologies, including Pb-Acid and NiCd battery systems and some flow battery systems, have the potential to generate hydrogen during excessive charging. A number of mitigation measures may be employed to prevent either the generation or the release of hydrogen and these are described in Sections 9.2.2 and 9.2.3. The LEL and UEL for hydrogen is 4 and 75% by volume respectively – this represents a very wide range in which ignition is possible.
- Vent gases from Lithium-ion Cells:** Li-Ion cells use a non-aqueous, liquid electrolyte (with the exception of lithium polymer cells using a polymer or gel electrolyte). Typical electrolyte materials can include Ethylene Carbonate, Propylene Carbonate, Diethyl Carbonate, Dimethyl Carbonate and Ethyl Methyl Carbonate¹²⁰. A failure of an individual cell (e.g. by thermal runaway, see Section 9.2.5) has the potential to cause the cell to relieve the build-up pressure via the release of an amalgam of vent gases, including hydrogen, carbon monoxide, methane and electrolyte vapour. The most likely scenario following such an event would be the immediate ignition of a small quantity of vent gases (i.e. from the individual cell). The likelihood of the scenario required in order for vent gases to accumulate and an explosive failure to occur is low. This would require a failure of the mitigation measures against thermal runaway and the failure of a large number of cells, without the ignition of vent gases from each individual cell failure. However, should such an atmosphere be generated, there is a potential for either deflagration or detonation to occur, depending on the quantities of vapour evolved and the geometry of the enclosure(s). Atypically, it is worth noting that an explosive failure of a Li-Ion battery system does appear to have occurred at the General Motors Research and Development facility in Warren, Michigan (see Section 9.2.5). Flammability limits in air for some of the potential vent gases are provided in Table 9.1 on the following page.

Table 9.1: Flammability Limits of Components of Lithium-Ion Electrolyte¹²¹

Material	Lower Flammability Limit (%v/v)	Upper Flammability Limit (%v/v)
Hydrogen	4.0	75.0
Carbon monoxide	12.5	74.0
Methane	5.3	15.0
Ethylene	3.1	32.0
Ethane	3.0	12.5
Propylene	2.4	10.3
C4 Hydrocarbons	~1.6-1.9	~8.4-9.7
C5 Hydrocarbons	~1.4-1.5	~7.5-8.7

¹¹⁹ [http://www.mathesongas.com/pdfs/products/Lower-\(LEL\)-&-Upper-\(UEL\)-Explosive-Limits-.pdf](http://www.mathesongas.com/pdfs/products/Lower-(LEL)-&-Upper-(UEL)-Explosive-Limits-.pdf) Accessed 25/11/2014

¹²⁰ "Lithium-Ion Batteries Hazard and Use Assessment". Fire Protection Research Foundation. July 2011. Available online from: <http://www.nfpa.org/~media/Files/Research/Research%20Foundation/Research%20Foundation%20reports/Hazardous%20materials/rflithiumionbatterieshazard.pdf> Accessed 25/11/2014

¹²¹ Table 10. See Footnote Number 120. Accessed 25/11/2014

A number of mitigation measures can be employed to reduce the potential for an explosive failure, these include:

- In an electrochemical system, the SMCS should monitor the condition of cells and modules. This functionality can also include monitoring the voltage and temperature of individual cells. The SMCS should also generate alarms and prevent the system from further charging or discharging when necessary. In the context of reducing the potential for an explosive failure, an SMCS should be designed to prevent a number of the conditions which could give rise to the release of explosive gases (e.g. entry into an electrolysis state in Pb-Acid, NiCd and selected flow battery systems);
- Use of ventilation systems to limit the potential for any build-up of flammable gases;
- Compliance with the requirements of DSEAR and ATEX (see Section 6.3.3);
- Provision of guidance from system suppliers regarding the potential failure modes of the system being installed, in order to incorporate this into Risk Assessments for the operation of the EES system;
- If necessary, manufacturers should include any required pressure relief/venting arrangements systems within the EES system. This may be particularly applicable to containerised systems, where the potentially sealed nature of the container should form a part of an explosion Risk Assessment; and
- Consideration of site design and layout, such as to limit the potential for a failure of one part of the EES system to impact on another, causing further harm (e.g. an explosive failure of a PCS damaging the core storage technology, or vice-versa).

9.1.5 Slips and Trips/Working at Height

The primary focus of this section is the hazards associated with EES systems, both generic and technology specific. However, a range of non-EES specific hazards should be considered by EES system operators, specifically those in relation to slips and trips (e.g. an untreated access path in winter conditions) and those associated in any working at height (e.g. from any working on the roofs of containerised systems). These hazards make up the majority of workplace accidents within the UK, as reported by the HSE, as follows¹²²:

- Over half the fatal injuries to workers (total fatalities of 133 in 2013/14 (provisional figures)) were of three kinds: falls from heights, contact with moving machinery and being struck by a vehicle;
- Falls and slips & trips, combined, account for over a third (35%) of employee injuries. They made up more than half of all reported major/specified injuries and almost three in ten (29%) of over-seven day injuries; and
- An estimated 1.9 million working days were lost due to handling injuries and slips & trips.

The identification and mitigation of the impact of these hazards should be given the appropriate degree of attention, in the development of the Risk Assessments associated with the operation and maintenance of EES units. The design of particular systems may increase certain types of risks – for example where it is necessary to carry out maintenance work on apparatus located on the top of a containerised EES system, which may be located on a plinth.

¹²² HSE Statistics. Kinds of Accident. [Online]. Available from: <http://www.hse.gov.uk/statistics/causini/kinds-of-accident.htm> Accessed 07/11/2014.

9.2 Battery Technology Specific

9.2.1 Battery Mass - Lifting

The energy density of the various battery technologies and the quantities of energy being stored within utility scale applications results in a large mass of material (e.g. battery modules) being handled during installation and maintenance activities. Although the hazards from manual handling and other lifting (e.g. via crane) activities is not specific to energy storage installations it nevertheless should be considered by installers of EES systems. The hazards present have the potential to cause severe injury to personnel if inappropriate lifting techniques are employed. Specific mitigation measures against these hazards include:

- Avoid manual handling whenever possible, and reducing the size of the load;
- Ensuring compliance with manufacturer guidance and HSE manual handling guidelines by all employees when handling components;
- Use of appropriate lifting tools (e.g. forklifts, cranes, manufacturer specific tools);
- Careful planning of lifting procedures prior to commencing activities; and
- Wearing of appropriate PPE by those involved in lifting activities and others in the vicinity.

Further details of considerations in relation to the installation of EES systems are given in Section 8 of this guide. Guidance relating to manual handling is provided by HSE online^{123,124}.

9.2.2 Pb-Acid

Pb-Acid batteries are the most mature example of utility scale energy storage systems, as described in Section 4.1 and Appendix 3. Due to the maturity of the technology, the risks arising from Pb-Acid batteries are well understood. Indeed, DNOs currently use Pb-Acid batteries (albeit at a much smaller scale) within their substations. A British Standard has been developed to provide guidance for the safe installation of Pb-Acid and NiCd batteries. Further details are given in Section 6.2.2.

One of the principal hazards specific to Pb-Acid systems arises from the potential for hydrogen gas generation. During excessive charging, hydrogen can be emitted which can present an explosion hazard if it accumulates to a dangerous level. Ventilation systems for Pb-Acid battery enclosures are designed in order to maintain the hydrogen concentration below the 4% (by volume) hydrogen LEL. Battery locations and enclosures are considered safe from explosions when the concentration of hydrogen is kept below this safe limit. This can be achieved through either natural or forced ventilation. The required ventilation rate for a Pb-Acid battery room is set out within BS EN 50272-2:2001, according to the following equation¹²⁵:

$$Q = v \cdot q \cdot s \cdot n \cdot I_{gas} \cdot C_{rt} \cdot 10^{-3} [m^3/h]$$

Where:

Q	=	ventilation air flow in m ³ /h
v	=	necessary dilution of hydrogen: $\frac{(100\% - 4\%)}{4\%} = 24$
q	=	0.42x10 ⁻³ m ³ /Ah generated hydrogen

¹²³ www.hse.gov.uk/msd/faq-manhand.htm Accessed 13/02/2014

¹²⁴ Manual Handling at Work: A Brief Guide. INDG143(rev3). Available from: <http://www.hse.gov.uk/pubns/indg143.pdf> Accessed 13/02/2014

¹²⁵ BS EN 50272-2:2001 Section 8. Safety requirements for secondary batteries and battery installations- Part 2: Stationary batteries.

s	=	5 (general safety factor)
n	=	number of cells
I_{gas}	=	current producing gas in mA per Ah rated capacity for the flat charge current I_{float} or the boost charge current I_{boost}
C_{rt}	=	Capacity C_{10} for Pb-Acid cells (Ah), $U_f = 1.8V/cell$ at $20^\circ C$

The current (I_{gas}) producing gas is determined by the following formula, depending on whether the battery is operating in 'float' or 'boost' charge mode:

$$I_{gas} (float\ or\ boost) = I_{float\ or\ boost} / f_g \cdot f_s [mA/Ah]$$

Unless otherwise stated by the manufacturer, the standard sets out values for the quantities in the equation above for both vented Pb-Acid cells and VRLA batteries. These are given in Table 9.2.

Table 9.2: Relative Hydrogen Emission from Pb-Acid Variants¹²⁵

Quantity	Vented Cells (where the Antimony proportion is less than 3%)	VRLA Cells
f_g – gas emission factor	1	0.2
f_s - gas safety factor	5	5
I_{float} - typical float charge current (mA per Ah)	1	1
I_{gas} - The current producing gas (mA per Ah) when under 'float' charge	5	1
I_{boost} - typical boost charge current (mA per Ah)	4	8
I_{gas} - The current producing gas (mA per Ah) when under 'boost' charge	20	8

Table 9.2 and the equations above demonstrate that for a given cell capacity and number of cells, the ventilation requirement for vented cells is higher than that for VRLA cells. This corresponds to their higher propensity to emit hydrogen gas.

Manufacturers deploy a number of measures to restrict the quantity of gas generated and ensure ventilation rates are sufficient to prevent any build-up of gas. For installations of Pb-Acid based energy storage, Section 8 of British Standard BS EN 50272-2:2001 details the rate at which gas may be generated from the system and the necessary ventilation rates. The calculation of the required ventilation rate (as set out in the British Standard) may necessitate the inclusion of forced ventilation. In those cases where such a measure is not normally required, a further mitigation measure can be included via the use of hydrogen gas detection systems. Such a system can provide an assurance to the operator of the EES system that no accumulation of hydrogen has occurred and could also link to a forced ventilation system (if available). This configuration would ensure that forced ventilation is not applied when not necessary, reducing parasitic loads on the EES.

Pb-Acid batteries contain a sulphuric acid solution as their electrolyte. In a fault scenario where there is the potential for the electrolyte to be released (e.g. damaged battery casing) this represents a hazard, as follows:

- Sulphuric acid is corrosive. The more concentrated solutions can cause serious chemical burns to the mouth, eyes and skin;
- It is harmful by ingestion and through skin contact; and

- If a mist containing sulphuric acid is present then this is a severe irritant to the respiratory system, the eyes and skin.

The way in which this electrolyte is contained is dependent on the variant of Pb-Acid, as follows:

- **Vented Pb-Acid:** Excess liquid electrolyte is present; and
- **Valve Regulated Pb-Acid:** Electrolyte is either absorbed in a glass mat (Absorbed Glass Mat variant) or immobilised in a gel.

Valve Regulated Pb-Acid batteries therefore have a lower risk of leaking electrolyte. Details of suitable protective measures against hazards from battery electrolyte and first aid measures are set out in Section 9 of BS EN 50272-2:2001. Guidance should also be supplied by battery/system suppliers via the provision of a Material Safety Data Sheet (specific to the system installed).

There are numerous examples of Pb-Acid battery systems being installed in the power utility sector, as set out in Table A3.1 in Appendix 3. These installations demonstrate an overall very good safety track record when correctly installed and operated. Notwithstanding this, a number of incidents involving Pb-Acid systems are highlighted here:

- The installation at Chino, California, (40MWh, 10MW, installed in 1988) suffered a small fire due to water ingress through the roof during a storm. The water ingress caused a short circuit to occur between the PCS and one of the battery strings. This was addressed via enhancing the integrity of the roof and by improving the robustness of the electrical safety system¹²⁶; and
- The HMCS Chicoutimi submarine (the former HMS Upholder) was in transit from the UK to Halifax, NS, Canada in October 2004, when it suffered ingress of water through its conning tower. This triggered a series of electrical events culminating in electrical arcing of the main power cables and a subsequent fire. The incident resulted in one fatality and a number of other casualties. The crew were able to stabilise the situation, and with assistance from other vessels recover the boat to Faslane^{127,128}.

9.2.3 Nickel-Cadmium

In common with Pb-Acid batteries, nickel batteries produce hydrogen and oxygen during charging. This is due to the electrolysis of the aqueous electrolyte. Hydrogen presents an explosion hazard within the LEL to UEL range of 4% to 75% (by volume). BS EN 50272-2:2001 (see Section 6.2.2) provides guidance for the ventilation rates required to prevent the accumulation of hydrogen, as per the equations in Section 9.2.2. Unless otherwise stated by the manufacturer, the standard sets out values for the quantities in these equations for vented NiCd batteries. These are given in Table 9.3.

Table 9.3: Hydrogen Emission from NiCd batteries¹²⁵

Quantity	NiCd Batteries (Vented Cells)
f_g – gas emission factor	1
f_s – gas safety factor	5
I_{float} – typical float charge current (mA per Ah)	1

¹²⁶ EPRI:DOE Handbook on Energy Storage for Transmission and Distribution Applications. Ref. 1001834, December 2003.

¹²⁷ The Chicoutimi Accident: Lessons Learned and not Learned. www.journal.dnd.ca

¹²⁸ Board of Enquiry, HMCS Chicoutimi

I_{gas} - The current producing gas (mA per Ah) when under 'float' charge	5
I_{boost} - typical boost charge current (mA per Ah)	10
I_{gas} - The current producing gas (mA per Ah) when under 'boost' charge	50

N.B. Values for recombination type NiCd batteries should be provided by the systems supplier

NiCd batteries may either be sealed (recombination type) or vented. Sealed systems recombine the hydrogen and oxygen inside the cell and pose a reduced hazard to personnel from hydrogen gas generation. However, if they are charged at a very high rate (which would normally be prevented the use of a BMS and suitable alarms) the rate of gas generation may be greater than the rate of recombination. This would then lead to pressure build-up within the cells, until the safety valve is opened to relieve the pressure. This leads to damage to the cell, but is designed to avert the hazard to personnel. Vented systems (those where the values in Table 9.3 apply) vent the hydrogen and oxygen generated to the atmosphere¹²⁶. There should therefore be placed in a suitably ventilated location, as per the rates specified in BS EN 50272-2:2001. Similar additional mitigation measures to those for Pb-Acid systems can be included for additional security (see Section 9.2.2.)

The cadmium components of NiCd batteries are particularly toxic. Cadmium is a toxic heavy metal, is a cumulative poison and causes renal failure¹²⁹. Inhalation of cadmium dust (e.g. via poorly designed disposal/recycling means) is also a hazard to the respiratory system. Cadmium is also an environmental hazard when landfilled or incinerated¹²⁶. All batteries must be disposed of according to the requirement of the Waste Battery and Accumulators Directive (see Section 6.2.1). Manufacturers should then ensure that the correct recycling processes are then employed.

9.2.4 High Temperature Sodium Based Systems

Section 4.1 and Appendix 3 Section A3.1.3 provide details of a number of high temperature sodium based battery systems, as follows:

- Sodium Sulphur;
- Sodium Nickel Chloride; and
- Sodium Metal Halide

All these batteries operate at high temperatures (around 300°C) and employ the use of hazardous materials to variable amounts. This can include metallic sodium, which is combustible if exposed to water. The various high temperature systems are based on hermetically sealed cells which are connected in series-parallel arrays and employ a range of safety measures such as:

- Surrounding cells with sand to absorb any material ejected from failed cells, prevent fire and provide thermal insulation;
- Fusing between cells and modules to prevent failures due to short circuits between cells; and
- Battery management systems which monitor voltage and temperature within modules and report any system alarms.

¹²⁹ <http://www.webelements.com/cadmium/biology.html> Accessed 03/01/2014

In common with other utility scale EES technologies, the track record of high temperature sodium based batteries is good. The most high profile incident to date relates to a sodium sulphur installation at the Tsukuba Plant of Mitsubishi Materials Corporation, Japan, in September 2011. The cause of the fire was due to one faulty battery cell leaking material and causing a short circuit which produced heat and a propagating failure between cells. The resulting fire affected other modules within the enclosure.¹³⁰ Since the fire incident, safety enhancement measures have been implemented, including additional fusing to prevent short circuits, insulation both between parts of modules, and the modules themselves, modifications to the monitoring system and fire fighting guidance¹³¹. Existing sodium sulphur installations have had the modifications described above applied as a 'retro-fit' measure. Manufacturing operations recommenced in June 2012 following the investigation into the fire and the development of safety measures.

9.2.5 Lithium-Ion

Lithium-ion batteries have been used widely in the 3Cs (cameras, cellphones and computer) sector over the last twenty years and they are now commonplace in many applications. Their use in utility scale energy storage systems is increasing rapidly, as can be demonstrated by Table A3.3 in Appendix 3.

The potential failure modes and the likelihood of failure for a given system will depend on many factors, include the variant of Li-Ion employed and design measures included. This sub-section considers the potential failure modes of the Li-Ion 'family' of technologies. The safety of individual systems described in the case studies has been assessed as part of the procurement process and managed via the processes described in Section 10.

Within Li-Ion battery systems, each individual cell must be maintained within closely controlled operating limits (voltage, state of charge and temperature) to avoid permanent cell damage or failures. Unlike other technologies such as Pb-Acid they do not have any natural cell equalisation mode and this function must be provided by the BMS.

The phenomenon of 'thermal runaway' is of significance to the Li-Ion 'family' of electrochemistries. The tendency of a cell to enter into this mode depends on the specific variant of Li-Ion concerned and design measures which have been employed. Thermal runaway refers to the failure of a single cell, via the mechanism described below. This can potentially become a series of cascading cell failures, where this is not mitigated in the design of the system. The process of thermal runaway in Li-Ion batteries can be described by the following stages:

- An increase in cell internal temperature;
- Consequential increase in cell internal pressure;
- Pressure relief and venting;
- Potential for ignition of vent gases/vapours, ejection of cell contents (depending upon the format of the cells) and propagation to adjoining cells due to heat transfer from failed cells to adjacent cells (if not mitigated by design measures). The composition of gas species from overcharged Li-Ion batteries has been the subject of a range of research and have been found to include:
 - Carbon dioxide and carbon monoxide with a small fraction of methane (<10%) also being generated.

¹³⁰Further details regarding the causes of the incident are available from: <http://www.ngk.co.jp/english/news/2012/0607.html>
Accessed 08/10/2014

¹³¹Further details of the design modifications are available from: <http://www.ngk.co.jp/english/news/2012/0607.html> Section 2.
Accessed 08/10/2014

- Highly flammable gas products including hydrogen (approximately 50% of the gas generated), methane, ethylene (C₂H₄) and ethane (C₂H₆).
- The electrolyte within the cell can also decompose to form carbon dioxide, ethylene, fluoroethane, diethyl ether, highly toxic alkylfluorophosphates and fluorophosphoric acids¹³².

A number of these species will burn at even low percentages of oxygen (<10%). It should also be noted that exposure to these chemicals (especially fluorine compounds) can be hazardous. In the event of exposure to these chemicals, the quantity released should be compared to the Short Term Exposure Limit (STEL) to determine whether any further action (e.g. first aid/other medical treatment) is necessary.

There are a number of potential causes for thermal runaway such as cell over-charge or discharge, over-voltage, over-heating, mechanical abuse (e.g. penetration), external short circuits and internal defects/shorts such as “short shorts” (microscopic level defects).

Cell manufacturers and systems integrators employ a wide range of mitigation measures against the hazards of thermal runaway, such as: design and construction, quality assurance, measurement and control, abuse testing, fire suppression systems and emergency procedures.

An overview of the safety concepts for battery modules in automotive applications is given by Lisbona and Snee¹³² based on a paper published in 2010¹³³.

Table 9.4: Safety Features in Lithium Ion Systems^{132,133}

System Software	System Hardware	Cell Hardware
<p><i>Measurement of battery system characteristics:</i></p> <ul style="list-style-type: none"> • Cell/package voltage • Temperature • Device feedback • Sensor validity • Consistency check <p><i>In the event of a fault or failure:</i></p> <ul style="list-style-type: none"> • Control actions 	<p><i>Electronics hardware:</i></p> <ul style="list-style-type: none"> • Over and under voltage protection • Over temperature • Cell balancing circuitry <p><i>Electrical hardware:</i></p> <ul style="list-style-type: none"> • Fusing for over-current protection • Contactors <p><i>Mechanical hardware:</i></p> <ul style="list-style-type: none"> • Optimum thermal management • Structural protection 	<p><i>Cell-level design features:</i></p> <ul style="list-style-type: none"> • Pressure vent • Current interrupt device • Separator materials <p><i>System structure:</i></p> <ul style="list-style-type: none"> • Contain any vented materials

A number of safety related incidents have occurred in relation to Li-Ion batteries, although it should be noted that the specific Li-Ion variant involved and the design mitigation measures employed will vary in each case, and these examples are not drawn from the utility sector. Three incidents are highlighted from the military and transport sectors, as follows:

¹³² A review of hazards associated with primary lithium and lithium-ion batteries. D. Lisbona, T. Snee. Process Safety and Environmental Protection 89 (2011) 434-442.

¹³³ Key challenges for the development of advanced batteries. Rosenkranz, C. Presented at the Lithium Battery Technology and System Development: Breaking the Batteries for Electric Vehicles event, London. 9th March 2010.

- **United States Navy Advanced Seal Delivery System (ASDS) Mini-Submarine (November 2008):** Sparks and flames were noticed to be coming from near the battery compartments during battery re-charging¹³⁴. The resultant fire took six hours to extinguish and led to the total loss of the boat. The battery system is believed to be of the Lithium Cobalt Oxide variety. The incident led to a major review of battery handling procedures;
- **General Motors Battery Explosion, Warren Technical Centre (April 2012):** A Li-Ion battery (variant unknown) was undergoing extreme testing within an enclosed test chamber. An explosion occurred “due to the release of chemical gases from the battery cells and their ignition in the enclosed chamber¹³⁵.” Employees were evacuated from the facility and one was hospitalised. The total loss was reported to be in the region of \$3 million; and
- **Boeing Dreamliner Battery Incidents (January 2013):** Two safety incidents relating to fires involving the Li-Ion battery units used for auxiliary power have occurred. Following the incidents, the US Federal Aviation Authority issued a directive to temporarily remove all Dreamliners from service. Early indications (reported February 2013) were that the batteries had leaked electrolyte but not overcharged. Boeing carried out an investigation and designed and tested a solution between February and April 2013. A formal “Air Worthiness” Directive was issued on 19th April 2013, following the introduction of various mitigation measures, as follows:¹³⁶
 - Greater separation between cells and increased heat insulation;
 - A battery box has been developed that will ensure any vent gases from a failed/failing battery would be vented outside the aircraft¹³⁷; and
 - Improved production, operating and testing processes.

Following an investigation, a final report on the incident was released by the National Transportation Safety Board (NTSB). The NTSB determined that “the probable cause of this incident was an internal short circuit within a cell of the Auxiliary Power Unit lithium-ion battery, which led to thermal runaway that cascaded to adjacent cells, resulting in the release of smoke and fire.¹³⁸”

9.3 Flow Battery Systems

Electrochemical flow battery systems (“flow batteries”) represent the second principal category of electrochemical energy storage systems, as described in Section 4.2. They are characterised by storage of their electrolyte solutions in tanks and the circulation of the electrolytes to a series of cell stack assemblies, where the electrochemical reactions involved in the charging/discharging processes occur, with their associated DC input or DC output, respectively.

Flow battery systems can present a range of specific hazards, which are not necessarily seen in battery systems. The sub-sections below describe a range of hazards which are particular to flow battery systems, in general, together with those which are electrochemistry specific. The commentary principally relates to the vanadium redox and zinc bromine systems, which represent the most near market flow battery technologies, at present.

¹³⁴ ASDS Fire. www.op-for.com, November 2008

¹³⁵ <http://www.inautonews.com/gm-chemical-gases-from-the-battery-cells-were-released-and-ignited#.Uqz8J1FDIU> Accessed 13/12/2013

¹³⁶ <http://www.guardian.co.uk/business/2013/apr/19/boeing-787-dreamliner-cleared-fly-faa> Accessed 14/12/2013

¹³⁷ <http://boeing.mediaroom.com/index.php?s=43&item=2660> Accessed 14/12/2013

¹³⁸ Auxiliary Power Unit Battery Fire Japan Airlines Boeing 787-8, JA829J Boston, Massachusetts January 7 2013. Incident Report. NTSB/AIR-14/01 PB2014-108867. National Transportation Safety Board. Available online: <http://www.nts.gov/doclib/reports/2014/AIR1401.pdf> Accessed 11/12/2014

9.3.1 Uncontained Discharge of Electrolyte Solution

As noted above, the basic system architecture of a flow battery system involves electrolyte storage in tanks and the forced circulation of electrolyte solutions, to the cell stack assemblies. The nature of the electrolyte solutions will be a function of the electrochemistries concerned, with those for the two principal systems technologies deployed to date being:

- **For vanadium redox systems:** solutions of vanadium compounds, in sulphuric acid (H_2SO_4); and
- **For zinc bromine systems:** aqueous solutions of zinc bromide (ZnBr_2).

The possibility therefore exists for the uncontained discharge of electrolyte solutions, via such factors as leakage or rupture of the electrolyte tanks themselves, failure/leakage from pipework connections or failure/leakage from the cell stack assemblies.

In practice, the probability of such an uncontained discharge occurring should be mitigated by the application of sound system engineering design, construction and operational practice. In addition, the incorporation of appropriate bunding (or sumps), sized such that it/they can contain any credible gross discharge. The incorporation of associated sensors in the Storage Management and Control System should provide an extra layer of protection, designed to detect any actual leakage(s), at an early stage. Such sensors could include level sensors in the electrolyte tanks themselves, leak detection sensors in the bunding/sumps and pressure sensors in the flow and return pipe-loops.

9.3.2 Discharge of Electrolyte Spray

Closely associated with Section 9.3.1 (above) is the specific circumstance of the spray discharge of electrolyte, at the discharge pressure of the circulation pump(s), via a failed pipework connection, valve, cell stack assembly or associated. Any such spray discharge could result in a potentially aggressive and/or toxic electrolyte solution impinging on personnel, cable runs, electrical systems, safety systems and other Balance-of-Plant (B-o-P).

Mitigation measures are likely to include those as described in Section 9.3.1, with associated design considerations in relation to the siting of performance/safety critical sub-systems, relative to the hydraulic flow circuits.

In the context of both the gross discharge and spray discharge scenarios, consideration may also be given to further measures, should these be assessed as necessary, to manage any residual risk. Such measures could include:

- Access control;
- Use of Personal Protective Equipment (PPE);
- Provision of emergency showers; and
- Provision of spill kits.

9.3.3 Hydrogen Generation from Electrolyte Gassing

The possibility of hydrogen generation from flow battery systems inadvertently entering an electrolysing state, is a potential hazard for a number of flow battery systems, including the vanadium redox and zinc bromine systems, which represent the majority of installations to date.

Again, the application of sound engineering design and construction measures, supported by appropriate functionalities in the SMCS and appropriate inspection/maintenance régimes, should limit the possibility of any such hydrogen generation. Any residual risk may be mitigated via the application of appropriate ventilation, hydrogen sensors and venting, as may be identified from the Risk Assessment.

9.3.4 Exposure to Toxic Substances/Compounds

The potential hazard of exposure to toxic substances/compounds is small, although finite, for both the vanadium redox and zinc bromine systems. For the former, the toxic exposure hazard is principally associated with the oxides of vanadium, e.g. via dust inhalations. In the flow battery application of interest, such vanadium oxides are dissolved in sulphuric acid, with the exposure to the acid itself representing the far greater risk.

The release of any free bromine from the zinc bromine system does represent a potential toxic exposure hazard, either by inhalation of the vapour or exposure to the liquid. Again, the hazard is mitigated in practice via the application of sound engineering design principles and the maintenance of the operation of the system, within a defined operational envelope. The bromine is also complexed in its polybromide state, which reduces the hazard considerably. However, in the event of either abnormal system operation, or in the event of electrolyte release, then free bromine may be evolved. The management of such residual risk may be addressed by the formulation of appropriate procedures and the provision of wash-down showers and spill kits.

9.4 Thermodynamic Cycle Systems

Section 4 of the GPG addresses two thermodynamic cycle systems, namely LAES and PHES. A number of hazards are associated with such systems and these are as described in the sub-sections below.

9.4.1 Catastrophic Failure of Pressure Systems

The LAES and PHES systems both involve the handling of high pressure gases, as part of their respective operating cycles. Any catastrophic/explosive failure of such pressure systems has the potential to impact very severely on adjoining personnel, property and structures.

In practice, the risk associated with this hazard may be mitigated via the application of sound system engineering design and construction principles, in accordance with recognised pressure systems/vessels regulations and associated design codes (as described, for example, in Section 6.3). The application of sound operational procedures and the implementation of appropriate inspection régimes, will further serve to safeguard the integrity of such pressure systems and mitigate the explosion hazard, throughout the operational lifetime of the storage systems concerned.

9.4.2 Machinery Related

The use of rotating machinery, in the form of compressors and expanders, is fundamental to the operating cycles of such thermodynamic systems. There are a number of hazards associated with any rotating machinery ranging from, in extremis, explosive failure due to over-speed, through to the entanglement of personnel, due to inadequate guarding provision.

As for the above, such hazards may be mitigated in practice via the application of sound engineering design and construction principles, complemented by the application of sound operational procedures and the implementation of appropriate inspection schedules. Within the UK and European context, such machinery must be designed and constructed in accordance with the requirements of the Machinery Directive and be CE marked (see Section 6.4). This will provide the user with a basic level of assurance, in relation to the safety of the machinery concerned.

9.4.3 Exposure to Hot and Cold Surfaces or Pipework

The two reference systems of interest involve the use of high and/or low temperatures in their operating cycles, with the resultant risk of high and/or low temperature (cryogenic) burns, in the event of any personnel exposure.

Again, the application of sound engineering design and construction, such as to minimise exposure to any such surfaces either via design, in itself, or via the application of lagging, will represent the first line of defence in mitigating this hazard. The development of appropriate operational procedures, complemented by the use of PPE, may also be considered, to cover any residual risk, associated with those minimum number of scenarios, where operating personnel may be required to be in some degree of proximity to such plant.

9.4.4 Noise

The inherent nature of any thermodynamic system is such that the machinery involved is likely to generate noise which, in the immediate confines of the plant, could well be in excess of allowable exposure limits. There is also the possibility of system venting/pressure relief occurrences generating intense noise, in the immediate vicinity of the plant. Some mitigation of the former acoustic hazard may be considered as part of the design process, e.g. by elimination of the noise at source, or via containment of particular sources, in acoustically lined enclosures.

Any further risk may be mitigated by limiting operator exposure and the application of the appropriate PPE (i.e. ear defenders).

9.4.5 Asphyxiation

An asphyxiation hazard may be present, dependent upon the working fluids employed. For the LAES system, the prima facie working fluid is air, which does not present an asphyxiation hazard. However, it is understood that, in the development of the technology, nitrogen, has, on occasions, been used as a working fluid. Indeed, the current DECC supported Viridor/Highview demonstration of the technology is based on the use of nitrogen (see Case Study A1.16, Appendix 1). Likewise, it is understood that Argon is a potential working fluid for the PHES system.

Any use of such gases will present an asphyxiation hazard, which must be identified and qualified, in the appropriate Risk Assessment, noting the characteristics of the asphyxiant concerned. Appropriate mitigation measures which may be considered may include the provision of oxygen sensors, ventilation provision and access control measures, include the implementation of appropriate "Permit-to-Work" systems.

10 The Risk Assessment Process

10.1 Introduction

A number of regulations apply to the use of EES that are applicable at different stages of the asset lifecycle or throughout. Overarching legalisation including the Health and Safety at Work Act etc.¹³⁹ and the Electricity at Work Regulations¹⁴⁰ (see Section 6.1) places duties on employers and employees to manage safety. Specifically, they include a duty on employers to carry out a Risk Assessment; which is the main subject of this Section.

When EES systems are deployed by the DNOs/the TO/SO they may be situated at existing or new substations or outwith of these (e.g. as street furniture or at 3rd party premises). Within the former categories DNOs/ the TO/SO are subject to specific duties under the Electricity Safety, Quality and Continuity Regulations¹⁴¹ (ESQCR), notably:

- Inspections must be carried out at a reasonable frequency to ensure compliance and a record of these inspections and recommendations shall be maintained for not less than 10 years;
- Equipment is used and maintained as to prevent danger, interference with or interruption of supply, So Far As is Reasonably Practicable (SFARP);
- Precautions shall be taken to prevent, SFARP, danger due to the influx of water, noxious or explosive gas into any enclosed space, arising from installation or operation of the equipment;
- Display a notice in a conspicuous position which identifies the substation, the name of the owner and the telephone number to contact (all hours) a suitably qualified person; and
- Display other signs of suitable size and in positions necessary to give warning of the presence and nature of danger and the measures taken to ensure the physical security of the equipment.

A requirement for inspections under ESQCR is set out above. Due to the relatively immature nature of the EES systems deployed to date, and their use in research and development trials, a higher inspection frequency is recommended. Monthly inspections are being used for a number of installations or more often where manufacturer's guidance suggests this is necessary (e.g. as stipulated in warranty agreements).

During the design, construction and installation phase, CDM regulations¹⁴² will apply. The HSE provide guidance on the CDM regulations, including publishing the 'Approved Code of Practice'¹⁴³ (ACOP). The ACOP provides practical guidance on complying with the duties set out in the Regulations (i.e. the Construction, (Design and Management) Regulations 2007). The Projects can either be "notifiable" (to the HSE) or "non notifiable", depending on the length of the construction phase. Those that have construction phases lasting longer than 30 days or more than 500 person-days of work are "notifiable" and this places additional duties on various parties. Notifiable projects require the formal appointment of a CDM Co-ordinator and Principal Contractor. In most cases the Client would be a EES owner/operator; the Principal Contractor would be responsible for safety and the maintenance of the Health and Safety File, until handover to the Client's operational

¹³⁹ UK Statutory Instrument 1974 Chapter 37, Health and Safety at Work etc. Act 1974

¹⁴⁰ UK Statutory Instrument 1989 No. 635, The Electricity at Work Regulations 1989

¹⁴¹ UK Statutory Instrument 2002 No. 2665, The Electricity Safety, Quality and Continuity Regulations 2002

¹⁴² UK Statutory Instrument 2007 No. 320, The Construction (Design and Management) Regulations 2007

¹⁴³ Available from: <http://www.hse.gov.uk/pubns/priced/l144.pdf> Accessed 16/02/2014

engineers after commissioning. Under this framework, assuming that the Client has already selected competent personnel that are adequately resourced and given enough time for the tasks, the Client's main responsibilities are¹⁴⁴:

- To ensure that any implications for public, employee or customer safety are properly addressed;
- Designers and contractors identify hazards and control measures in accordance with the regulations;
- There is systematic monitoring and review to ensure safety; and
- Revisions to designs, work programmes and Method Statements are managed safely and without risk to health.

Further details of the requirements of the CDM Regulations are provided in Sections 6 and 8.

After handover to the Client's operational staff the main concern becomes the management of safety during the operation of the EES system. Safety should be considered all stages of the project. For example, by considering operational safety via the completion of a draft Risk Assessment while in the specification phase of an EES project. The assessment of safety of staff and members of the public during the installation, commissioning, operational and decommissioning phases (including those specific to EES) form the EES Safety Case. The development of a rigorous Safety Case for EES systems will be an essential pre-requisite for the "business-as-usual" uptake of EES systems as a routine network technology. These Safety Cases will need to demonstrate the appropriate degree of rigour and hold up to scrutiny if challenged. The development of this Safety Case and Risk Assessment is the main focus of this Section.

The fact that utility-scale EES systems are a new class of technology, presenting new and unfamiliar hazards (alongside more 'traditional' hazards), means that operators of EES sites must exercise appropriate diligence in the identification and mitigation of these hazards. This requires dialogue with the manufacturer to understand the hazards, failure modes and effectiveness of mitigations. The specific hazards of EES include the risk of DC electric shock, the storage of large quantities of chemical energy, etc. and are discussed in Section 9 of this Guide.

10.2 Approaches to the Development of a Risk Assessment

A number of approaches have been taken by DNOs in the development of the Operational Risk Assessments (ORA) for their various deployments of EES systems. These have all been undertaken with the same overarching aim of preventing harm to either DNO employees, contractors or the general public. A number of different studies/analyses have been undertaken in order to inform the development of ORAs. The following list provides examples of the studies completed by DNOs to date (it is not necessary to complete all those listed below for any single project):

- **Completion of a Hazard and Operability (HAZOP) study, with an accompanying Hazard Identification (HAZID) study:** HAZOP studies are a structured and systematic examination of either a planned or existing operation which is designed to identify and evaluate problems which may represent risks to personnel or equipment. Prior to completing the HAZOP study, a HAZID exercise is completed to identify the hazards. HAZOP was initially developed to analyse chemical process systems but

¹⁴⁴ <http://www.hse.gov.uk/construction/cdm/clients.htm> Accessed 16/02/2014

has been extensively used in other sectors. In the context of EES systems, HAZOP studies may include consideration of:

- The core storage technology (e.g. battery) and inverter build stage;
 - Overall system safety;
 - Site and network protection;
 - Lifting and manual handling;
 - Waste;
 - Site access and egress;
 - Security;
 - Underground obstructions;
 - Background noise and Electromagnetic Field (EMF) study; and
 - Detailed assessments on switching transients and the point of connection.
- **Provision of Failure Mode and Effect Analysis (FMEA) from the system supplier:** A FMEA identifies failures modes and their potential causes and effects. Provision of FMEA information by the manufacturer to the operator of energy storage systems gives assurances of the level of rigour behind the supplier's safety case. It can also inform the development of:
 - Risk Assessments by outlining mitigation measures against failure which are inherent to the design; and
 - Method Statements for the actions to be taken in the event of routine maintenance or operational failures.
 - **Application of existing company Risk Assessment procedures:** These Risk Assessments can separately consider the risks to people, the environment, the asset and the company reputation. These procedures can also include carrying out site Risk Assessments for each visit to the energy storage installation to capture any new or changing risks. These site Risk Assessments take into account any changes to the site since the last visit (e.g. due to ongoing construction work) or other risks from the external environment (e.g. weather conditions). Fire Risk Assessments should also be completed, as described in Section 9.1.3. The process for completing Risk Assessments for EES systems is considered in more detail in Section 10.3.1 (below).
 - **Completion of a Hazard Elimination Management List (HEML):** A HEML forms a record of the hazards identified and eliminated during the design phase and any mitigating actions. This approach considers the various activities associated with a particular site (e.g. a site visit) and then lists the hazards which may be presented and who may be at risk (employees, visitors to the site, contractors or members of the public). Each hazard is then rated according for its severity and probability and therefore the 'risk rating'. The actions taken to reduce this risk (e.g. fencing to prevent unauthorised access) are then recorded, before the risk residual risk rating is developed.
 - **Structured "So, What If?" Test (SWIFT):** This structured "brainstorming" method is designed to consider risks which could prevent successful completion of the project, the likelihood of each one occurring and the consequences of each. These risks could relate to various failures within the project, including:
 - Damage to the asset;
 - Health and safety issues;
 - Environmental pollution arising from the project; and
 - Failure of the unit to operate as expected.

The means of preventing each risk from materialising are then considered and graded based on whether the measure prevents it occurring, reduces the probability (but does not prevent), limits the significance of the event by proactive action (but does not reduce the probability) or is reactive action (following the risk materialising) which reduces the significance of the event.
 - Development of an evidential safety case via a structured review comprising an assessment of the track record of candidate technologies during procurement,

independent review of the safety related material provided by the system supplier, development of Risk Assessments and a site review to ensure compliance with original design and Risk Assessment.

The various approaches described above (from the case studies) include additional detail beyond that which is carried out for 'off-the-shelf' pieces of equipment which are deployed by, for example, DNOs. The majority of implementations of storage within the case studies represent a 'first' of some kind for each owner/operator (e.g. 'first' implementation of EES, or of a particular electrochemistry or system). EES systems also represent a new and atypical technology in the context of electricity network operations. Therefore, a Safety Case is currently being developed for each deployment, with the requisite amount of effort expended. In a scenario where EES systems are to be deployed as 'off the shelf' pieces of equipment it would be expected that the relevant information would be provided by manufacturers, in order to limit the additional work required by storage operator (above their standard procedures). This will be driven by both the availability of standards (applicable to the UK) to which utility-scale EES systems can be certified, and then procured against, and an increase in level of detail provided by manufacturers and system suppliers. This should include a thorough understanding of failure modes and the countermeasures to these. In the context of GB DNOs, the following pieces of information should be provided by manufacturers in order to comprise a thorough and rigorous safety case (although this does not necessarily represent an exhaustive list for any given application):

- Operating history of equivalent systems and comprehensive type testing;
- Failure modes and effects analyses, potentially with input/verification from an independent third party;
- Abuse testing;
- Learning from previous incidents or 'near misses';
- Installation and commissioning procedures including connection to the distribution network;
- Compliance with applicable standards; and
- Fire fighting guidance.

10.3 Risk Assessments and Method Statements

10.3.1 Risk Assessment

The completion of Risk Assessments for all employers is a legal requirement under the Health and Safety at Work Act. Risk Assessments must be recorded for all companies employing five or more people¹⁴⁵.

EES devices deployed today are typically first-in-the-UK applications and the sector and technologies are evolving quickly. While some failure modes and hazards are fairly common between one system and the next, there is likely to be significant differences which would prevent a Risk Assessment for one system simply being adopted for another. In addition, the hazards present are often new in the context of a business's operations (even to the DNO/TO/SO sector) (e.g. large quantities of stored energy, DC electric shock, chemicals inventory). The case studies within Appendix 1 show how DNO companies are adapting their Risk Assessment procedures in order to apply these to EES installations. This can provide useful guidance for other parties planning to deploy EES systems.

A large amount of guidance is available from various sources regarding the process for developing Risk Assessments, including that provided by the HSE. Individual companies within the power utilities sector have also developed their own procedures and templates for

¹⁴⁵ <http://www.hse.gov.uk/risk/faq.htm> Accessed 26/09/2014

assessing the risks from their activities. The stages involved in developing Risk Assessments can be broadly defined¹⁴⁶ as:

- 1. Identify the hazards:** This should recognise both more familiar hazards (e.g. those which could lead to slips, trips and falls or hazards which are typical in a substation environment) and those which relate specifically to EES systems, such as those outlined in Section 9 of this guide. The hazards may emanate from the EES system itself (e.g. DC electric shock, release of material from the system) or could result from the interaction between the environment and the EES system (e.g. a fire in the surrounding area). Various systematic methods are available to assist with identifying hazards, such as those described in Section 10.2 (above).
- 2. Decide who may be harmed and how:** Companies have a legal obligation to ensure that their activities do not harm either their employees, contractors working at their sites and the general public. The distinction between “voluntary” and “involuntary” risk may be useful for consideration here. A voluntary risk is one which is associated with an activity which a person decides to undertake (e.g. from their employment). In contrast, involuntary risk relates to situations where the person has no prior consent or knowledge (e.g. a member of the public walking past a street-side deployment of EES). The Risk Assessment should therefore consider issues such as the potential hazards to the public in the event of various failure modes (e.g. any potential for release of harmful gases) and preventing unauthorised access to EES installations which may cause harm.
- 3. Evaluate the risks and decide on precautions/mitigation measures:** The level of risk arising from a hazard is generally evaluated as a function of how severe the consequences from the hazard would be and the likelihood of the risk materialising. A grading system for the probability of a hazard occurring can be based on the operational track record of the technology (e.g. has this type of incident occurred within the business, or is it known of elsewhere in the industry?) This presents a particular issue when assessing the probability of hazards specific to EES devices (e.g. thermal runaway) occurring, as due to the very low number of previous deployments, it is extremely unlikely that an event will have occurred previously within the organisation in question. Mitigation measures against hazards should then be determined. A number of mitigation measures applied to current and planned EES installations are outlined within the case studies (see Appendix 1). These are summarised in Table 10.1, along with those from BS EN 50272-2:2001 (see Section 6.2.2) below. It should be noted that BS EN 50272-2:2001 relates to “lead-acid and NiCd batteries” so whilst other electrochemistries are outside of its direct scope it nevertheless provides useful guidance.

¹⁴⁶ HSE Guidance. Available from: <http://www.hse.gov.uk/risk/fivesteps.htm> Accessed 15/01/2014.

Table 10.1: Hazards and Mitigation Measures

Hazard	Mitigation Measures	Relevant To:					
		Battery Technologies				Flow Battery	Thermodynamic Energy Storage
		Pb-Acid	NiCd	High Temperature Sodium	Li-Ion		
Electric Shock	<p>Electrical protection in the DC/DC Battery Transfer Box via circuit breakers and fuses.</p> <p>Compliance with the Low Voltage Directive and CE Marking of system.</p> <p>Alterations to remote inhibit procedure via SCADA</p> <p>Site is treated as live at all times thus operational safety rules and safe systems of work apply.</p> <p>A number of measures to protect against direct (where the voltage exceeds 60 V DC) and indirect contact with live parts are set out in detail in BS EN 50272-2:2001 (strictly only applicable to Pb-Acid and NiCd systems), including:</p> <ul style="list-style-type: none"> • Insulation of live parts; • Barriers or enclosures; and • Automatic disconnection of supply. <p>Devices to disconnect the battery installation from all lines of incoming and outgoing circuits and from earth potential shall be used, including:</p> <ul style="list-style-type: none"> • Circuit breakers, switches; • Plug and socket outlets; • Removable fuses; • Connecting links; and • Specially designed clamps. <p>Persons working with the battery should be competent to carry out such work and trained in any special procedures necessary.</p> <p>For battery systems where the nominal voltage is > 120 V DC, insulated protective clothing and local insulated coverings will be required to prevent personnel making contact with the floor or parts bonded to earth.</p> <p>(continued overleaf)</p>	<p>✓</p> <p><i>(applies to all technologies)</i></p>					

Hazard	Mitigation Measures	Relevant To:					
		Battery Technologies				Flow Battery	Thermodynamic Energy Storage
		Pb-Acid	NiCd	High Temperature Sodium	Li-Ion		
Electric Shock (continued)	<p>Battery systems shall be designed to minimise the risk of injury to personnel carrying out maintenance on the system, as follows:</p> <ul style="list-style-type: none"> • Battery terminal covers which allow routine maintenance whilst minimising exposure of live parts; • A minimum distance of 1.5m between simultaneously touchable conductive live parts of the battery having a potential exceeding 120 V DC; • Devices to disconnect the battery into groups of less than 1500 V DC when operating batteries with nominal voltages above 1500 V DC. • Fuse carriers which prevent contact with live parts. <p>All metallic personal objects shall be removed from hands, wrists and neck before starting work.</p>	<p>✓ <i>(applies to all technologies)</i></p>					
Fire from EES System	<p>Additional fire fighting equipment placed on site</p> <p>Fire suppression systems (suppression medium may be 'life supporting', or could present an asphyxiation hazard).</p> <p>Defence in depth approach taken by supplier with several layers of protection including cell/module design, monitoring and protection systems and a fire suppression system</p> <p>Very Early Smoke Detection Apparatus (VESDA) linked to fire suppression system.</p> <p>Fire detection system, emergency stops and CCTV monitoring employed.</p> <p>Separation of storage modules (e.g. multiple containers) to reduce the volume of flammable material in a given location.</p> <p>Keep batteries clean and dry.</p>	<p>✓ <i>(applies to all technologies)</i></p>					
Continued operation of units following an alarm incident	Alterations to alarm priorities and self-reset commands	<p>✓ <i>(applies to all technologies)</i></p>					

Hazard	Mitigation Measures	Relevant To:					
		Battery Technologies				Flow Battery	Thermodynamic Energy Storage
		Pb-Acid	NiCd	High Temperature Sodium	Li-Ion		
Risk to personal safety	Security lighting for substation compounds/storage installations Assessment of risk (e.g. avoiding lone working) CCTV	✓ <i>(applies to all technologies)</i>					
Failure of safety related systems due to lack of mains supply	Auxiliary supplies to safety systems can be provided. Uninterruptible Power Supply (UPS) can be used to supply critical loads. Failsafe shutdown of systems in the event of loss of power to safety critical systems. Testing of operation of auxiliary power/UPS/failsafe systems as part of FAT/commissioning tests.	✓ <i>(applies to all technologies)</i>					
Unauthorised access to site	Sites fenced or surrounded by existing walls (various heights) to prevent unauthorised access Electrified fencing Castell interlocks Keypad entry to containers	✓ <i>(applies to all technologies)</i>					
Damage to network or storage device through incorrect operation	Restricted access to control of devices Issuing of operational guidance	✓ <i>(applies to all technologies)</i>					
Malicious remote operation of the device (i.e. cyber-attack)	Employment of good cyber-security measures (firewalls etc.)	✓ <i>(applies to all technologies)</i>					

Hazard	Mitigation Measures	Relevant To:					
		Battery Technologies				Flow Battery	Thermodynamic Energy Storage
		Pb-Acid	NiCd	High Temperature Sodium	Li-Ion		
Malfunction of units following software changes (e.g. upgrades to firmware)	<p>Consideration of which software updates are necessary (i.e. minimise the number of updates whilst still maintaining functionality and security)</p> <p>Successful deployment of software on other systems prior to update on network connected EES.</p> <p>Ability to return to previous version if necessary.</p> <p>Planning of timing of upgrade (e.g. to avoid critical operational periods)</p>	<p>✓</p> <p><i>(applies to all technologies)</i></p>					
Water ingress to storage units	<p>Alterations to battery casings to seal units from water ingress.</p> <p>IP rating of containers.</p> <p>Installation of flood protection measures during site design and construction phase – e.g. placing containers or buildings on concrete plinths where a flood risk is identified.</p>	✓	✓	✓	✓	✓	
Hydrogen gas generation (leading to fire/explosion hazard)	<p>Hydrogen detection system linked to forced ventilation system</p> <p>Design and operation in accordance with BS EN 50272-2:2001 (Section 8)</p>	✓	✓			✓	
Release of compressed gas	<p>Compliance with relevant design and construction Directives (e.g. see Section 6.3.4).</p> <p>Pressure testing of system.</p>						✓

It should be noted that Table 10.1 summarises the mitigation measures detailed within the project case studies and is not an exhaustive list of the measures employed at each site. Technologies which are not included within the suite of project case studies may represent different hazards and would employ mitigation measures not listed above. It is likely that measures against day-to-day hazards (e.g. use of handrails to prevent slips, trips and falls on steps) have been excluded from the case studies.

4. **Record findings and implement them:** It is then necessary to ensure that the mitigation measures identified within the Risk Assessment are implemented at site prior to the commissioning or installation of the EES system.
5. **Review your assessment and update if necessary:** Risk assessments should be periodically reviewed and, in particular, further reviewed following any incident (“near miss” or accident). In addition, as Risk Assessments are carried out on each site visit the original document should be updated if a site visit shows material changes to the installation or surrounding environment.

10.3.2 Method Statements

In contrast to Risk Assessments, Method Statements do not have a clearly defined legal basis. However, they are beneficial in defining the way in which certain activities should be carried out in order to minimise the potential risks.

Method Statements can be developed for activities throughout the lifetime of the project, for example:

- Specific construction/installation activities which should be shared with relevant contractors as part of CDM activities;
- Maintenance activities such as replacement of a battery module or routine inspections;
- How to reset the Power Conversion System after tripping; and
- Anticipated fault/failure conditions or events such as fire or flood. This type of Method Statement should include input from the manufacturer regarding the most appropriate actions to take and the relevant emergency services.

10.3.3 Liaison with External Bodies

Liaison with various external bodies in relation to the safe operation of EES systems has also taken place in the various EES deployments in GB to date, including with:

- **Fire and emergency services:** Fire and Rescue services have taken part in meetings to agree the appropriate fire-fighting/containment strategy in the event of an incident at an EES site. Training exercises are planned for some EES installations;
- **Local Authorities:** The majority of engagement with Local Authorities has taken place in relation to planning permission (see Section 6.5.1). Where storage has been deployed in local authority housing, the council call centres have been briefed in order to provide necessary information to householders where necessary. Local Authorities have also taken part in the development of emergency planning procedures. This led to a recommendation from one particular Local Authority that the EES system should be included on the Community Risk Register, under the terms of the Civil Contingencies Act¹⁴⁷. The Community Risk Register is the first step in the emergency planning process and acts as a repository for Risk Assessments in

¹⁴⁷ Civil Contingencies Act 2004. Available online via: <http://www.legislation.gov.uk/ukpga/2004/36/contents> Accessed 20/01/2014

relation to sites which may pose particular hazards in the event of an emergency;
and

- **The local community:** Engagement with the community surrounding EES installations has taken place during a number of projects. For example, as part of the CLNR project, where access needed to be arranged to allow the delivery of a containerised system.

Early engagement with external stakeholders has been found to be beneficial. This is particularly true where the technology involved is relatively 'unknown' and may carry with it associated pre-conceptions, not necessarily based upon matters of fact. Early engagement with external stakeholders can prevent delays in the latter stages of the project. This engagement could allay any pre-conceptions, fully explain the technology involved and the mitigation measures applied against potential risks.

10.3.4 Training

The provision of training for employees who will interact with EES installations forms one of the mitigation measures against the incorrect operation of the device, or hazards during specific phases of the project (e.g. installation). This training could relate to the various ways in which employees may interact with the system:

- **Employees involved in installing the EES system:**
 - Briefing of those taking part in the installation of EES storage systems prior to going to site, detailing the relevant hazards (e.g. particularly those in relation to lifting, DC electric shock, removal of personal jewellery etc.).
 - 'Toolbox talks' during the installation to reinforce the key points from pre-installation training.
- **Employees monitoring the device remotely:** this needs to include an understanding of the expected state of the system and the actions to take in the event of any alarms.
- **Employees operating the device:** this can include site based training in addition to classroom training and could include items such as access and egress from site, disarming fire suppression systems (where necessary) and isolating the device from the network. Work instructions can be prepared detailing the procedures for operating the device. In some cases this training is being provided by the system supplier. Annual 'refresher' courses can be included within planned maintenance of the system in order to re-familiarise staff with the system, if necessary. Existing authorisations (e.g. those with DNO or generation companies) have been used to stipulate the level of operations which a given employee is able to carry out.
- **Staff who may disconnect EES systems from the distribution network:** in a number of cases, staff must be an Authorised Person in order to connect or disconnect EES devices from the network.

10.4 Lessons Learnt

The project case studies provide details of the 'lessons learnt' in relation to training and the safety and operational assessment for each project. An overriding point is the importance of starting the Risk Assessment development process early (i.e. at the project conception) and anticipating the potential hazards so that these can be mitigated at a design stage. A summary of the other 'lessons learnt' is provided below:

- It is beneficial if the disconnection procedures for the EES system correspond closely to business as usual practices, allowing suitably authorised staff to disconnect the

device where necessary. If further interaction with the system is then required (e.g. for fault finding) this can then be undertaken by a more experienced member of staff;

- It is important to build a relationship with those who will be responsible for operating the device at an early stage of the project. They should also provide input to discussions regarding safety procedures;
- Appropriate screening of siting options relative to potential system failure modes and the residual risk is important;
- Sites which include DC equipment (up to 1500V) are treated as an LV network under the Distribution Safety Rules (DSR);
- The alarms which are necessary should be considered. For innovative projects, it may be necessary to create additional alarms for the control room in order to provide further information; and
- It is important to engage with the local emergency services and other stakeholders (such as the Environment Agency and local community) early in the project. It can be beneficial to describe the EES system by referencing existing installations and applications already deployed which they are familiar with.

11 Applications and Operating Regimes

Section 3 of this Guide outlined the wide range of potential applications for EES. This section demonstrates those applications being investigated in the UK, the ways in which energy storage can be dispatched, and a number of case studies demonstrating the benefits of operating EES.

11.1 Applications Addressed by Current GB EES Deployments

EES can be used to fulfil a wide range of applications, as detailed in Section 3 and Appendix 2. One of the advantages of EES, when compared to other solutions (e.g. Demand Side Management (DSM) or ANM) is the ability to carry out multiple applications, potentially for different stakeholders within the energy industry. Fulfilling multiple applications can allow a storage owner/operator to derive multiple benefits/revenue streams (e.g. revenue from providing response services), this is important in developing the financial justification for deploying EES systems, and is discussed further in Sections 12 and 13.

The tables below (Table 11.1 and Table 11.2) illustrate the range of applications being investigated via projects being undertaken by system developers and GB DNOs. Further details of each of these projects are provided within the case studies in Appendix 1.

Table 11.1: Applications Addressed in DECC/ETI Supported Demonstrations

Project Lead		Renewable Energy Dynamics Technology (REDT)	Viridor Waste Management	EValu8 Transport Innovations Ltd	Moixa Technology Ltd	Iisentropic
Project and Location		Vanadium Redox Flow Battery Demonstration, Isle of Gigha, Scotland	Liquid Nitrogen Cryogenic Energy Storage Demonstration, Pilsworth Landfill Site, Bury	Electric Vehicle Embedded Renewable Energy Storage & Transmission (EVEREST)	MASLOW – Distributed Energy Storage, locations across England	Pumped Heat Energy Storage, within WPD's East Midlands Licence Area
Rating		105 kVA	5.5 MW (gross) 4.5 MW (net)	181 kVA	500 kVA	1.4 MVA
Capacity		1.26 MWh	15 MWh	125 kWh	1.2 MWh	5.6 MWh
Technology		REDT Vanadium Redox Flow Battery	Highview Power Storage Cryogenic (liquid nitrogen) energy storage	'End of first Life' EV batteries	MASLOW distributed Energy storage with DC Lighting and Charging	Iisentropic Pumped Heat Energy Storage
Network Location		Wind Farm, LV/11 kV Transformer	Power generation plant	Within the Lotus Engineering test centre in Hethel, Norfolk	Customer	DNO Primary Substation, 11 kV distribution board
Applications	Voltage or Reactive Support				✓	✓
	Thermal Support of:	33/11kV Tx		✓		
		33kV		✓		
		HV/LV Tx				
		HV				
		LV				✓
	Harmonic Filtering					
	Constraint Management		✓		✓	
	System Balancing Services		✓	✓		✓
In-Home Benefits					✓	

Table 11.2: Applications Addressed in DNO Demonstrators

DNO		Northern Powergrid				UK Power Networks		
Project and Location	CLNR - Rise Carr	CLNR - Maltby Edgar, Wooler St. Mary, Harrowgate Hill	CLNR - High Northgate	CLNR - Wooler Ramsay	Short-term discharge energy storage - Hemsby	Smarter Network Storage - Leighton Buzzard		
Rating	2.5MW 2.5MVA	50kW 50kVA	100kW 100kVA	100kW 100kVA	200kW 600 kVA (short duration)	6MW 7.5 MVA		
Capacity	5MWh	100kWh	200kWh	200kWh	200kWh	10MWh		
Technology	Li-Ion	Li-Ion	Li-Ion	Li-Ion	Li-Ion	Li-Ion		
Network location	Substation				New substation at NOP	Substation		
Ownership	DNO Owned				DNO Owned	DNO Owned		
Applications	Voltage or Reactive Support	✓	✓	✓	✓	✓	✓	
	Thermal Support of:	33/11kV Tx	✓				✓	✓
		33kV Network	✓(UG)					✓ OHL (primary application)
		HV/LV Tx		✓	✓	✓		
		HV Network			✓(UG)		✓	
		LV Network		✓(UG)		✓(UG)		
	Harmonic Filtering							
	Constraint Management					✓(wind)	✓(load)	
	System Balancing Services						Frequency Response, STOR	
	In-Home Benefits							
	Wholesale-related services						✓ (supplier arbitrage/tolling)	
Replacement DC Supplies								

Definitions: Tx: Transformer, UG: Underground, OHL: Overhead Line, NOP: Normal Open Point

DNO		WPD		SSEPD			
Project and Location	Sola Bristol - Bristol (26x homes, 5x schools/offices)	FALCON - Milton Keynes (5 units)	Orkney Energy Storage Park - Orkney	Flow Battery Trial - Nairn	LV Connected Batteries - Chalvey (3 units)	NINES-Shetland (Lerwick Power Station)	
Rating	2kW (per domestic installation)	50kW/50kVA	2MW/2MVA	100kW	25kW/25kVA	1MW/1.25MVA	
Capacity	4kWh (per domestic installation)	100kWh	500kWh	150kWh	25kWh (each)	3MWh	
Network location	Customer side of the meter	Substation	Kirkwall Power Station	Substation (132/33kV)	"T" connection off LV feeder	Power station (island network)	
Ownership	DNO Owned	DNO Owned	3 rd Party Owned (DNO procure an EES service)	DNO Owned	DNO Owned	DNO Owned	
Applications	Voltage or Reactive Support	✓	✓		✓	✓	
	Thermal Support of:	33/11kV Tx					
		33kV Cable			✓(sub-sea)		
		HV/LV Tx				✓(reverse power)	
		HV					
		LV				✓(UG and phase balancing)	
	Harmonic Filtering		✓				
	Constraint Management			✓(wind via ANM, primary application)		✓(solar PV)	✓(wind via ANM)
	System Balancing Services			Frequency Response			For Shetland power system (island)
	In-Home Benefits	✓					
Wholesale-related services							
Replacement DC Supplies				✓			

Definitions: Tx: Transformer, UG: Underground, OHL: Overhead Line, NOP: Normal Open Point

11.2 Scheduling Approach and Dispatch Mechanism

In order to fulfil the applications described above, each EES system must be instructed to charge/discharge at the appropriate time. These instructions are then dispatched to the device via a particular control system.

The way an EES operates may be scheduled/controlled in a number of ways; at the extremes of complexity are:

- Purely manual, real-time control by a human operator, potentially at the device itself; and
- Automated control as part of an advanced ANM system controlling network conditions to particular set points and evaluating the optimum solution (e.g. EES, DSM etc.) to use in order to achieve the set conditions. A further level of complexity within this type of operation could be to evaluate when the EES could operate in other markets/applications – e.g. when it could provide ancillary services, increasing the benefits of the installation further.

There are advantages and disadvantages associated with any method of scheduling/control, and the most appropriate method will depend on the particular applications concerned. For example, within an early stage R&D project, or when obtaining confidence of a device's operation during commissioning, manual control offers simple, adaptable control which can be set as part of a test programme. However, for a BaU deployment to manage network conditions, this level of interaction with the EES installation is likely to be overly labour intensive. Within the context of DNO applications, the type of scenario in which EES was to be deployed could influence the type of control preferred. For example, if EES was being operated to ensure network security in 'n-1' conditions (see Section 12.2.2.2) then direct control of the device by control engineers may be the preferred option. If the EES system was to be in day-to-day operation (e.g. for regular peak shaving) then a more automated system may be preferred.

The factors affecting the dispatch of energy storage can be highly variable and, in some instances, difficult to predict on a long timescale. The ability to predict generation output, demand and network conditions is important to enable storage operation to be scheduled in the optimal manner. For example, a storage device may be used in order to store excess generation at times of peak output. A forecast of when this output will occur is necessary to ensure the storage unit has sufficient capacity available to store the excess energy at the required time. In a manual configuration this 'pre-peak generation discharge' would need to be commanded by the system controller in anticipation of the high generation output. An alternative, more complex scenario could integrate a forecast of renewable generation output and the price obtained for selling the stored energy into a scheduling algorithm to ensure that the device is automatically discharged prior to the forecast peak, whilst maximising the revenue obtained for discharging the device.

A variety of approaches have been taken in the current round of demonstrations/trials, often driven by other aspects of the project (e.g. where storage is one part of a wider Smart Grid demonstration, or early-stage R&D work). These are shown in Table 11.3 below.

Table 11.3: Scheduling Approach/Operating Approach in EES Projects

Project		Scheduling Approach/Operating Regime
DNO Projects	CLNR (Northern Powergrid)	During trialling periods the unit is in operation daily and depth of discharge varies dependent on the thermal support requirement of the assets being supported (primary and secondary transformer and cables), as configured for the ANM controller trial.
	LV Connected Batteries (SSEPD)	The project was operated for the purposes of R&D (to inform a larger deployment of similar technology). The schedules are manually set for a period of time and the results recorded. The system has the capability to respond automatically to real or reactive power set points based on measurements at the substation in order to peak lop both demand and generation and also balance phases. The system can be set to run basic charge / discharge schedules to dispatch fixed power at certain times of the day to support network operation.
	Nairn Flow Battery (SSEPD)	This unit was deployed as part of an early stage trial investigating the potential use of EES on GB distribution networks. It was operated manually via a Human Machine Interface (HMI) as part of a contrived test plan.
	NINES (SSEPD)	Battery operation is primarily managed via an ANM system. At the time of writing, a Human Machine Interface (HMI) in Lerwick Power Station control room provides the means for manually scheduling the battery. In due course, the battery will be scheduled autonomously by the ANM system. The full NINES ANM system (with which the battery will be integrated) performs generation and demand forecasting, load scheduling and real time system control. The ANM system is fully integrated with the power station control system, which provides control and alarms to the local operators. This will be exploited further once new renewable generation connections connect under the NINES project.
	Orkney Energy Storage Park (SSEPD)	This system provides constraint management services to SSEPD as part of the Orkney ANM System. It is owned and operated by a 3 rd party but is available to SSEPD as a 'service' during fixed periods of time. For constraint management service (i.e. for SSEPD) the request is dispatched by the ANM system. The ANM system receives data from network monitoring points and if applicable it requests the storage to provide the service if the device is available. Outside of times when constraint management is being provided, the 3 rd party service operator decides how/when to operate (e.g. potentially based on the revenue streams available). Whilst the system is operating in any other market the output is controlled by ANM to ensure the network stays within limits. The 3 rd party has a contractual obligation to provide a response service to the DNO during the defined constraint windows and are therefore responsible for managing the system's SoC prior to the start of each window.
	Short-term discharge energy storage (UK Power Networks)	A fully autonomous system received network measurements from the distribution network and algorithms decided on the appropriate behaviour (e.g. energy import, energy export, voltage support etc.)

Project	Scheduling Approach/Operating Regime
<p>Smarter Network Storage (UK Power Networks)</p>	<p>The SNS facility has been designed to operate as autonomously as possible (across a number of applications), once configured with a portfolio of available services & network applications.</p> <p>The exact dispatch mechanism is dependent on the particular service scheduled by the 'Forecasting & Optimisation System' (FOSS), as follows:</p> <ul style="list-style-type: none"> • Peak shaving is scheduled, based on a site-specific demand forecast, which is carried out on a range of timescales. If site demand is forecasted to exceed firm capacity, the peak shaving mode is scheduled for this period, including any pre-charge needed to cover the estimated energy required. During this mode, the on-site battery management system then reacts to measured demand at site, dispatching the storage in real time to maintain overall site demand below the firm capacity threshold. • When there is forecast headroom available, the FOSS system performs an optimisation to determine the best combination of services from the available portfolio to maximise the value from the storage facility. • Depending on the services selected and scheduled, the following other dispatch mechanisms are supported: <ul style="list-style-type: none"> ○ Automatic dispatch based on local frequency measurement ○ Automatic dispatch based on measured voltage or reactive power ○ Dispatch via messaging system by Aggregator's control room system ○ Manual/scheduled dispatch to provide tolling contracts, TRIAD avoidance and future applications. <p>The operating philosophy is based around the site-specific demand forecast, which prioritises the need for peak shaving to maintain security of supply. Periods when peak shaving is needed are effectively reserved and sufficient energy automatically charged into the storage to cover the peak. A safety margin can be factored in to account for the error margin in the forecasting.</p>
<p>FALCON (WPD)</p>	<p>These units are controlled via proprietary software which provides local and remote dispatch of manual or time scheduled charge/discharge or advanced control functions of peak shaving, voltage control and frequency control.</p>
<p>Sola Bristol (WPD)</p>	<p>The operation of this in-home battery system is managed based on PV output, network conditions, the SoC and a time of use tariff. How often any given system charges and discharges is dependent on the individual properties demand and generation profile, coupled with the network requests and tariff information.</p> <p>The system is capable of managing and maintaining the SoC of the batteries by exporting to the grid on demand. Commands to charge/discharge based on network conditions depend on on voltage levels (statutory limits).</p> <p>Network related tariff based information is also used to manage the battery SoC.</p>

Project		Scheduling Approach/Operating Regime
DECC Funded Demonstration	REDT – Gigha VRFB Project	<p>The output of the fourth wind turbine on Gigha is constrained to an output of 225kW (relative to an accredited maximum of 330kW). Charging/discharging of the VRFB is therefore determined by the output of the fourth wind turbine.</p> <p>The prime operation of the VRFB system will be to ‘unconstrain’ the fourth turbine. When the wind speed is high and the turbine output is greater than 225kW (and up to 330kW), the control system will instruct the VRFB to start charging from the ‘constrained energy’ that would, otherwise, be lost (wind turbine output curtailed).</p> <p>When wind speed weakens and power generation at the site reduces, the control system will instruct the VRFB to export its stored energy through the grid connection when such opportunity permits.</p>

This demonstrates the range of ways in which storage can be scheduled and dispatched, based on generation output, network conditions (both thermal and voltage issues and the requirement for transmission system balancing services) and ‘customer side of the meter’ considerations such as time-of-use tariffs.

11.3 Benefits of EES Operation – Case Studies

The sections above outline the applications which the current round of trials and demonstrations are addressing, and how the operation of EES will be scheduled in each case. The case studies below show the resulting benefits from the operation of EES in the UK. These examples have been chosen in order to demonstrate a range of applications and are based on information available at the time of writing. The majority of the projects which form the case studies used to inform this Guide are currently ongoing and further results will be published in due course. Section 15 contains references for the majority of the projects, where results will be published in the future.

The case studies below describe:

- **Case Study 1:** Peak shaving using a 1 MW/3 MWh Pb-Acid battery (SSEPD NINES project);
- **Case Study 2:** Peak shaving using a 2.5 MVA/5 MWh Li-Ion battery (Northern Powergrid CLNR project);
- **Case Study 3:** Voltage regulation using real and reactive power from a 200 kW/200 kWh Li-Ion battery (UK Power Network’s Hemsby project);
- **Case Study 4:** Voltage control on an LV feeder using real and reactive power from a 50 kW/100 kWh Li-Ion battery (Northern Powergrid CLNR project);
- **Case Study 5:** Reduction in losses by reducing neutral current (SSEPD LV Connected Batteries project); and
- **Case Study 6:** Operation based on frequency by a 50 kW/100 kWh high temperature sodium battery system (WPD’s FALCON project).

Case Study 1: NINES – Peak Shaving¹⁴⁸

Project Name: Northern Isles New Energy Solutions (NINES) **DNO:** SSEPD

Network Location: Connected to 11kV network at Gremista primary substation, Lerwick.



Project Description: This project demonstrates the operation of a 1MW/3MWh VRLA Pb-Acid battery, deployed as part of a wider Smart Grid trial. The system is intended to inform the strategy to replace Lerwick Power Station, and will provide peak shaving, frequency response (on Shetland’s island network), voltage support and allow the connection of additional renewable generation.

Application Demonstrated in Case Study: Peak shaving



A charge/discharge schedule for the 1MW/3MWh system on Shetland was developed following a study of network demand on the island. Operation during the summer is outlined above, whereby the system discharges to support higher demand during peak times (07:30 to 08:30, 12:30 to 13:30 and 16:30 to 17:30). In each period the system discharges 1MWh of energy, before charging up overnight, when demand is low. Charging is completed using a three-tiered approach (1MW to 80% SoC, 0.66MW from 80 to 90% SoC and 0.33MW from 90 to 100% SoC).

The impact of this charge/discharge cycle is shown on the demand curve above, with a reduction in the peak demand (when thermal generation output would otherwise have been ramped up to service demand) and a small increase overnight. Analysis of winter demand indicates that the battery will be able to reduce the peak lunchtime demand in winter by 1MW for the duration of the peak.

¹⁴⁸ Demand curve obtained from: LCNF Tier 1 Close-Down Report. 1MW Battery, Shetland. SSET1001. July 2014. Available from: <https://www.ofgem.gov.uk/ofgem-publications/89496/sset10011mwbatterysketland-closedownreport20141.1.pdf> Accessed 06/10/2014

Case Study 2: Customer Led Network Revolution – Powerflow Management (Peak Shaving)

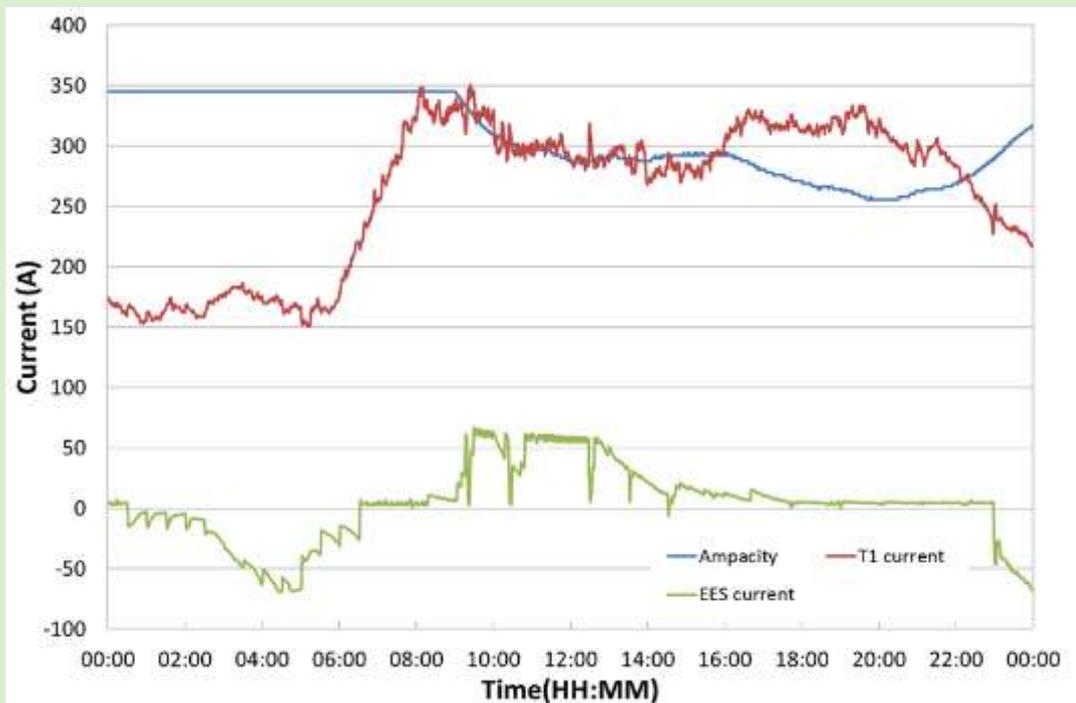
Project Name: Customer Led Network Revolution – EES1 (Rise Carr) **DNO:** Northern Powergrid

Network Location: Connected to a 6kV primary substation bar at Rise Carr, Darlington.

Project Description: This project involved multiple EES devices interacting, and controlled within a large Smart Grid trial. EES1 is a 2.5MVA/5MWh Li-Ion storage unit. The units were dispatched via both local and central control systems during the trial. Applications trialed include peak shaving, voltage support and thermal support of the distribution transformer, HV underground 6kV feeder and demand reduction.



Application Demonstrated in Case Study: Peak shaving at a primary transformer



In this example, EES1 was used to ensure that the current supplied by the transformer did not exceed a maximum ampacity of 345A (1.5 times its static rating of 230A).

From 00:00 to 06:00 the demand on the transformer (red trace) did not exceed the thermal limit (blue trace) and the unit charged in preparation for use during the day. The first persisting overload occurred at 9:00 and the system discharged to ensure the transformer current remained below its ampacity. The unit continues to discharge to reduce the load throughout the morning and early afternoon. During the second excursion at 16:00 the SoC of the battery had reached its lower limit and so the load was not supported. After 23:00 the EES unit charges.

Post-trial analysis of the data has been completed by Newcastle University to calculate the number of additional low carbon technologies which could be connected, without exceeding the rating of the transformer in N-1 conditions. This analysis showed that the deployment of EES1 (2.5MVA/5MWh) to the 23MVA primary transformer could support the connection of around 1500 additional EVs and 500 air source heat pumps

Case Study 3: Short Term Discharge Energy Storage (Hemsby) – Voltage Regulation¹⁴⁹

Project Name: Demonstrating the Benefits of Short-Term Discharge Energy Storage on an 11kV Distribution Network

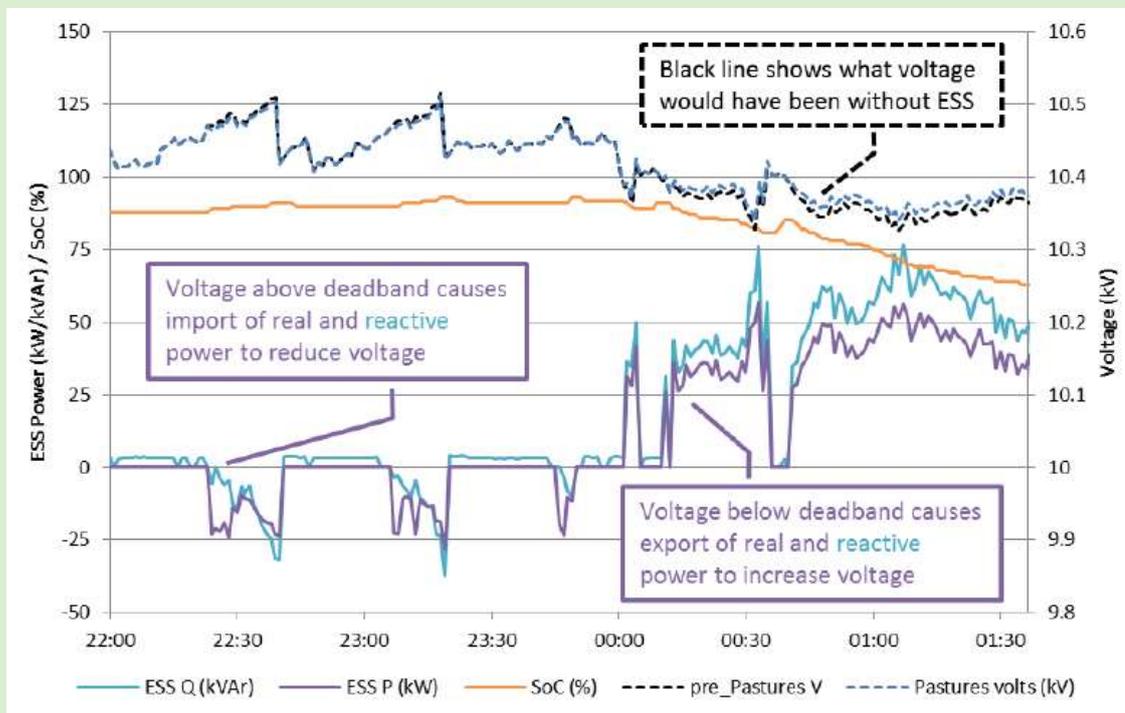
DNO: UK Power Networks

Network Location: Connected to an 11kV normal open point supplied by Martham and Ormesby primary substations



Project Description: This project was the first DNO battery energy storage project installed as part of the LCN Fund. The 200kW/200kWh Li-Ion system was used to carry out peak shaving, wind farm output regulation, voltage support and aggregated demand reduction.

Application Demonstrated in Case Study: Voltage regulation in response to voltage measurement at far end of feeder



A control algorithm was used to read voltage at a secondary measurement location ('Pastures', furthest point from the EES device) and determine EES set point to control this voltage. The graph above illustrates the use of the system to control voltage at the end of the feeder using both real and reactive power. Trial and model data indicate that in the case of Hemsby/Pastures each 10kW of imported or exported real power affects the voltage 0.04%. Small changes in voltage were deliberately requested in order to introduce measurable effects without significantly disturbing normal network operation.

¹⁴⁹ Results reported in LCNF Tier 1 Close-Down Report. Demonstrating the benefits of short-term discharge energy storage on an 11kV discharge network. UK Power Networks. Version 1.1. 6 June 2014. Available from: <http://innovation.ukpowernetworks.co.uk/innovation/en/Projects/tier-1-projects/demonstrating-the-benefits-of-short-term-discharge-energy-storage/Project-Documents/Shor-term+discharge+energy+storage+closedown+report.pdf> Accessed 07/10/2014

Case Study 4: Customer Led Network Revolution (EES3) – Voltage Control

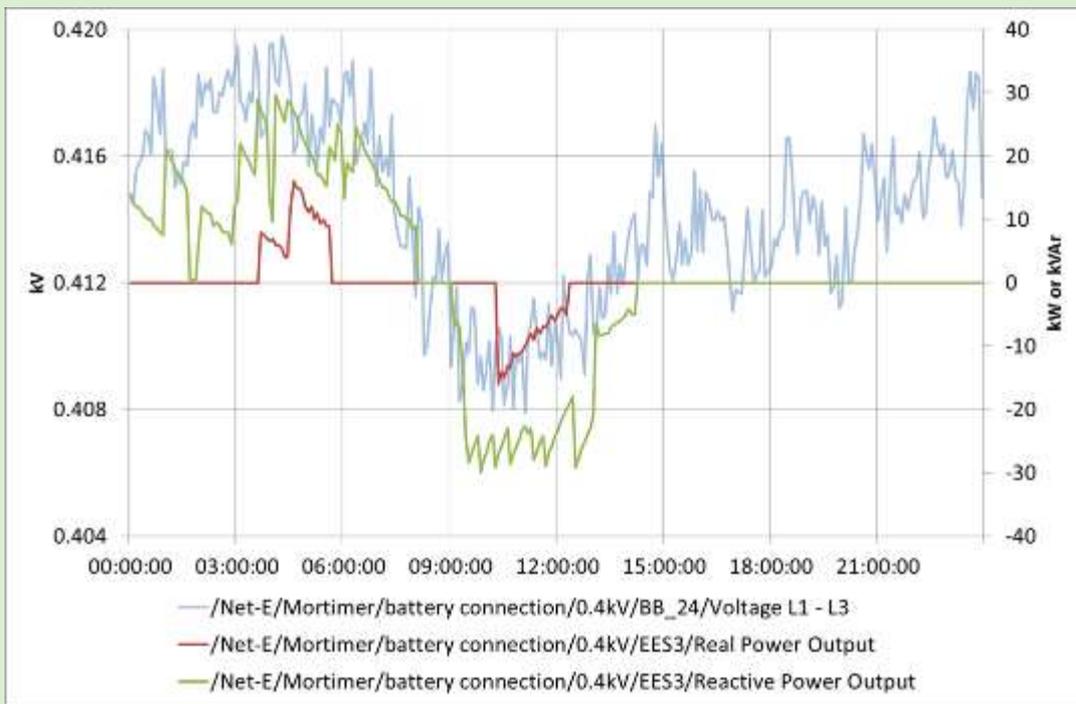
Project Name: Customer Led Network Revolution – EES3 (Maltby) **DNO:** Northern Powergrid

Network Location: Connected to an LV network with large amounts of PV generation.

Project Description: This project involved multiple EES devices interacting, and controlled within a large Smart Grid trial. EES 3 is a 50kVA/100kWh unit. The units were dispatched via both local and central control systems during the trial. Applications trialed include peak shaving, voltage support and thermal support of the distribution transformer, HV underground 0.4kV feeder and demand reduction.



Application Demonstrated in Case Study: Voltage Control using real and reactive power



In this example, the EES3 was used within a local control loop to manage voltage to within very tight limits. The controller was set to use reactive power in the first instance to resolve voltage issues as this does not alter the SoC of the battery (i.e. leaving real power available to manage any thermal issues).

During the morning period (approx. 7:00 onwards) the voltage decreased. From 9:00, first reactive then real power was dispatched in order to increase the voltage beyond 412V.

Case Study 5: LV Connected Batteries – Reduction in losses due to neutral current¹⁵⁰

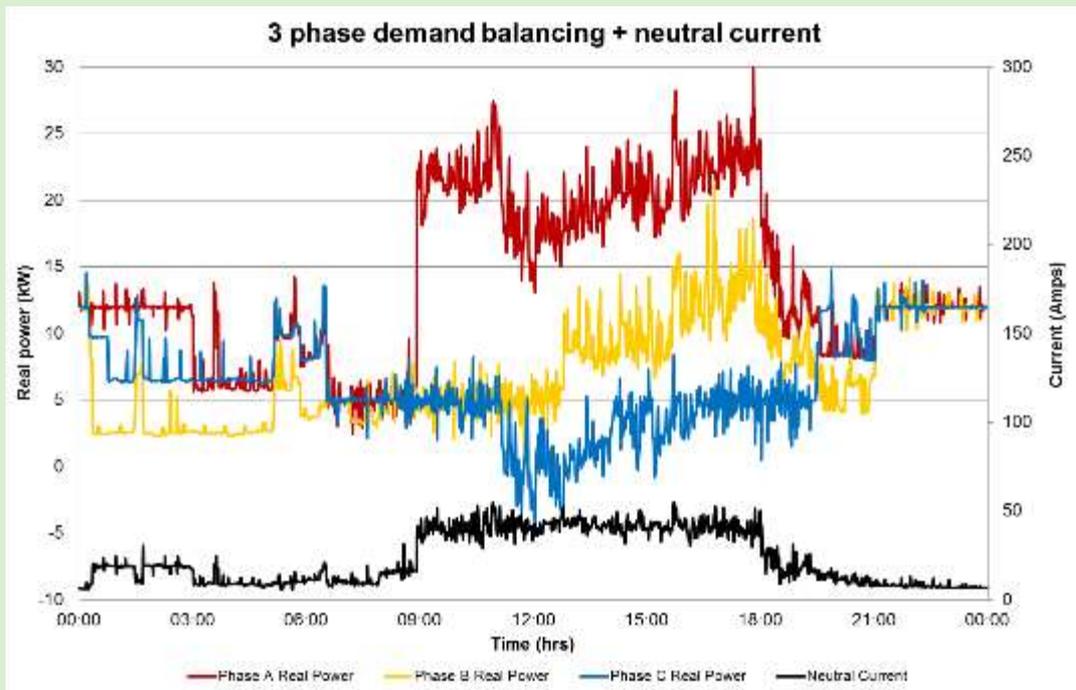
Project Name: LV Connected Batteries **DNO:** SSEPD

Network Location: “T” connection off LV Feeder

Project Description: This project demonstrates the operation of a fleet of LV connected energy storage units (3 x single phase 25kW/25kWh Li-Ion batteries) with renewable generation. During the testing of the units the use of the EES devices for peak shaving, solar power absorption, voltage support, phase balancing and aggregated demand reduction was demonstrated.



Application Demonstrated in Case Study: Reduction in losses due to neutral current (via phase balancing)



In this example, the EES device on Phase A was discharged between 6:30 and 9:00, reducing the imbalance between the phases. At 9:00 the EES device stops discharging, demand on Phase A increases, thus increasing the imbalance and the neutral current. The units were charged after 21:00, balancing demand on the three phases, and lowering the neutral current. This reduction in neutral current leads to lower losses. In a three phase system with the ability to transfer power between phases (i.e. three phase inverter) the EES device could be used to balance the phases throughout the day, further reducing losses.

¹⁵⁰ LCNF Tier 1 Closedown Report. Low voltage Connected Energy Storage. SSET1008. SEPD. Available from: <https://www.ofgem.gov.uk/ofgem-publications/89553/sset1008lvconnectedbatteriesclosedown2ndsubmission.pdf> Accessed 22/10/2014

Case Study 6: FALCON – Frequency Regulation

Project Name: FALCON **DNO:** WPD

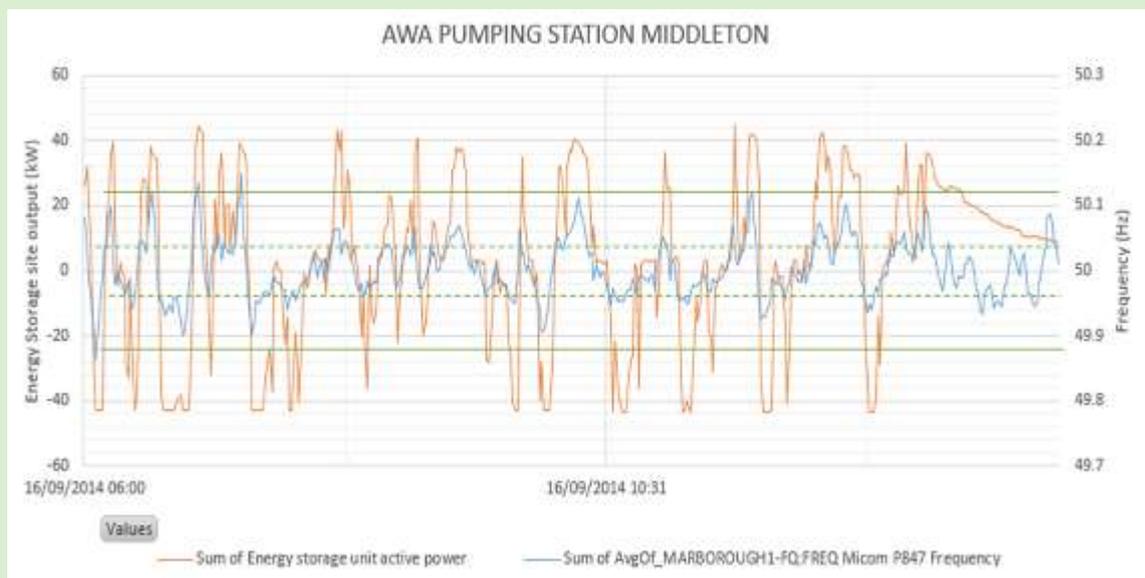
Network Location: Connection to existing LV distribution board

Project Description: This project is the first deployment of Sodium Metal Halide batteries in the UK. Five, three phase 50kVA/100kWh units are being deployed as part of a wider Smart Grid trial (FALCON).

Applications being trialled include peak shaving and voltage support via manual and time/day/date scheduled charge/discharge of real and reactive power.



Application Demonstrated in Case Study: Frequency Regulation



The chart above shows early operational experience of frequency regulation using the inverter and battery unit installed as part of FALCON, and frequency measured elsewhere on the network.

The EES units begin to charge (orange trace) when the frequency (blue trace) exceeds 50.04Hz (the upper dashed green line). Conversely, the EES unit discharges when frequency falls below 49.96Hz (low dashed green line). The output from the EES device is proportional to the difference between the measured frequency and the dead band boundary.

Frequency regulation is disabled to the far right of the chart as the system is charged up, at progressively slower rates.

12 Costs and Benefits of EES Systems

Sections 12 and 13 together provide an introduction to the costs and benefits (revenue streams) of owning/operating EES and how this information can be used to develop a financial justification for progressing with an installation.

The financial justification for a given EES installation will depend on various factors, including:

- The cost of procuring, installing, operating, maintaining and, ultimately, de-commissioning the system, over the course of its life;
- The benefits which the system can provide (as discussed in Section 11) and the resulting revenue stream/monetary value of these benefits; and
- The ability of the owner of the storage system to access the various revenue streams which can be provided by the system.

The resulting cost:benefit analysis can also be compared with results from other solutions (where available/suitable) to determine the optimum course of action.

The present section first outlines some cost data for a number of EES technologies, and then describes the various revenue streams available to owners/operators of EES devices. Section 13 describes methods for combining this information via a cost:benefit analysis and presents a number of examples, based on the case studies provided in Appendix 1.

12.1 Costs of EES Systems

The cost of owning/operating an EES system is dependent upon a wide variety of factors. This section aims to provide an introduction to these factors, and some indicative values of the cost of different EES technologies.

The total cost of purchasing, installing and operating an EES system depends on a number of factors, including:

- **Technology choice:** the cost of energy storage technologies vary, as shown in the various sub-sections below. This variation may be due to factors such as the raw materials involved, manufacturing costs and the commercial maturity of the product. However, the technology employed in a given project will be a function of a number of factors, such as: the duty cycle requirements, footprint available, desired lifetime and budget available (e.g. based on projected revenues). These factors will form part of the procurement specification, and this subject is explored in more detail in Section 7. A thorough assessment process should therefore take place during the development of specifications/screening of tender responses to balance the initial system costs with the applications required and system life-time. A procurement process may be 'technology agnostic', whereby a prospective EES owner/operator specifies response characteristics, lifetime, dimensions etc., without defining which technology is required. This is the approach taken by the DNOs throughout the projects described in Appendix 1.
- **System size/rating:** the cost of a system will vary according to both the power rating and capacity. The nature of the relationship between cost and rating, and cost and capacity, is dependent upon the technology type. For example, increasing the capacity (MWh) of a flow battery or thermodynamic system involves an increase in the storage volume (tanks) and quantity of electrolyte/storage medium, with no impact on the rating (MW) of the system. When sizing a system a balance must be

struck between the required rating/capacity to provide the necessary functionality, and the system cost. In some cases it may be possible to design in a degree of modularity or expansion space, such as to allow for future requirements, whilst minimising the upfront costs.

- **Site issues:** the particular site chosen will affect the cost of civil engineering works required. These issues are explored in greater detail in Section 8. The system enclosure type could also affect these costs. For example, in some locations a containerised system could be used, allowing for minimal on-site building work (beyond the preparation of foundations and ground, any plinths etc.). In other areas, a purpose built building may be necessary, increasing the building work required at site and therefore the costs. If spare land is not available then the cost of acquiring a suitable site should be included within the project costs. The quantity of land required will depend on the technology, due to variations in energy density and footprint.
- **Commissioning:** costs are likely to be involved in the commissioning of the system, for example the integration of the EES unit with wider control systems, and testing these interfaces. Commissioning of EES systems is described in more detail in Sections 7.7 and 8.5.
- **Cost of Operation and Maintenance:** The costs of operating and maintaining systems will depend on various factors: technology choice, system supplier, design implementation, insurance requirements, security, warranty arrangements and the nature of any support contract implemented. A number of options may be available for the maintenance of the system, ranging from the owner taking responsibility for this and procuring parts from the manufacturer when required, to taking out a maintenance agreement with the supplier. Each technology has an element of 'losses' in the form of the round-trip efficiency and parasitic losses (e.g. from air conditioning units and self-discharge). The cost of the energy required to supply these losses should be included within the operational costs.
- **Connection to Network:** the cost of connection to the distribution network will include elements such as a step-up/isolation transformer and protection. For 3rd parties installing an EES system the cost of connection will vary according to the network location and any reinforcement required (similar to other generation technology). The cost of this connection can be obtained via an application to the relevant DNO.
- **Auxiliary Systems/Balance of Plant:** the cost of auxiliary systems/Balance of Plant should be included within the calculation of total project costs. This may include heating, ventilation and air conditioning loads or safety systems. The ongoing costs of these systems should also be included within the O&M costs, as described above.
- **Project Management:** considerable labour costs are likely to be involved in project planning and oversight. Elements of these costs will scale according to the complexity of the system, but may include time spent on the procurement exercise, system and site design, liaison with 3rd parties such as the DNO, emergency services and local council, oversight of installation health and safety (e.g. employing a CDM co-ordinator, where necessary) and setting up relevant contracts to pursue the various revenue streams outlined in Section 12.2.2. These costs may decrease as the industry gains familiarity with deploying EES equipment.
- **Decommissioning and Disposal:** At the end of the systems lifetime, it will require some form of decommissioning and disposal. The Waste Batteries and Accumulators Directive (see Section 6.2.1) puts an obligation on suppliers to provide a 'take-back' facility for batteries at the end of their life, but this can involve a cost. There may also be cost associated with returning the site to its previous condition. Depending on the ownership/arrangements with the system supplier, the EES owner may be able to recoup some of the value of the battery, via the recycling chain.

Some of the costs above are only relevant to owner/operators of EES systems, whilst others will also be incurred by those who procure an EES service. The various business models for energy storage systems are explored in greater detail in Section 12.3.

Indicative, budgetary, cost estimates for EES systems may be derived via various means, including:

- Experience based on previous projects, with an allowance made for experience gained and improvements/cost reduction in the reference technology;
- Informal dialogue with suppliers;
- Published information and data; and
- The application of “bottom-up” parametric costing methodologies.

However, true costs/price data will only become apparent when the market is tested via the execution of a formal procurement process. The prices/tender responses received will reflect the realities of a competitive supply base, with individual vendors choosing to price their offerings, based upon their interpretation of the requirements and market conditions.

Clearly, price data of this form is highly proprietary and not readily available to a general readership. The following sections will therefore utilise indicative system cost data, as sourced from EPRI/DOE publications on the subject. Whilst such costings are in no way intended to substitute for sourcing “true” system costings (e.g. via a procurement process) they do provide a basis for the illustrative development of the cost:benefit case.

Research into the cost of various EES technologies has been undertaken by Sandia National Laboratories and EPRI in the United States¹⁵¹. This research was based on dialogue with more than 50 battery original equipment manufacturers (OEMs), power electronics system providers and system integrators. A survey was undertaken in relation to performance, cost and O&M data for energy systems to be used for various uses of storage. Various metrics are provided within the document including the installed cost (\$/kW), levelised cost of capacity (\$/kW-yr), levelised cost of energy (LCOE) (\$/MWh), present value of lifecycle costs (based on rating, i.e. \$/kW installed) and present value of lifecycle costs (based on capacity i.e. \$/kWh installed). These metrics can be used for various purposes, and further details are provided within Appendix B of the DOE/EPRI Electricity Storage Handbook.

The focus of the current section of this GPG is on providing an indicative cost of various energy storage technologies. The revenue from the operation of these storage devices could then be calculated via consideration of different revenue streams and various cost:benefit analysis techniques (see Section 13). The relevant metrics presented are therefore:

- **Present value of life-cycle costs (\$/kW Installed):**
 - Includes the installed costs (i.e. all equipment, delivery, installation, interconnection and step-up transformer costs);
 - Includes ongoing fixed and variable operating costs;
 - Excludes the cost of land, permitting and project planning; and
 - The present value of the annual costs is divided by the kW of energy storage discharge rating installed.

¹⁵¹ DOE/EPRI 2013 Electricity Storage Handbook in Collaboration with NRECA. Sandia Report. SAND2013-5131. Unlimited Release. July 2013. Available from: <http://www.sandia.gov/ess/publications/SAND2013-5131.pdf> Accessed 26/10/2014.

- **Present value of life-cycle costs based on capacity (\$/kWh installed):**
 - The present value of life-cycle costs described above, divided by the usable kWh of energy storage capacity installed.

The present value of lifecycle costs are designed to be compared against corresponding estimates of present value benefits or revenues to estimate the cost-effectiveness of an individual technology for a specific application. Actual costs at specific sites will vary considerably from the estimates provided here. However, they provide useful indicative figures – for example, how a low cost, less efficient storage technology compares to a higher-cost, more efficient technology.

Total costs (equipment only, rather than ‘whole life’ costs) are provided in Appendix 5.

Sandia/EPRI provide confidence factors for each cost estimate, depending the maturity of the technology, these are defined in Table 12.1, and indicated against each technology figure in the sub-sections below.

Table 12.1: Confidence Rating of Cost Estimates¹⁵²

Confidence Rating	Key Word	Description
A	Actual	Data on detailed process and mechanical design or historical data from existing units
B	Detailed	Detailed process design
C	Preliminary	Preliminary process design
D	Simplified	Simplified process design
E	Goal	Technical design/cost goal for value developed from literature data

The following sub-sections present indicative costs for the various technologies within the scope of this GPG. It should be noted that the figures below comprise a single estimate, and the actual costs from any given supplier (including as part of the case studies within this Guide) may fall outside of the range presented. A distinction is made in the sections below between battery and flow battery systems and thermodynamic energy storage. This is due to differences in the data source used (US/DOE estimates, described above and manufacturers’ data), rather than any preference for a particular technology.

12.1.1 Battery and Flow Battery Systems

The assumptions and confidence ratings (see Table 12.1) used for each technology are as follows:

- **Pb-Acid:** A number of variants of Pb-Acid technologies exist, as discussed in Section 4.1 and Appendix 3. Cost estimates are provided for advanced Pb-Acid systems from a number of suppliers in different applications. A ‘Confidence Factor’ of D is provided.
- **High Temperature Sodium:** A number of variants of high temperature sodium battery systems are available, each currently available from a single vendor. Costs for different applications are presented within the Sandia/EPRI research for Sodium Sulphur and Sodium Nickel Chloride (ZEBRA) systems. A ‘Confidence Factor’ of A and D is provided for Sodium Sulphur and Sodium Nickel Chloride respectively, due

¹⁵² Reproduced from Table 3. DOE/EPRI 2013 Electricity Storage Handbook in Collaboration with NRECA. Sandia Report. SAND2013-5131. Unlimited Release. July 2013. Available from: <http://www.sandia.gov/ess/publications/SAND2013-5131.pdf> Accessed 26/10/2014

to the number of commercial systems deployed to date. At the time of writing cost data is not available for the Sodium Metal Halide system.

- **Li-Ion:** A wide variety of Li-Ion systems exist, with differing properties. These are described in more detail in Appendix 3, Section A3.1.4.1. The technological maturity of the variants of Li-Ion differs, however, Sandia/EPRI apply a 'Confidence Factor' of C to the figures below.
- **Flow Batteries:** Section 4.2 outlined a number of flow battery technologies. These technologies are at varying stages of development and deployment. At the time of writing, 99% of the total capacity of flow batteries installed worldwide were based on either the Vanadium:Vanadium or Zinc:Bromine variant (see Table 4.3). This subsection therefore provides illustrative costs for these two technologies. Sandia/EPRI apply a 'Confidence Factor' of C to the figures below for both V:V and ZnBr.

Table 12.2: Present Value Lifecycle Costs of Battery and Flow Battery Technologies¹⁵³

Technology	Application	Low Estimate		Median Estimate		High Estimate	
		Rating/ Capacity	Present Value (\$/kW Installed Cost)	Rating/ Capacity	Present Value (\$/kW Installed Cost)	Rating/ Capacity	Present Value (\$/kW Installed Cost)
Pb-Acid ¹⁵⁴	Bulk	50MW 5 hours	3,500	Average of 100MW, 4 hours and 50MW, 5 hours	8,100	20MW, 6 hours	10,500
	Frequency Regulation	1MW, 0.25 hours	2,500	1MW, 0.5 hours	3,650	1MW, 1 hour	6,150
	Utility T&D	1MW, 1 hour	4,150	Average of 1MW, 4 hours and 1MW, 4 hours (2 vendors)	8,900	20MW, 6 hours	10,700
Sodium Sulphur ¹⁵⁵	Bulk	50MW, 6 hours	5,750	<i>(2 estimates only)</i>		100MW, 7.2 hours	6,100
	Utility T&D	12MW, 7.2 hours	6,100			1MW, 7.2 hours	6,550
Sodium Nickel Chloride ¹⁵⁶	Bulk	50MW, 5 hours	5,000			53MW, 5 hours	8,000
	Utility T&D	1MW, 4 hours	5,000			1.2MW, 5 hours	10,050
Li-Ion ¹⁵⁷	Utility T&D	3MW, 1 hours	2,300	3MW, 4 hours	9,100	10MW, 3 hours	11,300
	Frequency Regulation	1MW, 0.25 hours	1,900	Average of 12MW, 0.25 hours and 100MW, 0.25 hours	3,000	1MW, 1.2 hours	7,500
Vanadium: Vanadium Flow Battery ¹⁵⁸	Utility T&D	1.2MW, 3.33 hours	6,000	10MW, 4 hours	6,200	10MW, 5 hours	7,100
ZnBr Flow Battery ¹⁵⁹	Utility T&D	2MW, 2 hours	3,400	Average of 10MW, 5 hours and 1MW, 5 hours	4,450	1MW, 2 hours	5,800

¹⁵³ DOE/EPRI 2013 Electricity Storage Handbook in Collaboration with NRECA. Sandia Report. SAND2013-5131. Unlimited Release. July 2013. Available from: <http://www.sandia.gov/ess/publications/SAND2013-5131.pdf> Accessed 26/10/2014

¹⁵⁴ Figures 74, 77 and 80. See Footnote 153.

¹⁵⁵ Figure 35. See Footnote 153.

¹⁵⁶ Figure 41. See Footnote 153.

¹⁵⁷ Figures 101 and 104. See Footnote 153.

¹⁵⁸ Figure 47. See Footnote 153.

¹⁵⁹ Figure 58. See Footnote 153.

12.1.2 Thermodynamic Systems

Two different thermodynamic energy storage systems are described within Section 4.3 – LAES and PHES (see also Case Studies A1.16 and A1.18). Within the UK, each of these technologies is being developed by a single vendor, and both are at a relatively early stage of commercial deployment.

- **Liquid Air Energy Storage:** To date, a pilot plant has been deployed in Slough (350kW, 2.5MWh) and a pre-commercial demonstrator has been funded by the DECC Energy Storage Technology Demonstration competition. A cost calculator is available from the manufacturer¹⁶⁰ which takes account of charge and discharge durations, system rating, integration with other systems (e.g. provision of waste heat/cold) and number of systems. This provides an estimate of the capital expenditure required, cost per kilowatt and cost per kilowatt-hour.
- **Pumped Heat Energy Storage:** PHES is being developed in the UK by Isentropic and is currently in receipt of funding from the ETI to develop two systems. The first is a Scaled Validation System (SVS) (200kVA, 600kVAh) and the second a Field Test Article (FTA) (1.4MVA, 5.6MVAh). The project case study in Appendix 1 quotes a target cost of \$200 per kWh (≈£130/kWh). A report (publicised by the system developer)¹⁶¹ on larger scale (over 100MW) Isentropic PHES design has concluded that the system would have a cost of \$103/kWh (≈£66/kWh).

12.2 Benefits of EES and Capturing the Revenue Streams

12.2.1 Storage Applications and Functionalities

The various potential applications of network connected EES are outlined in Section 3 and Appendix 2. Some of these relate to a need to increase the capacity of electricity networks (e.g. because of the forecast electrification of heat and transport). Others are due to a requirement for additional flexibility within the GB electricity system (e.g. needed because of increasing amounts of non-dispatchable generation). This section explores the ability of EES systems to capture these various revenue streams. It has been informed by work from various LCN Fund projects, particularly UK Power Network's Smarter Network Storage¹⁶².

Some of the applications below can also be serviced by other solutions – both conventional (e.g. reinforcing the distribution network by increasing the rating of transformers and cables/overhead lines (OHL)) and 'smart' (e.g. DSM, increased inter-connection, flexible demand or ANM schemes).

The ability of these competing solutions to provide flexibility is illustrated in Figure 12.1 below.

¹⁶⁰ <http://www.highview-power.com/cost-estimator/> Cost Estimator. Highview Power Storage. [Online]. 26/10/2014

¹⁶¹ New electricity storage technique developed by Isentropic Ltd to cost less than 30% of Pumped Hydro Storage. Isentropic [Online]. Available from: <http://www.isentropic.co.uk/news/77/66/New-electricity-storage-technique-developed-by-Isentropic-Ltd-to-cost-less-than-30-of-Pumped-Hydro-Storage> Accessed 26/10/2014

¹⁶² Smarter Network Storage Low Carbon Network Fund. Electricity Storage in GB: SNS4.13 – Interim Report on the Regulatory and Legal Framework. UK Power Networks. Available from: [http://innovation.ukpowernetworks.co.uk/innovation/en/Projects/tier-2-projects/Smarter-Network-Storage-\(SNS\)/Project-Documents/Smarter-Network-Storage-LCNF-Interim-Report-Regulatory-Legal-Framework.pdf](http://innovation.ukpowernetworks.co.uk/innovation/en/Projects/tier-2-projects/Smarter-Network-Storage-(SNS)/Project-Documents/Smarter-Network-Storage-LCNF-Interim-Report-Regulatory-Legal-Framework.pdf)



Figure 12.1: Provision of Flexibility to Electricity Networks¹⁶³

As shown in Section 4 (and in particular Figure 4.1) different storage technologies have different technical characteristics, in terms of both their rating and capacity. These technical characteristics then govern the applications which can be provided by the EES system. For example:

- **Flywheel energy storage systems:** although out of scope of the present publication, these systems are able to respond quickly and provide significant amounts of power (10kW to 1MW range), but only for a short duration (tens of seconds/minutes). They are therefore best suited to mitigating short term power quality issues and for uninterruptible power supplies.
- **Battery energy storage systems:** various types of battery technology have been installed by GB DNOs (see Table 4.1). When deployed at utility scale they can provide a rating from tens of kW to multiple MW, for a small number of hours. They can therefore be used to provide short term responses such as uninterruptible power supplies and applications on transmission and distribution networks (e.g. thermal support during times of peak load).
- **Pumped hydroelectric energy storage:** also out of scope of the present publication, these systems provide large amounts of power (hundreds/thousands of MW) for multiple hours. For example, Dinorwig pumped hydro station can provide 1.7GW of power for five hours¹⁶⁴. This type of technology has the potential to be used to provide bulk power management.

The choice of technology strongly affects the results of the cost:benefit analysis for a particular project. Technology costs (e.g. £/kWh) vary for a number of reasons (cost of raw materials, competition within the market etc.), as demonstrated in Section 12.1 above. The

¹⁶³ Figure reproduced from: Smarter Network Storage Low Carbon Network Fund. Electricity Storage in GB: SNS4.13 – Interim Report on the Regulatory and Legal Framework. UK Power Networks. Available from: [http://innovation.ukpowernetworks.co.uk/innovation/en/Projects/tier-2-projects/Smarter-Network-Storage-\(SNS\)/Project-Documents/Smarter-Network-Storage-LCNF-Interim-Report-Regulatory-Legal-Framework.pdf](http://innovation.ukpowernetworks.co.uk/innovation/en/Projects/tier-2-projects/Smarter-Network-Storage-(SNS)/Project-Documents/Smarter-Network-Storage-LCNF-Interim-Report-Regulatory-Legal-Framework.pdf)

¹⁶⁴ <http://www.electricmountain.co.uk/en-GB/Dinorwig> Accessed 13/10/2014

resulting benefits are also dependent upon the applications which can be fulfilled, which are also influenced by the technology choice, as shown above.

12.2.2 Revenue Streams

The potential revenue streams which could be accessed via the operation of an EES system relate to different entities within the electricity supply chain, this is shown visually in Figure 12.2¹⁶⁵.

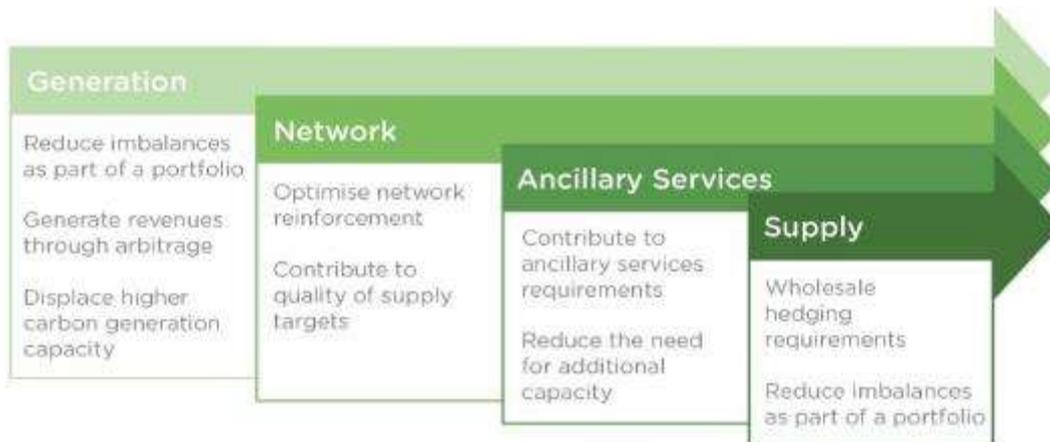


Figure 12.2: EES Applications Across the Value Chain (Source: UK Power Networks)

The table below summarises different potential revenue streams, the relevant entity within the electricity supply chain and the case studies which are investigating this revenue stream.

Table 12.3: Summary of Revenue Streams

Revenue Stream	Relevant To?	Regulated/Non-Regulated Business?	Relevant Case Studies
Arbitrage (see Section 12.2.2.1)	Energy suppliers Generators	Non-regulated	Smarter Network Storage (via 3 rd party); REDT Demonstration
Avoidance of imbalance charges (Section 12.2.2.1)	Energy suppliers Generators	Non-regulated	None to date.
Reduced expenditure on network reinforcement (Section 12.2.2.2)	DNO	Regulated	CLNR (all units); LV Connected Storage; NINES; Orkney; Hemsby; Smarter Network Storage; FALCON; SolaBristol; Isentropic Demonstration.
Improved quality of supply (Section 12.2.2.2)	DNO	Regulated	CLNR (all units); LV Connected Storage; NINES; Hemsby; Smarter Network Storage; FALCON; SolaBristol; Isentropic Demonstration.
System Balancing Services e.g. Short Term Operating Reserve, Frequency Response etc. (Section 12.2.2.3)	TSO Aggregators Demand Side Response providers	Non-regulated	Smarter Network Storage (via a 3 rd party); Highview Demonstration.

¹⁶⁵ Adapted from Figure 15 within SNS Report (see Footnote 166)

Revenue Stream	Relevant To?	Regulated/Non-Regulated Business?	Relevant Case Studies
Capacity Market (Section 12.2.2.4)	Aggregators Demand side response providers	Non-regulated	N/A – 1 st Capacity Market auction to be held December 2014 for delivery from October 2018 onwards.
Maximising the use of on-site generation for 'customer side of the meter' installations (Section 12.2.2.5)	Customers (Industrial, Commercial and Domestic)	Non-regulated	SolaBristol.
Use as an Uninterruptible Power Supply/Standby Generation (Section 12.2.2.5)	Customers (Industrial, Commercial and Domestic)	Non-regulated	SolaBristol
Reduction of network charges, including triad avoidance (Section 12.2.2.5)	Customers (Industrial and Commercial)	Non-regulated	Smarter Network Storage; Highview Demonstration
Minimising the cost of connection (Section 12.2.2.5)	Customers (Industrial and Commercial)	Non-regulated	None to date
Minimising energy consumption at times of peak prices (Section 12.2.2.5)	Customers (Industrial, Commercial and Domestic)	Non-regulated	None to date
Removing constraints for renewable generation (Section 12.2.2.6)	Generators	Non-regulated	REDT Demonstration.

Within the UK the sources of revenue can come from regulated businesses (e.g. a DNO) and non-regulated or market arrangements (e.g. energy trading). This is shown for each revenue stream as part of Table 12.3. The nature of the business (regulated or non-regulated) providing the revenue stream affects the business case for storage¹⁶⁶:

- **Storage predominately for regulated businesses (e.g. capex avoidance for a DNO):** the regulatory framework and processes for acquiring such services needs to allow storage to capture appropriate value;
- **Storage predominately for a non-regulated business (e.g. energy trading):** storage needs to be able to access the market on an equal basis to other participants; and
- **Combining applications for regulated and non-regulated businesses:** the balance and relative priorities between regulated and non-regulated services must be structured in an appropriate way to allow both the business case to hold and the required services to be delivered.

Each of the revenue streams identified in Table 12.3 is described in more detail within the sub-sections below.

¹⁶⁶ Smarter Network Storage Low Carbon Network Fund. Electricity Storage in GB: SNS4.13 – Interim Report on the Regulatory and Legal Framework. UK Power Networks. Available from: [http://innovation.ukpowernetworks.co.uk/innovation/en/Projects/tier-2-projects/Smarter-Network-Storage-\(SNS\)/Project-Documents/Smarter-Network-Storage-LCNF-Interim-Report-Regulatory-Legal-Framework.pdf](http://innovation.ukpowernetworks.co.uk/innovation/en/Projects/tier-2-projects/Smarter-Network-Storage-(SNS)/Project-Documents/Smarter-Network-Storage-LCNF-Interim-Report-Regulatory-Legal-Framework.pdf) Accessed 13/10/2014

12.2.2.1 Arbitrage and Avoidance of Imbalance Charges

Revenue can be generated by EES via energy arbitrage and helping to avoid imbalance charges. Both of these revenue streams require an interaction with the wholesale energy market, which is summarised within Appendix 5, Section A5.2.

Energy Arbitrage

The basic premiss of energy arbitrage is the principle of 'buy low' (i.e. charge when energy prices are lowest) and 'sell high' (i.e. discharge when energy prices are highest). Arbitrage can be carried out over different timescales – i.e. buy and sell within the space of a few hours, or within the day, or seasonally. However, the seasonal storage of energy requires a large capacity and low losses. The revenue generated from this revenue stream is dependent upon a number of factors:

- **The differential between the lowest and highest energy prices:** there is considerable variation in energy prices across each day and season. Analysis of data from the UK APX (provider of power exchange and clearing services for the wholesale energy market) shows that peak prices (around £100/MWh) typically occurred between 17:00 and 20:00 during January, February and March. On average, the six lowest and highest energy prices each day were £38/MWh and £60/MWh respectively, based on 2011 data.
- **The amount of energy which can be stored and discharged:** payment for arbitrage is dependent on the volume of energy discharged. This revenue stream is therefore most suited to technologies which can store large quantities of energy (various battery technologies, flow batteries, thermodynamic cycle systems, CAES and pumped hydro). The amount of energy discharged (i.e. the quantity for which the owner receives payment) is also dependent on the round-trip efficiency of the technology.
- **Interaction with other revenue streams/constraints:** The highest revenues from arbitrage are achieved if the storage is able to charge/discharge at the optimum time (i.e. to achieve the greatest price differential). Other revenue streams being pursued by the storage operator or network constraints may prevent operation at these times. For example, the EES system may be charged overnight, with the intention of discharging at the time of peak price. However, prior to this time the system could also be called to provide another service, such as DNO constraint management or balancing services to the TSO. Optimisation of the applications/revenue streams to be provided may be required on an ongoing basis in order to define the operating regime. An example of this is the FOSS system developed for the Smarter Network Storage project (see Table 11.3). Detailed analysis is necessary to determine the optimum combination of revenue streams and this should form part of analysing the business case for a given EES installation.

The ability of any individual EES operator to exploit this application/revenue stream is dependent on how they are able to trade in the energy market. A suitable commercial arrangement is typically required via an Energy Supplier which passes on significant price variability. Experience of developing the necessary arrangements for EES systems of the scales described in the present GPG in the UK is currently at an early stage. The ability to obtain the commercial arrangements required may vary between suppliers, system rating and capacity, certainty in its operating regime, and the price volatility in the market.

Avoidance of Imbalance Charges

Following each 30 minute settlement period an 'imbalance settlement' occurs. This is the mechanism by which generators and suppliers are charged for differences between the amount they sold/bought prior to gate closure and the amount which was delivered/consumed. Parties which are 'out of balance' are paid/charged as follows:

- **Parties with a net surplus of energy:** e.g. a generator who has delivered more than was sold, or a supplier whose customers consumed less than predicted. These parties are paid the System Sell Price (SSP); and
- **Parties with a net deficit of energy:** e.g. a generator who has delivered less than was sold, or a supplier whose customers had consumed more than predicted. These parties must pay the System Buy Price (SBP).

The System Buy/Sell Prices tend to be penal compared with market prices – i.e. generally, a better price is received for energy sold in advance compared to the SSP received via the settlement mechanism. An adjustment may be made to this where the imbalance occurred in a manner which 'helped' the system – e.g. if the system was short (not enough energy generated, or higher than predicted demand) and a supplier's demand was less than predicted, then that supplier would not be penalised in the same way as another who's demand exceeded that predicted.

A supplier or generator with access to an EES device could use the system to minimise the periods in which they are out of balance. They could also submit offers and bids to the balancing mechanism to assist with balancing and then sell this energy back to the system later. Further information on Balancing Services is provided in Section 12.2.2.3. One example of this could be a wind generator who also owned an EES system:

- **Scenario 1 – Wind generation exceeds amount sold before gate closure:** 'excess energy' could be stored in the EES system, and then sold via the spot exchange at the most advantageous time (either based on the price available or the need to reduce the SoC of the unit prior to another 'charge' event). In this case, the generator would receive the spot market price for the energy, rather than the SSP, maximising the revenue from the energy generated; and
- **Scenario 2 – Wind generation is less than the amount sold before gate closure:** If available, stored energy could be dispatched to minimise the imbalance. In this case the generator would avoid paying the SBP during the settlement process. The timing of the charging of the system to allow for discharge could also be scheduled to maximise the revenue generated. For example, charging using energy generated in excess of that sold (Scenario 1 above), or energy generated at the periods of lowest sell prices.

The graph below illustrates the difference between the Day Ahead Market Price which could be obtained for electricity to be sold on 24th October 2014, and the System Sell Price.

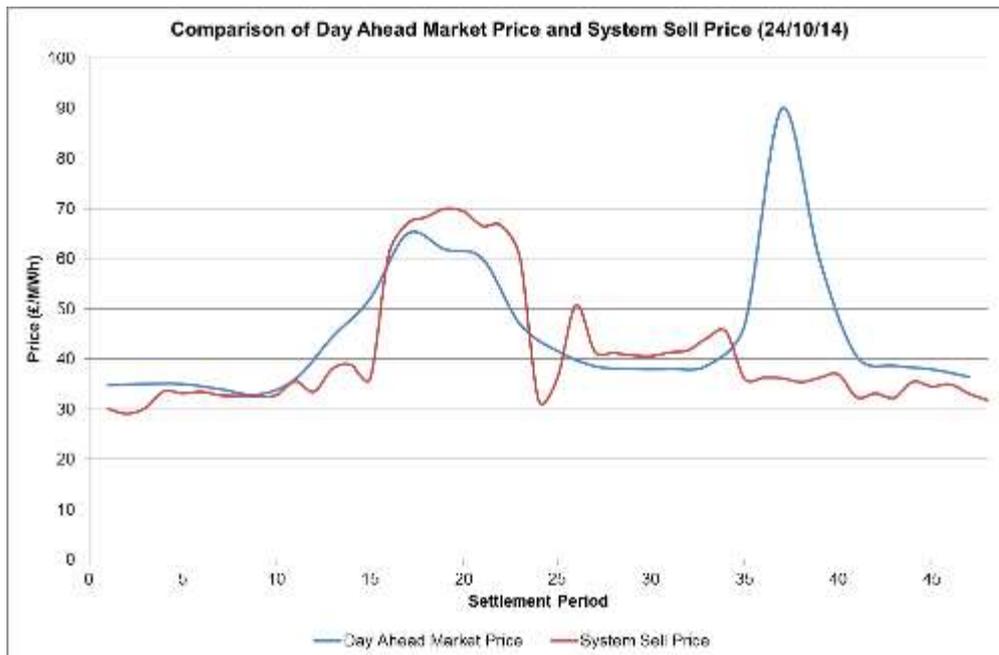


Figure 12.3: Comparison of Day Ahead Market Price¹⁶⁷ and System Sell Price¹⁶⁸

In order to avoid imbalance charges via the use of EES the system must be in the correct SoC when required. For example, in Scenario 1 (above) the SoC of the unit at the start of the settlement period (or when the generator output exceeds the sold amount) must be low enough to store the 'excess' energy. Careful management of the SoC may therefore be required to facilitate this. In some scenarios, it may be possible to generate more revenue from other applications and so managing the SoC to avoid imbalance charges may not be possible. This would depend on factors such as: the timing of 'calls' for other services (e.g. balancing services, DNO constraint management), opportunities to charge/discharge in preparation for this, relative value of revenue streams, cost of energy to charge the EES system and the predictability of operating regime.

12.2.2.2 DNO Applications

The majority of the current round of EES installations described within this GPG (detailed in Appendix 1) are primarily addressing the needs of DNOs. DNO applications of EES can be broadly separated into those relating to avoiding the need for network reinforcement (i.e. reduced capital expenditure) or improving quality of supply. These areas are explored separately below.

Reducing Expenditure on Network Reinforcement

Reinforcement of distribution networks may be required for reasons of network security (i.e. reaching the thermal limit of the assets) or statutory voltage limits. The use of EES is being investigated as a potential alternative to conventional reinforcement via the project case studies. The potential use of EES for these two applications is described below:

- Network Security:** Assets within the distribution network (underground cables, OHL, transformers etc.) are subject to maximum ratings which determine the maximum current which they can supply. Many components are also required to have in-built redundancy, such that the network can be operated in 'N-1' conditions (e.g. a network will be supplied via two primary transformers, with each one able to provide

¹⁶⁷ Data sourced from: <https://www.apxgroup.com/market-results/apx-power-uk/dashboard/>

¹⁶⁸ Data sourced from: <http://www.bmreports.com/bsp/SystemPricesHistoric.htm>

the total peak demand alone, should the other transformer be unavailable). The maximum demand that an asset can support, once the requirement for any redundancy is taken into account is its 'firm capacity'. Network assets must be sized to meet the peak demand.

Load growth (e.g. potentially arising from EVs or heat pumps) may result in the peak demand exceeding the firm capacity of an asset. In this case further capacity is required on the network. This additional capacity could be obtained in a number of ways: conventional reinforcement (e.g. a larger cable), entering into a Demand Side Response contract with a 3rd party to reduce demand when necessary or by using an EES installation for peak shaving.

Peak network demand is variable throughout the day and seasons and may only exceed the firm capacity for a relatively small number of hours per year. The EES system would need to be available during these periods. However, due to the redundancy available in 'normal' conditions the system may not be very well utilised. This difference between 'availability' periods and 'utilisation' could reduce the revenue available to a storage operator.

An EES system could provide the necessary response at these times and still be free to pursue other revenue streams outside of these critical windows. Considerable analysis is necessary to investigate the rating (i.e. amount of power to supply) and capacity (length of time for which demand > firm capacity). This should include consideration of load growth scenarios to ensure that the system provides sufficient capacity over the full lifetime of the asset, or is modular in design to enable future expansion.

- **Voltage Control to ensure voltages remain in statutory limits:** Statutory voltage limits apply to distribution networks. This requires that single phase premises connected to the LV network receive a voltage between 216 and 253V (i.e. 230V -6% +10%). The voltage on distribution networks varies along feeders and in time (e.g. lower voltages furthest from the substation and at times of peak demand). Increasing demand could cause a decrease in network voltage below the statutory limit. The connection of distributed generation (e.g. significant numbers of residential PV systems) can cause an increase in voltage above the statutory limit. DNOs are required to operate their networks within the statutory limits and investigate/respond to any voltage related complaints made by customers. A number of options exist to resolve voltage issues such as the installation of an On-Load Tap Changer (OLTC) at LV substations, reconfiguring of networks (where possible) or the use of an EES system to influence voltage. Voltage can be affected using both real and reactive power and this is demonstrated in a number of the case studies contained within Section 11.3. Where voltage can be controlled using reactive power only this does not affect the SoC of the system and therefore allows real power to be used for other applications (e.g. peak shaving).

In both of the cases described above some form of network reinforcement could be deferred/avoided via the installation of EES. The revenue associated with this is dependent on the cost of the avoided/deferred reinforcement. This is likely to be highly network specific (i.e. it is dependent on the assets involved, their rating/capacity and quantities needed) and should be evaluated on a case-by-case basis. A number of examples of the cost of reinforcement are provided within the project case studies (Appendix 1), as follows:

- **LV Connected Batteries (see A1.7):** Three 25kW/25kWh single phase units were shown to release 100 Amps of additional capacity to the network. This is equivalent to replacing a 95mm² cable with 185mm². The costs of traditional cable overlay works for this project would be equivalent to 450m of cable @178 per metre = £80,100;

- **Smarter Network Storage (see A1.15):** The installation of this EES system will defer the need for a third 33kV circuit from Sundon Grid Supply Point to Leighton Buzzard primary substation and a third 38MVA transformer at the site. The cost of this reinforcement (deferred by the installation of EES) is estimated to be £5.1 million (in Net Present Value terms (see Section 13.1), £6.2 million in absolute cost terms); and
- **SolaBristol (see A1.13):** The alternative to the installation of in-home EES systems to limit the export of PV generation would be £63,720 per substation, based on a 120m LV overlay and harmonic filtering on three LV feeders.

Where EES systems are required to provide network security (e.g. peak shaving to avoid the need for network reinforcement, as in the Smarter Network Storage project) this application must take precedence over other revenue streams. For systems which are owned and operated by a DNO this ensures their availability (subject to reliability/maintenance issues). However, if EES systems which are owned/operated by a 3rd party are providing this response to a DNO then contractual measures will be required to guarantee availability.

Improved Quality of Supply

EES installations can be used to improve the quality of supply to customers. This could relate to power quality (e.g. mitigation of harmonics on the distribution network and reduction of flicker, as described in Appendix 2, Section A2.7) and reducing customer interruptions via increasing network security (see above) or providing an alternative source of energy to customers.

The value of security of supply (i.e. the avoidance of a power outage) can be calculated based on the principle of the 'Value of Lost Load' (VoLL). The calculation of the VoLL is outside the scope of this GPG, but the value does provide an indicative figure for the benefit which an EES system could provide by improving security of supply.

An extensive study has recently been completed¹⁶⁹ which studied the VoLL for different types of consumer (domestic, Small to Medium Enterprise (SME) and Industrial & Commercial (I&C)), at different times of the day and year. From these results a single VoLL figure was produced based on a weighted average of the figures for domestic and SME customers. This provided a VoLL for a winter weekday (peak demand period) of £16,940 per MWh. An EES system which prevented an outage to customers which otherwise would have resulted in 1MWh of 'lost load' (e.g. a thousand customers with average demand of 1kW, for an hour) has therefore provided £16,940 of value. The contribution this makes to the financial justification for a given EES installation would depend on the likelihood of an outage occurring, the number of customers who would be affected and the total load.

DNOs are also incentivised via the regulatory framework to ensure security of supply. The next distribution price control period (RIIO-ED1, from April 2015 to March 2023) is targeting a reduction in customer interruptions via the 'Interruptions Incentive Scheme (IIS)' (modified from the previous price control period). DNOs will be rewarded if they achieve fewer customer interruptions (CIs) and customer minutes lost (CMLs). The key features of the IIS are as follows:

¹⁶⁹ The Value of Lost Load (VoLL) for Electricity in Great Britain. Final report for Ofgem and DECC. London Economics. July 2013. Available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/224028/value_lost_load_electricity_gb.pdf
Accessed 30/10/2014

- Improving reliability target throughout each year of the price control period. This target varies between licence area;
- A symmetrical incentive system, such that outperforming/underperforming against the target is “worth” the same to the DNO; and
- The payment received as a result of improving reliability is capped to a maximum value.

An ‘incentive target rate’ is set for each licence area. This rate relates to the number of customers within the licence area and equates to costs of £15 per CI and £0.37 per CML¹⁷⁰. The level of these penalties has been set based on the VoLL and is consistent with a figure of £16/kWh (based on average load (kW) ‘lost’ during an interruption).

Further information is available via the relevant ‘Strategy Decision’ published by the energy regulator, Ofgem¹⁷¹.

Many of the EES installations within the case studies have the potential to improve quality of supply via the provision of additional capacity/flexibility to the distribution network (e.g. peak shaving to prevent assets exceeding their firm capacity). In addition, two DNO projects have provided storage on the ‘customer side of the meter’ which would provide some power in the event of an outage, as follows:

- **WPD SolaBristol (see Appendix 1, A1.13):** this system would provide power to lighting, computing, telecommunications and potentially central heating pumps during an outage; and
- **SSE Power Distribution Kilchoan ‘Lights On’ Trial¹⁷²:** during winter 2008, 22 vulnerable customers in the village of Kilchoan were provided with Point of Use Reliability Equipment (PURE). This UPS system provided enough power to ‘keep the lights on’ during power outages, minimising the impact on vulnerable customers.

12.2.2.3 System Balancing Services

Balancing Services are procured by National Grid to ensure that supply and demand are kept in balance at all times across the GB Transmission System. This is achieved through a variety of mechanisms, including:

- Buying and selling electricity in the Balancing Mechanism;
- Buying and selling electricity through Trading; and
- Entering into commercial contracts for Balancing Services.

A wide range of different Balancing Services are procured by National Grid, those relevant to EES are highlighted below.

Frequency Response Services

System frequency is controlled by the real time (second by second) balance between the demand and generation. If demand is greater than generation, the system frequency falls and vice versa. In order to comply with its licence obligation to maintain system frequency within specified limits, National Grid ensures that sufficient generation and/or demand is held in readiness to respond to fluctuations in system frequency via a number of frequency response services. Mandatory frequency response is the service that generators are obliged

¹⁷⁰ Appendix 2. Table 7 of Footnote Number 171.

¹⁷¹ Ofgem. Strategy decision for the RII0-ED1 electricity distribution price control. Reliability and safety. Published 04 March 2013. Available from: <https://www.ofgem.gov.uk/ofgem-publications/47073/riioed1decreliabilitysafety.pdf> Accessed 24/10/2014

¹⁷² SSEPD Priority Customer Care Initiatives. Available via: <https://www.ofgem.gov.uk/ofgem-publications/47515/scottish-and-southern-energy-pcc-submission.pdf> Accessed 24/10/2014

to provide as a condition for connection to the GB Transmission System. Alternatively, generators and/or demand can provide supplementary frequency response services secured via competitive tender. These commercial frequency services are open to both Balancing Mechanism (BM) and non BM participants, and include Firm Frequency Response (FFR) and Frequency Control by Demand Management (FCDM). The technical characteristics are summarised below:

- FFR is the firm provision of dynamic (i.e. where the level of service fluctuates with system frequency) or non-dynamic response to changes in frequency; and
- FCDM is the provision of frequency response when the system frequency transgressed below a threshold. The service must be delivered within 2 minutes and sustained for at least 30 minutes.

Reserve Services

Reserve services provide National Grid with additional generation or demand reduction resource to enable it to deal with unexpected increases in demand and/or generation unavailability. A number of services are procured, each characterised by the timescale for delivery, and the length of time that the service must be provided. Those applicable to EES are Fast Reserve and Short Term Operating Reserve (STOR). The technical characteristics of these services are summarised below:

- Fast Reserve must be delivered within 2 minutes of the despatch instruction from National Grid and sustained for a minimum of 15 minutes; and
- STOR must be delivered within 4 hours and sustained for at least 2 hours.

System Security Services

System Security Services include a range of mechanisms to maintain the security and quality of the electricity supply across the GB Transmission System. The service most relevant to EES is Transmission Constraint Management. Constraints occur whenever the system is unable to transmit the power generated to the location of demand due to congestion on the network. EES can help by ‘mopping-up’ excess generation output in one location thereby avoiding constraining a generator. Alternatively, EES can assist by exporting electricity to the grid to meet demand. Unlike Frequency Response and Reserve Services, the location of the Transmission Constraint provider is critical, as it must be located on the constrained part of the network to effectively alleviate the constraint. The service requirement is identified on an ad-hoc basis depending upon outage patterns and forecast demand/generation levels.

In addition to the technical requirements highlighted above, EES would also need to comply with the minimum volume (MW) requirements for each Service. These requirements range from service to service, but typically require 3MW or more. However, the response of several providers can be aggregated to meet these requirements. As such, smaller scale EES may need to participate via a demand side aggregator rather than contracting directly with National Grid.

The following table provides a summary of the prices paid by National Grid for these services. The prices represent the average paid across all providers (Balancing Mechanism and Non-Balancing Mechanism Units). The price paid to a non-balancing mechanism provider (e.g. an EES installation) is likely to be lower than the value shown below. Reserve providers are typically paid for availability and also when they are called to provide response (the utilisation payment), whilst frequency response providers receive only an availability payment.

Table 12.4: Summary of Revenue Streams

Balancing Service	Availability Payment	Utilisation Payment	Reference
Firm Frequency Response	£35.49/MWh	n/a	Monthly Balancing Service Summary 201/15 ¹⁷³ .
FCDM			
Fast Reserve	£3.88/MWh	£145/MWh	Firm Fast Reserve Post Assessment Tender Report ¹⁷⁴ .
STOR	£7.38/MWh	£202.27/MWh	Short Term Operating Reserve Annual Market Report 2012/2013 ¹⁷⁵ .

12.2.2.4 Capacity Market

The Capacity Market¹⁷⁶ was introduced as part of the Electricity Market Reform (EMR) in order to support security of supply and is administered by the System Operator. It is required due to the closure of flexible generating plant (e.g. due to the Large Combustion Plant Directive) and predicted increase in variable generation by 2020. Its introduction is intended to ensure that there are sufficient incentives on capacity providers in order to maintain an adequate security of supply.

The market is designed to be technology neutral and offer a revenue stream to providers of capacity, in return for which they commit to deliver energy in periods of system stress. They are exposed to penalties if they fail to deliver. Various parties are ineligible to take part in the Capacity Market – those receiving low carbon support (through the Renewables Obligation, Contracts for Difference or small-scale Feed in Tariffs), those with long term STOR contracts and interconnected non-GB capacity¹⁷⁷. Each ‘Capacity Market Unit’ (CMU) must have a minimum size of 2MW, although it is possible to aggregate smaller systems of the same type to achieve the minimum.

Capacity contracts will be allocated to providers through auctions intended to secure a capacity requirement needed to meet a three hour loss of load expectation reliability standard. The price received by providers of capacity will be based on the auction clearing price, with payments capped at £75/kW¹⁷⁸. CMUs will be required to respond in times of ‘system stress’. This is defined as any settlement period in which either voltage control or controlled load shedding are experienced for a period of 15 minutes or longer. The System Operator will issue a warning four hours ahead of an anticipated event (Capacity Market Warning (CMW)). If an event occurs with less than four hours of warning, CMUs will not be subject to penalties for non-delivery.

The first auction is due to take place in December 2014, for delivery in the winter of 2018/19. Parties wishing to take part in the auction must complete a pre-qualification phase. This pre-

¹⁷³ National Grid. August 2014. [Online]. Available from: <http://www2.nationalgrid.com/UK/Industry-information/Electricity-transmission-operational-data/Report-explorer/Services-Reports/> Accessed 24/10/2014

¹⁷⁴ National Grid. October 2014. [Online]. Available from: <http://www2.nationalgrid.com/UK/Services/Balancing-services/Reserve-services/Fast-Reserve/Fast-Reserve-Information/> Accessed 24/10/2014

¹⁷⁵ National Grid. [Online]. Available from: <http://www2.nationalgrid.com/UK/Services/Balancing-services/Reserve-services/Short-Term-Operating-Reserve/> Accessed 24/10/2014

¹⁷⁶ Information provided via: UK Power Networks. Smarter Network Storage. SNS4.13 – Interim Report on the Regulatory and Legal Framework. Annex E. Available from: [http://innovation.ukpowernetworks.co.uk/innovation/en/Projects/tier-2-projects/Smarter-Network-Storage-\(SNS\)/Project-Documents/Smarter-Network-Storage-LCNF-Interim-Report-Regulatory-Legal-Framework.pdf](http://innovation.ukpowernetworks.co.uk/innovation/en/Projects/tier-2-projects/Smarter-Network-Storage-(SNS)/Project-Documents/Smarter-Network-Storage-LCNF-Interim-Report-Regulatory-Legal-Framework.pdf) Accessed 24/10/2014

¹⁷⁷ National Grid. Capacity Market User Support Guide. July 2014. Available from: <http://www2.nationalgrid.com/UK/Our%20company/Electricity/Market%20Reform/Announcements/Capacity%20Mechanism%20User%20Guide/> Accessed 24/10/2014

¹⁷⁸ <http://utilityweek.co.uk/news/decc-confirms-capacity-market-details-to-reassure-gas-investors/989422#.VEo1F2dOXIU> Accessed 24/10/2014

qualification phase opens four months ahead of the auction and is used to confirm the eligibility and bidding status of all potential capacity¹⁷⁹. In addition, auctions will be held one year head of delivery for demand side response (including embedded generation and smaller storage), with the first auction taking place in 2015, for delivery in 2016/17. The timescales for the announcement of ‘successful bidders’ from the auction (i.e. those which will take part in the Capacity Market) is not yet clear.

There are a number of issues relating to the use of storage within the Capacity Market, as follows:

- The capacity offered into the market will be limited to export capacity only. This means that the capacity agreements signed by storage operators will not take account of the ‘full swing’ potential of an EES unit (i.e. an EES system going from full charge to discharge). It would, however, be entitled to over-delivery payments if it stops importing at a time of system stress.
- Although a four hour warning will be provided by a CMW, the period for which a response will be required is not defined. The event could remain in place until either:
 - If the system stress event does not occur (i.e. ‘a false alarm’), then the event ends at the end of the day on which the CMW was issued.
 - If the system stress event occurs, then the response is required until the end of the system stress event.

Therefore, there is no defined time limit over which delivery must be maintained. This presents an issue for operators of EES as the discharge duration is limited by the capacity and SoC at the start of the event. If the EES unit was fully discharged before the end of the stress event then the operator is exposed to potentially substantial penalties. This penalties are equivalent to the volume of under-delivery (i.e. declared rating (MW) x hours for which the system failed to deliver) multiplied by a price linked to the Value of Lost Load (~ £17,000/MWh). The penalty is capped to 100% of the annual capacity payment but still represents a substantial risk to storage developers, which may prevent their participation.

12.2.2.5 ‘Customer Side of the Meter’ Applications

EES systems can be used to generate revenue/avoid costs when installed on the customer side of the meter. This could also be combined with other revenue streams/applications outlined elsewhere within this Section. For example, an industrial customer who used an EES system to store energy produced from on-site generation may also be able to provide System Balancing Services.

The potential uses of EES on the customer side of the meter are dependent upon the type customer (e.g. demand profile, size of demand etc.), their tariff type (e.g. subject to a Time of Use (ToU) tariff) and whether they have any on-site generation. A number of potential use cases/revenue streams are explored and quantified below:

- **Minimising distribution network usage charges:** all customers are charged for their use of the distribution network via Distribution Use of System (DUoS) charges. The Common Distribution Charging Methodology (CDCM) introduced an element of ToU pricing to the DUoS charges paid by half hourly metered customers. The table below illustrates the structure of the charge for HV customers in one licence area:

¹⁷⁹ Implementing Electricity Market Reform. Finalised policy positions for implementation of EMR. DECC. June 2014. [Online]. Available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/324176/Implementing_Electricity_Market_Reform.pdf Accessed 30/10/2014

Table 12.5: Example of ToU DUoS Charges¹⁸⁰

	Red Band (p/kWh)	Amber Band (p/kWh)	Green Band (p/kWh)
Applies:	Weekdays 16:00 to 19:00 (including bank holidays)	Weekdays 08:00 to 16:00 and 19:30 to 22:00	Weekdays 00:00 to 08:00 and 22:00 to 24:00 and all weekends
DUoS Charge – HV HH Metered Customer	8.87	0.55	0.06

If this tariff was passed on in full to a customer by the supplier, then a saving of approximately 9 p/kWh could be avoided by shifting consumption from the 'red' to 'green' period (e.g. by charging the system during the green period with the energy to be used in the red period). This could be combined with other revenue streams described in this section.

- Minimising transmission network usage charges (TRIAD avoidance):** customer pays for their use of the transmission network via Transmission Network Use of System (TNUoS) charges. The TNUoS charges to be paid by half hourly metered customers (i.e. those with connections greater than 100kW) are based on their peak demand (kW) during 'triad periods'. These triad periods are defined as the three half hour periods with the greatest demand on the UK's transmission network. The exact date and time of these periods changes from year to year. A customer who imports a larger amount of power during the triad periods will be subject to greater TNUoS charges. Various companies provide 'triad warnings' which allow customers to modify their demand to avoid consumption during the anticipated triad period, thus reducing their TNUoS charges. A customer with an EES system could use it to supply some of their demand during the triad period (i.e. in conjunction with a triad warning service). The demand tariff for customers varies depending on their geographically location, ranging from £16.17/kW in Northern Scotland to £38.79/kW in the Southern region¹⁸¹. As well as the 'per kW' element of the charge, customers are also subject to a per kWh charge for the amount of energy consumed (between 2.2 and 5.4 p/kWh). Triad avoidance is one of the revenue streams being investigated as part of UK Power Network's Smarter Network Storage project.
- Minimising connection charges:** The cost of connecting a site to the distribution (or, for the largest sites, transmission) network is dependent on the size of connection (kVA) required. This is currently based on the peak power demand of the site. An industrial or commercial site could use an EES within their site to carry out peak shaving and reduce their peak power demand, and reduce the cost of their connection. The system would be available to exploit other revenue streams outside the time of peak system demand.
- Use as an Uninterruptible Power Supply/Standby Generation:** a number of industrial and commercial customers employ back-up generation on their sites, such as diesel generators. These generators are used to provide power in the event of a network fault, by operating the site as an islanded network (subject to the necessary protection arrangements). An EES system could also be configured to provide back-up power. The value of this operation would depend upon the circumstances of the site/operations (e.g. the 'lost' production time or other impacts), but could be equated to the Value of Lost Load described in Section 12.2.2.2. A number of sites use their standby generation to provide DSM services to either the System Operator (e.g. as

¹⁸⁰ Northern Powergrid Northeast Area. DUoS Charges. Final for 2014-15. Available from: <http://www.northernpowergrid.com/asset/0/document/135.xlsx> Accessed 26/10/214

¹⁸¹ Table 1.12. The Statement of Use of System Charges. April 2014. National Grid. Available online from: <http://www2.nationalgrid.com/UK/Industry-information/System-charges/Electricity-transmission/Transmission-Network-Use-of-System-Charges/Statement-of-Use-of-System-Charges/> Accessed 16/11/2014

part of STOR) or the DNO (as part of LCN Fund trials). EES could also be used to provide these services, providing a further revenue stream.

- Minimising energy consumption at times of peak prices (Industrial/Commercial customers):** Customers with connections of greater than 100kW have their electricity consumption recorded in half hourly blocks (half hourly metered). In some cases an Industrial or Commercial customer will be on a Time of Use (ToU) tariff and therefore subject to varying prices throughout the day. An EES system could be used by these customers to avoid high costs of energy at peak times, by charging the system off-peak. The ability of a customer to use an EES system in this way would depend on the relative size of the peak/off-peak time period (e.g. a long 'peak' period would limit the opportunity for charging sufficient energy during the off-peak) and the variation of demand at the site. The value of this application is dependent on the relative peak/off-peak energy prices and amount of demand which can be shifted to the off-peak (depends on the demand, rating and capacity of system).
- Minimising energy consumption at times of peak prices (domestic customer with ToU tariff):** the most common form of ToU tariff currently in use in the UK is 'Economy 7'. This tariff was originally introduced in combination with electric storage heating, allowing customers to heat their home with 'off-peak' electricity purchased and stored overnight. A domestic customer could use a small EES system to take advantage of these off-peak rates for their day-time electricity use. Analysis of a typical residential demand profile and varying total annual electricity demand shows the financial benefit which could be obtained per year. It has been assumed that the household transfers from a 'flat-rate' (i.e. non-ToU) tariff of 12 p/kWh to a ToU tariff with peak and off-peak prices of 7p/kWh and 6p/kWh respectively. The resulting annual savings are shown below.

Table 12.6: Potential Savings for a Domestic Customer (without own generation)

Annual electricity consumption (kWh/yr)	3500	5500	10000
Store size required (kWh)	9	14	24
System power rating required (kW)	1	1.5	2.5
Value captured (£/yr)	125	204	358

The savings above depend on the differential between peak and off-peak prices. If domestic tariffs were to evolve to include more complex ToU tariffs, or elements of 'Critical Peak Pricing' (where a much greater price differential exists, but only for a limited number of days per year) then these savings could increase.

- Maximising the use of on-site generation (i.e. minimising import of energy):** Customers with on-site generation (either industrial/commercial or residential) are likely to receive less money for export to the grid than the cost of importing energy. This results in a financial benefit to the customer if the use of energy generated on-site can be maximised. An EES system could allow the customer to store excess generation for use later, when demand is greater than the amount of power being produced. For example, under current settlement and metering arrangements in the UK, customers with PV generation receive a Feed-In Tariff payment for each kWh of energy generated, and a 'deemed' (i.e. not metered) export payment of 3p/kWh for 50% of the energy produced. If generation exceeds demand (e.g. because the customer is out of the house during the day) then this excess is exported to the network. When demand exceeds generation (e.g. in the evening) the customer must import electricity at a current cost of around 14p/kWh¹⁸².

¹⁸² Average variable unit costs and fixed costs for electricity. DECC Statistics. Available from: <https://www.gov.uk/government/statistical-data-sets/annual-domestic-energy-price-statistics> Accessed 14/11/2014

An EES system could therefore be used within the home to store any excess electricity generated for use when demand exceeds generation. The exact revenue received for this type of operation is dependent on the generation and demand profile of the house, the rating and size of the EES system and the import tariff. An estimate has been made of the value of this operation for various sizes of PV installation and size of EES system, based on a 'spread' (i.e. import – export rates) of $\approx 10\text{p/kWh}$.

Table 12.7: Value of EES for a Domestic PV Customer

PV size (kW)	2.8	4	8
Consumption (kWh/yr)	5500	5500	5500
Storage Capacity (kWh)	4.4	8.2	11.8
System power rating required (kW)	2.8	4	8
Value (£/year)	107	199	287

12.2.2.6 Removing Constraints for Renewable Generation

The main revenue stream for those owning renewable generation comes from the sale of generated energy. As discussed elsewhere within this guide, the locations where new generation can be connected may be limited due to grid constraints. An example of this is illustrated for UK Power Network's Eastern Power Networks area, showing where generation capacity is utilised or available¹⁸³. This indicates that significant areas of the licence area would not be available for new generation to connect due to a lack of capacity.

A number of options exist for generation companies seeking a connection, as follows:

- Limiting applications/connections to those sites where an unconstrained connection is available. This may limit the locations which are available, particularly once other considerations such as the wind resource and likelihood of receiving planning consent are taken into account;
- Limit the size of generation installed to the available capacity (i.e. unconstrained capacity) available. Although this option reduces the capital expenditure of the project to an extent, it clearly affects the revenue which will be generated;
- Paying for considerable network reinforcement to allow an unconstrained connection. This may not be technically feasible, may be prohibitively expensive, or have a long lead time; or
- Accept a constrained connection, whereby the output of the site is limited to the capacity available on the distribution network. This will limit the revenue which can be earned at a given site due to 'lost' constrained energy.

EES offers a potential alternative to the third option listed above. In this scenario, the 'constrained' energy could be stored and exported to the network when the generation output has decreased.

The suitability of EES to 'unconstrain' renewable generation at a given site will depend on the nature/frequency of the constraint, and the generation profile. For example, if forecasts of wind generation output at a site and the level of the constraint indicate that the output would be limited (i.e. EES charging) for long periods, then a significant storage capacity would be necessary. This has the potential to increase the capital costs and installation size required. It would also be necessary to consider whether suitable 'unconstrained' time periods exist to discharge the store.

¹⁸³ EPN Generation Capacity Map. Drawing Number: HQ-2000-4702. Available from: <http://www.ukpowernetworks.co.uk/internet/en/connections/documents/EPN-heat-map-190314.pdf> Accessed 24/10/2014

The revenue generated by this application is dependent on the volume of ‘constrained’ energy through the year, the ability of the EES system to capture this energy (i.e. it mustn’t already be full), then discharge it and the sale price of the energy when the store discharges. The removal of a generation constraint is the principal application for the REDT Vanadium Flow Battery being installed on the Isle of Gigha as part of the DECC Energy Storage Technology Demonstration Competition. Details of the application can be summarised as follows¹⁸⁴ (see also the case study in Appendix 1, Section A1.17):

- At the start of the project, three wind turbines were operational, with a maximum output of 775kW. A fourth wind turbine with a capacity of 330kW has since been installed.
- The fourth turbine must operate at an extreme 0.85 power factor to overcome voltage rise and is constrained to 225kW. The voltage constraint results in a loss of 3GWh over the 25 year turbine life, with a value of £300k and 1.5ktCO₂ at today’s rate. Future increases in the cost of energy would increase the value of this ‘lost’ energy.
- To remove the constraint on the fourth turbine, a method of accepting 105kW at times of peak wind output is required.
- The capacity of the system has been selected based on a year’s worth of wind speed data for the site and the power curve for the fourth turbine. The use of an EES device was simulated, such that it would charge when the output of the fourth turbine exceeded 225kW and discharge below this. A number of combinations of rating and capacity were analysed to determine the constrained wind energy which could be ‘saved’ under each combination. A law of diminishing returns applies, such that at higher ratings and capacities, each further increase only increases the ‘saved’ energy marginally.
- A system size of 105kW/1.2MWh has been chosen, which is able to ‘save’ 60% of the previously constrained energy.

Other revenue-generating activities can then pursued using the stored ‘constrained’ energy, such as:

- The sale of wind energy to the market during peak times and price spikes;
- Provision of local back-up power in the event of network faults;
- Enablement of further generation connections downstream of the EES;
- Trading electricity when not operating to unconstrain the turbine;
- Dispatch of network services (voltage control, peak shaving); and
- Provision of Balancing Services.

12.3 Business models

Various business models are available to those seeking to obtain the benefits of EES systems. These range from a business that owns and operates an EES system, to procurement of a service which may utilise EES to meet a particular need. The extent and ownership of the various costs and benefits of EES, outlined in Sections 12.1 and 12.2, are dictated by the business model employed. In addition, the business model influences a number of areas of EES procurement and operation including access to finance, long-term availability of the asset and regulatory oversight. This subject is explored in more detail in a report recently completed for Elexon (GB Balancing and Settlement Code Company)¹⁸⁵.

¹⁸⁴ An Energy Storage System for the Scottish Isle of Gigha. S D Wilson. J Samuel. G Simmonds. Paper presented to the IET Power in Unity Conference. October 2013.

¹⁸⁵ Storage Business Models in the GB Market. A report to Elexon. July 2014. Pöyry and Swanbarton. [Online]. Available from: http://www.poyry.com/sites/default/files/imce/374_elexon_storagebusinessmodelsandgbmarket_v2_0.pdf Accessed 30/10/2014

When considering EES for Distribution Network applications, a particular constraint or power quality requirement is likely to provide the incentive for the EES installation; other revenue streams are likely to be determined on the basis of availability after securing the Distribution Network requirement. Similarly, where other target applications, such as removing a generation constraint, have been identified, they are likely to provide the basis for both the EES specification and business case development.

This section introduces three case studies, based on those set out by UK Power Networks in the Smarter Network Storage – Business Model Consultation document¹⁸⁶. Whilst set out in the context of DNO owners, these business models may also be applied to other companies wishing to gain the benefits of EES for a particular primary benefit.

12.3.1 DNO Owned and Operated

In this business model a DNO would manage and finance the procurement of the EES system, after which they would also operate the EES asset to achieve the desired network benefit. In order to achieve the most benefit from the EES system, the DNO could then be active in the electricity trading, capacity and balancing markets to maximise revenue when the EES system is not required for distribution network applications.

Under this business model, a DNO would have exclusive use of the EES system to fulfil the primary, distribution network, requirements; secondary revenue streams could then be pursued to offset the cost of the EES. However, in the DNO context, this operation must be conducted in a manner which does not breach the various conditions set out in the DNO's Electricity Distribution Licence which restrict influence and participation in the electricity supply and generation markets. Similarly, income from secondary revenue streams is likely be considered as falling outside of the core distribution business and be subject to limitations on the DNO's income arising outside the core business¹⁸⁷.

Sole ownership of an EES system, without contractual restrictions, would guarantee availability of the EES where required. For example, estimates of demand and the capacity of network assets may indicate that a response from EES may be required between 17:00 and 19:00 on a winter weekday. If an incident (e.g. abnormally high demand) occurred outside this defined period under the 'DNO Contracted' model, there may be contractual restrictions preventing the DNO from accessing the resource. This restriction would not exist in the 'DNO Owned and Operated' model. However, in order to exploit additional revenue streams the DNO may need to operate the EES system within the electricity trading, capacity and balancing markets. Contractual and trading activities of this type are outside of typical DNO operations. Therefore, to maximise revenue, the DNO would be required to source the necessary expertise. The cost of this expertise would reduce the profit associated with the secondary applications of EES.

12.3.2 DNO Contracted

To utilise a DNO Contracted business model, a DNO would procure, own and operate an EES asset, ensuring that the EES was utilised to deliver its primary benefit for the distribution network. However, it is likely that the primary distribution network application would only occur during specific, predictable, time periods. Outside of these time periods,

¹⁸⁶ Smarter Network Storage Low Carbon Network Fund. Business Model Consultation: SNS4.1. UK Power Networks. Available from: [http://innovation.ukpowernetworks.co.uk/innovation/en/Projects/tier-2-projects/Smarter-Network-Storage-\(SNS\)/Project-Documents/Smarter-Network-Storage-Business-model-consultation.pdf](http://innovation.ukpowernetworks.co.uk/innovation/en/Projects/tier-2-projects/Smarter-Network-Storage-(SNS)/Project-Documents/Smarter-Network-Storage-Business-model-consultation.pdf) Accessed: 27/10/2014

¹⁸⁷ See, for example: Electricity Act 1989: Standard conditions of the Electricity Distribution Licence. Gas and Electricity Markets Authority 22 April 2014. Available from: <https://www.ofgem.gov.uk/licences-codes-and-standards/licences/licence-conditions> Accessed: 27/10/2014

the DNO would enter into a contract with a third party, where the DNO would accrue additional revenue in exchange for operating the EES system to the third parties instructions. The third party would then be free to enter the electricity trading, capacity and balancing markets using the EES asset(s). This is the model being adopted by UK Power Network's Smarter Network Storage project (see case study in Appendix 1, Section A1.15).

This model is likely to benefit from the DNO's expertise in operating electrical assets, whilst the third party is free to exploit their expertise in operating within the various electricity markets. Furthermore, this business model would allow the DNO to procure the EES with a well-defined revenue stream for the EES. This would allow the DNO to avoid direct participation in the various electricity markets and limitations associated with the distribution licence conditions discussed in Section 12.3.1. However, the revenue received from the third party for access to the EES system would still be likely to be considered as revenue arising from outside the core distribution business.

A business model of this nature would be heavily dependent on the contractual arrangement between the two parties, in order to maximise the revenue achieved by the EES without impeding the primary application. Therefore, contractual terms between the two parties would be likely to require significant detail which would contribute additional cost and reduce flexibility throughout the contracted period. It is likely that a long term contract would be most desirable to offset the risk associated with the procurement of the EES system. However, care would be needed to allow changes to EES usage – either to increase or reduce access for the third party – where the primary application changes (e.g. a change in the time of peak demand or additional generation connections).

12.3.3 Contracted Services

To implement a Contracted Services business model, a DNO would identify the requirement for a network application of EES, identify a site and open a tender for the provision of EES subject to specified parameters (i.e. availability, rated power, rated capacity). This would allow a third party to finance and procure an EES system with a secure revenue stream associated with the access required for the identified DNO application. This is the model being adopted by SSEPD in the Orkney Energy Storage Park project (see case study in Appendix 1, Section A1.8).

By transferring the procurement and operation to a third party, the DNO also transfers the risk associated with construction of the system and availability of secondary revenue streams. However, the DNO relies on a sufficiently mature market for the tender to achieve consistent procurement of effective, economic solutions; Section 7 considers this area in detail. In addition, the reductions in commercial risk are offset against the dependence on the availability and continuity of the third party throughout the contracted time period.

In common with the DNO contracted model, it is likely that detailed contractual terms would be required. However, the DNO achieves the required distribution network benefit for a defined cost and has no requirement to operate the asset or enter into electricity markets which are outside its core market and for which it may be subject to regulatory restrictions. In this respect, this solution allows the most direct comparison with the cost of alternative solutions to the distribution network requirement.

13 Constructing the Cost:Benefit Case and the Financial Justification

The previous section outlined the costs of procuring an EES system and the potential revenue streams available to an owner/operator of energy storage. In order to develop a sound financial justification for proceeding with a project it is necessary to combine these pieces of information into a cost:benefit analysis (CBA).

This section presents four different methodologies which can be used to complete a CBA, how they can be applied to an EES project and their advantages and disadvantages. A number of case studies are then provided which show the results of CBA for a sub-set of the projects within Appendix 1.

13.1 Cost:Benefit Analysis Approaches

The aim of a CBA is to systematically compare the full costs and benefits of various solutions/actions over their lifetime, in order to show the most cost effective solution. A number of approaches are commonly used within the energy sector which could potentially be applied when developing a financial justification for an EES project. This section reviews a number of approaches and provides some advantages/disadvantages of each.

A number of common terms are used within the various CBA methodologies, which can be defined as follows:

- **Net Present Value (NPV)/Net Present Worth (NPW):** the net result of all costs and benefits, when expressed as a 'Present Value';
- **Present Value:** the use of 'present value' figures accounts for the time value of future financial outlays and revenue streams, by discounting back to the present date. This is due to the fact that inflation tends to increase the value of goods and services, which erodes future value and costs. In the methodologies below the present value is calculated via the use of an inflation and discount factor;
- **Inflation:** A factor which takes account of the predicted increases in the cost of procuring materials and services in the future. For example, the cost of spare parts will increase with inflation in the future. In the outline methodologies provided in Appendix 5 a fixed percentage is applied (e.g. 2.5%). For convenience and for comparative purposes, investment appraisals are often referenced to a fixed set of 'money values', e.g. year 2015 money values;
- **Discount Factor:** the factor applied to take account of the income earning potential of investments (the 'time value of money', as described under 'present value' above). The discount factor chosen reflects the level of return which an organisation wishes to see before deciding to invest, based on the rates available for alternative investments, attitude to risk etc.
- **Capital Recovery Factor:** Defined as "the ratio of constant annuity to getting the current value of annuity at the given time period". It is calculated from a formulae based on the chosen discount factor (i) and the lifetime of the project (n years), as follows:

$$\text{Capital Recovery Factor} = \frac{i(1+i)^n}{(1+i)^n - 1}$$

- **Annuitised Costs/Benefits:** A cost or benefit expressed on a 'per year' basis.

13.1.1 Present Worth/Net Present Value (NPV)

A Present Worth/NPV calculation can be used to assess the difference between income and outgoings over the whole of the project life-cycle. A present worth factor is applied to all income and expenditure to refer back to a common starting year. This present worth factor takes into account the effect of both inflation (increasing the cost of items into the future) and the discount factor. The NPV value is calculated according to the following formula:

$$\text{NPV} = \text{NPV of Benefits (summed over project lifetime)} - \text{NPV of Costs (summed over project lifetime)}$$

The NPV can then be interpreted as follows:

- **NPV > 0:** benefits would exceed costs based on the assumptions used, and the project may be financially justifiable.
- **NPV < 0:** costs would exceed benefits based on the assumptions used, so the installation is not cost effective based on the revenue streams identified.
- **NPV = 0:** costs and benefits are equal. Changes to the assumptions made (e.g. revenue streams which could be exploited and their value) would lead to a more conclusive result.

Sandia National Laboratories have employed the NPV method to calculate the costs (maroon bars) and benefits (light yellow bars) of an example EES installation. In this case the EES system is assumed to be transportable. It provides T&D upgrade deferral in one location in odd numbered years, and a power quality/reliability service in another location in even numbered years. The effect of the present worth factor can be seen, with both costs and benefits declining in the latter years.

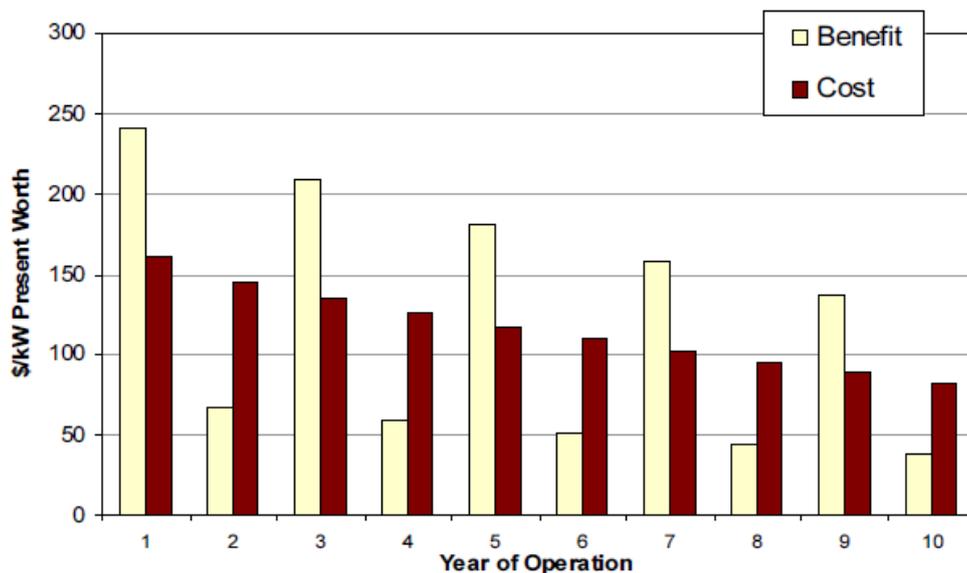


Figure 13.1: Example NPV Graph¹⁸⁸

The total net present worth of benefits of over ten years is \$1,203 per kW. The costs in Figure 13.1 are based on one specific EES technology, and have a total present worth of \$1,200 per kW, indicating a slightly positive NPV. Figure 13.2 below presents an illustrative example of an alternative use of NPV data.

¹⁸⁸ Figure 7. Benefit/Cost Framework for Evaluating Modular Energy Storage. Sandia National Laboratories. Report Number SAND2008-0978. Available from: <http://prod.sandia.gov/techlib/access-control.cgi/2008/080978.pdf> Accessed 27/10/2014

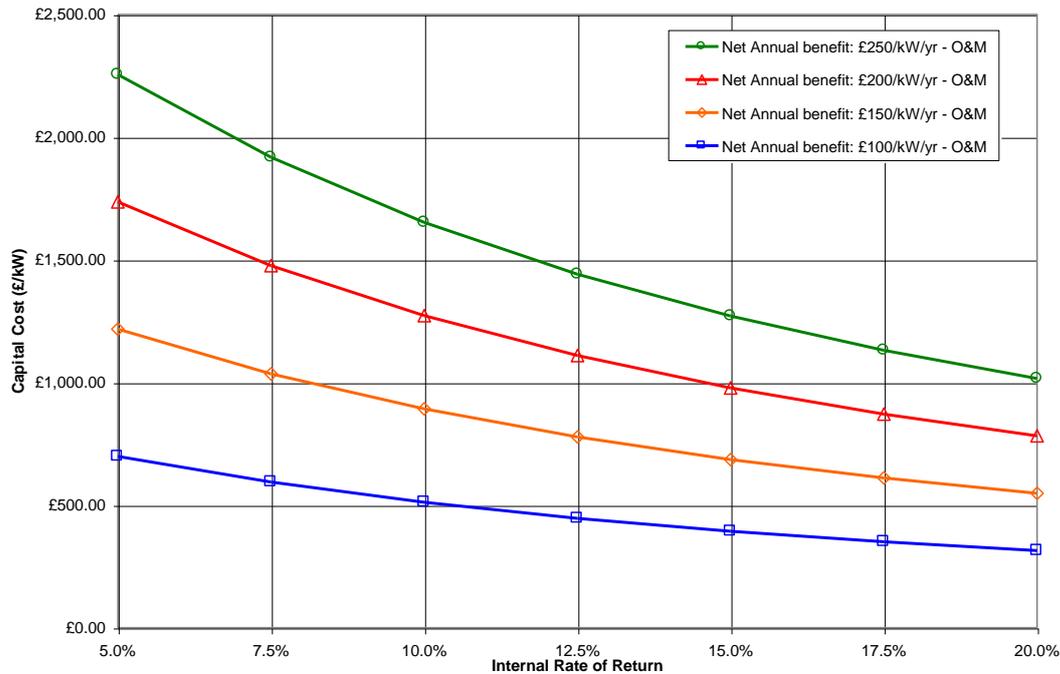


Figure 13.2: Example NPV Analysis Result (assumed 15 year lifetime)

In this example, the target capital costs for an EES system is plotted as a function of the internal rate of return (discount factor), for a series of project annual revenue flows. For example, if net annual benefits of £250/kW can be achieved (the green curve) and the internal rate of return is 7.5%, then systems with a capital cost of around £1,800 per kW will provide the necessary rate of return. However, if only £100/kW per year can be obtained (blue curve) then the system must cost less than around £600 per kW. This approach clearly shows the impact of both the rate of return required and the net income on the target capital costs.

The template on the following page gives an example format which could be used to complete an NPV calculation for an EES installation.

A template is provided in Appendix 5, Section A5.3 which gives an example format which could be used to complete a NPV calculation for an EES installation.

The advantages and disadvantages of this method are as follows:

- **Advantages:**

- The results of the NPV analysis (i.e. difference between net present value of benefits – costs over project lifetime) can be compared to several comparative metrics (e.g. Net Present Worth for the project, Net Present Worth per kW installed etc.);
- The calculation method required is relatively straightforward, although assumptions must be made regarding the benefit in each year from each revenue stream;
- The benefits can be presented separately across a number of applications/revenue streams. This allows the effect of different assumptions regarding the revenue from each application on the resulting NPV to be tested;
- Analysis takes account of both inflation and the cost of capital; and
- The method can be applied to competing solutions (e.g. conventional reinforcement of the network) by altering the costs included and the resulting

revenue streams/benefits. The NPV values from each option can then be compared.

- **Disadvantages:**
 - The method is sensitive to assumptions regarding the discount factor/interest rate (although this also applies to appraisals of alternative investments and other methodologies); and
 - Although it is possible to calculate the NPV on a per kW basis, analysis of this type must consider the minimum level of intervention required. For example, the NPV per kW depends on the net present value of the benefits, which in turn depends on the revenue from each application. As the rating of the unit changes the available revenue streams will also change (e.g. there is a minimum rating required to defer reinforcement of the distribution network).

13.1.2 Revenue Gap

The 'Revenue Gap' method can be used to show the relative impact of different applications/revenue streams on the business case, how this compares to the annuitised project costs and the resultant 'Revenue Gap'. The 'Revenue Gap' represents the additional income required per year to break-even. Like the NPV methodology, this provides a very intuitive "feel" for the viability of a project.

A template is provided in Appendix 5, Section A5.4 which gives an example format which could be used to complete a 'Revenue Gap' calculation for an EES installation.

The inputs to this calculation are broadly similar to the NPV methodology described in Section 13.1.1 above, as follows:

- Capital and operating costs are split across each year of the system's lifetime, with a capital recovery factor applied to the upfront capital costs incurred at the start of the project;
- Benefits are expressed based on current values (i.e. without a discounting/inflation factor) for each application revenue stream;
- An 'Annuitised Revenue Target' (£/kW) is then calculated based on the Total Costs in Year 1 (made up of the annualised capital cost, plus operating costs), divided by the rating of the unit. This represents the amount of revenue which would be required each year to break-even;
- The annual benefit from each application/revenue stream is expressed separately and divided by the rating of the unit (i.e. income per year per kW rating); and
- The difference between the sum of the annual benefits and the annual revenue target is the 'Revenue Gap' which must be filled in order to break-even.

An example of the output from this type of calculation is shown below. This shows the relative impact of each revenue stream on the total income, and also the importance of being able to access multiple revenue streams to the financial viability of this project. This information is more clearly visible, when compared with other methodologies such as Discounted Cash Flow/NPV (see Section 13.1.1). The example below shows a 'Revenue Gap' on the right of the graph, indicating that additional income (or a cost reduction, which would reduce the 'Annuitised Revenue Target') would be necessary to ensure the financial viability of this installation.

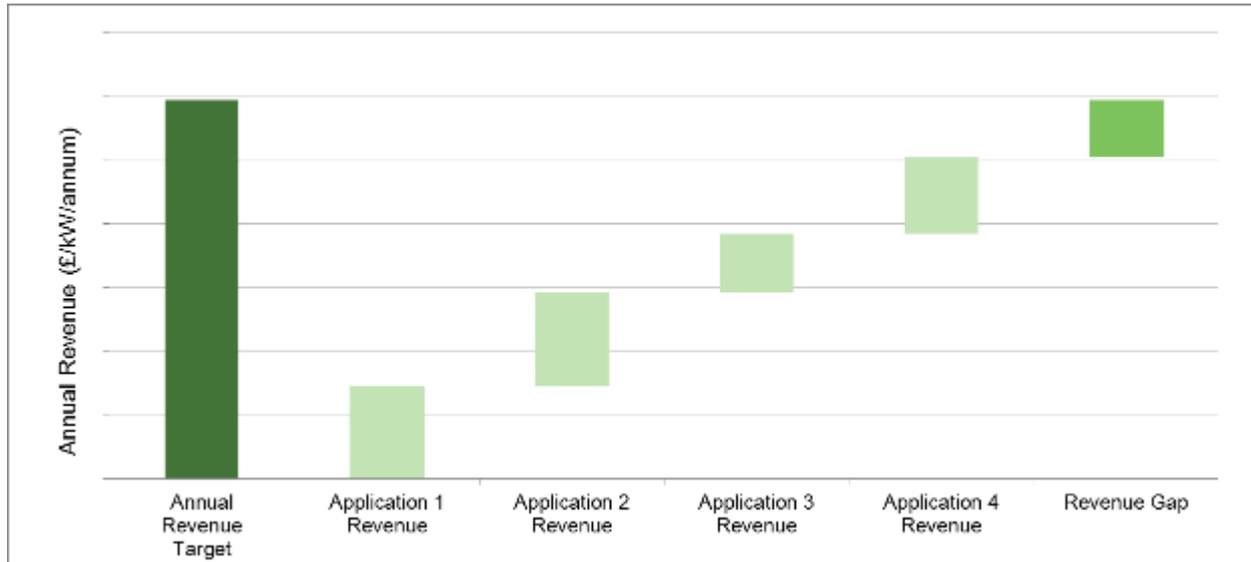


Figure 13.3: Example Revenue Gap Calculation Output

The advantages and disadvantages of this method are:

- **Advantages:**
 - The 'Revenue Gap' method gives a clear presentation of the benefits required to break-even, via the use of an 'Annual Revenue Target' figure (left hand side of Figure 13.3).
 - The results can be compared with other alternative solutions, where the costs/benefits of these can be expressed on a 'per kW' basis.
- **Disadvantages:**
 - Similarly to the NPV method described in Section 13.1.1, the use of a 'per kW' figure can result in losing the nuances of minimum levels of intervention. As the rating of the unit changes the available revenue streams will also change, so the benefits cannot necessarily be scaled to any rating (e.g. there is a minimum rating required to defer reinforcement of the distribution network).
 - Further analysis may be necessary to compare against other solutions due to the use of a 'per kW' figure.

13.1.3 NPV Scenario-Based (Full MW Method)

The NPV scenario-based methodology is that adopted by the Smarter Network Storage project. This compares the total lifetime costs (i.e. NPV of CAPEX and OPEX) and the NPV of total lifetime benefits of the project (see explanation in Section 13.1.1). The difference between the costs and lifetime benefits is the 'Net Costs' which can then be compared to 'Net Cost' of other solutions. An example of the output of this type of analysis is shown in Section 13.2.

The advantages and disadvantages of this method are:

- **Advantages:**
 - Provides a clear representation of the overall project costs/benefits;
 - Can easily be compared with other alternatives solutions, via the use of the 'net cost' result; and
 - The results can be presented based on the total lifetime costs and benefits, or on an annuitised basis.

- **Disadvantages:**

- The results of the analysis are specific to each installation and involve detailed assumptions regarding the costs and value of each revenue stream. The result (net cost) is therefore difficult to compare against generic projects, unless a similar level of detail is known regarding the assumptions made in the analysis.

13.1.4 Levelised Cost of Energy (LCOE)

The LCOE concept is typically used for comparing the cost-effectiveness of different generation technologies. It represents the per-kilowatt hour cost of building and operating a piece of equipment (e.g. a generator, or in this case an EES device) over an assumed financial life and duty cycle. The LCOE value (£/kWh or MWh) can be defined as:

“the constant unit cost of a payment stream that has the same present value as the total cost of building and operating a generating plant over its life¹⁸⁹”

This approach also uses the NPV method, as the expenses (upfront investment and ongoing costs) and payment streams are calculated based on discounting from a shared reference date. The benefits of operation of the system are factored in by netting of the annualised cost. The following formula is used for calculating the LCOE for new generation plant¹⁹⁰:

$$LCOE = \frac{I_0 + \sum_{t=1}^n \frac{A_t}{(1+i)^t}}{\sum_{t=1}^n \frac{M_{t,el}}{(1+i)^t}}$$

where:

- LCOE = Levelised Cost of Energy (£/kWh)
- I_0 = Investment Expenditure (£)
- A_t = Annual total costs in year t (£)
- $M_{t,el}$ = Produced quantity of electricity in year t (kWh)
- i = Interest Rate (%)
- n = Economic operational life in years
- t = Year of lifetime (1, 2, 3....n)

A template is provided in Appendix 5, Section A5.4 which gives an example format which could be used to complete a LCOE calculation for an EES installation.

The advantages and disadvantages of this method are as follows:

¹⁸⁹ Levelized Cost of Energy Calculation. Definition from: http://csep.efchina.org/report/20112844913435.70772110666485.pdf/Levelized%20Cost%20of%20Energy%20Calculation_BV_EN.pdf Accessed 27/10/2014

¹⁹⁰ Levelized Cost of Electricity Renewable Energy Technologies Study. Fraunhofer ISE. November 2013. Available from: <http://www.ise.fraunhofer.de/en/publications/veroeffentlichungen-pdf-dateien-en/studien-und-konzeptpapiere/study-levelized-cost-of-electricity-renewable-energies.pdf/view> Accessed 27/10/2014

- **Advantages:**
 - The LCOE methodology is widely used across various generation technologies. An example of this is the 'Project Costs of Generating Electricity' published by the International Energy Agency, comparing the LCOE of different generation technologies from different countries¹⁹¹.
- **Disadvantages:**
 - When this methodology is used to assess the LCOE of a generating technology the result (£/kWh) is equivalent to the price which would need to be received for the energy generated in order to break-even over the project life. In the case of EES systems the result is less easy to interpret;
 - A method must be devised to include the energy export/import. This is clearly dependent on a wide variety of factors, such as the relative incomes available from different revenue streams, the operating regime, round-trip efficiency, cost of 'charging' electricity (may be time variable) etc;
 - Analysis of the energy output per year is complex and involves a number of assumptions including; the mix of revenue streams to be exploited, number of times each will occur each year, response required etc. The complexity of these assumptions therefore has the potential to lead to inaccuracies in the final result; and
 - Whilst an established methodology exists to include the 'cost' elements of an installation within the LCOE methodology, there is a lack of consensus around the calculation and incorporation of benefits.

13.2 Cost Benefit Analysis Case Studies

This section presents a number of examples of cost:benefit analyses, using the information provided in Appendix 1. It should be noted that whilst only a sub-set of projects are included here, other projects are completing cost:benefit analyses (using various methodologies) as part of their work, and this will be disseminated in due course, via the channels shown in Section 15 (Further Reading). In addition, the true value (and accessibility) of each revenue stream will become clearer as projects progress and further operational data becomes available. In some cases the business case has been developed based on the modelling of the likely operating regime of the system and the future value of each revenue stream.

¹⁹¹ Projected Costs of Generating Electricity. 2010 Edition. International Energy Agency and Nuclear Energy Agency. [Online]. Available from: http://www.iea.org/publications/freepublications/publication/projected_costs.pdf Accessed 27/10/2014

Project Name:	LV Connected Batteries	DNO:	SSE Power Distribution
Network Location:	"T" connection off an LV Feeder		
Project Description:	This project demonstrates the operation of a fleet of LV connected energy storage units (3 x single phase 25kW/25kWh Li-Ion batteries) with renewable generation. During the testing of the units the use of the EES devices for peak shaving, solar power absorption, voltage support, phase balancing and aggregated demand reduction was demonstrated.		
Methodology Employed:	Comparison of lifetime costs of conventional solution and EES installation.		
Costs of EES:	Capital cost x1 CES unit	£65,000	
	Installation	£1,000	
	Lifetime costs of losses	£1,051	
	Cost of a single phase CES unit over 15 years = £67,051		
	Total cost of three CES units = £201,153¹⁹²		
	<i>Costs based on the following assumptions:</i>		
	<ul style="list-style-type: none"> • A UK compliant voltage PCS will be provided eliminating the need for an auxiliary transformer; • The capital cost is the same as the initial purchase price in 2011 (unlikely to be the case as the cost of Li-Ion units reduce); • The unit will operate at 1 cycle per day, at a depth of discharge of 80% for 15 years; • The average efficiency is 80%; • The cost of losses is taken as a static figure of 4.8p per kWh; and • The costs of the control system are not included as this is split across multiple storage units. 		
Cost of Alternative Solution:	The additional capacity potential provided by the CES units in this project is similar to that of an SEPD cable upgrade in the loading levels of the standard cables currently procured. Increasing a 95 mm ² to 185 mm ² provides approximately 100 Amps capacity – the cost of this cable overlay is therefore the alternative solution against which EES will be compared.		
	Cost of traditional cable overlay: 450m of cable @ £178 per m ¹⁹³ = Total cost of £80,100		
Result of CBA Analysis:	In this case, it can be shown that the cost of the EES units is significantly more than the alternative 'conventional solution'. In this case the only application/revenue stream which is being exploited is the avoidance of the cable overlay. The inclusion of other revenue streams (if accessible by units of this size, in this location) could alter the result of the CBA.		

¹⁹² LCNF Tier 1 Closedown Report. Low Voltage Connected Energy Storage. SSET 1008. [Online]. Available from: <https://www.ofgem.gov.uk/ofgem-publications/89553/sset1008lvconnectedbatteriesclosedown2ndsubmission.pdf> Accessed 30/10/2014

¹⁹³ SSEPD ED1 Business Plan http://www.yourfutureenergynetwork.co.uk/03_reliable2014.pdf

Project Name:	SolaBristol	DNO:	Western Power Distribution
Network Location:	Connected on the customer –side of the meter in 30 homes and 5 schools/offices with PV generation.		
Project Description:	The EES aspect of SolaBristol is exploring the use of EES installations on ‘the customer side of the meter’ to maximise the customer benefits of PV, whilst minimising the network impact.		
Methodology Employed:	Comparison of costs of conventional solution and EES installation.		
Costs of EES:	The cost of installing EES equipment in thirty properties per substation (across three LV feeders) is estimated based on: <ul style="list-style-type: none"> • LV Network Manager in substation: £2,400 • 30 x EES Units: 30 x £1,550 = £46,500 • Total per substation = £48,900 		
Cost of Alternative Solution:	The alternative solution would involve an overlay of 120m of LV cable and the installation of harmonic filtering equipment on three LV feeders, at a cost of £63,720.		
Result of CBA Analysis:	Analysis of the total potential saving has been undertaken based on the predicted uptake of micro-generation and the number of substations where reinforcement may be necessary. This is shown in the table below.		

The projection below is taken from the original project submission. It should be noted that the final cost of the Bristol solution will be analysed at project end in Jan 2016.

The costs for both solutions above are based on capital cost only, and do not include the impact of ongoing O&M expenditure.

Year	Estimated Number of Locations	Average micro-generation (kWe)	Cost Savings per Substation	Cost Savings per Year
2015	40	60	£14,820	£592,800
2016	60	60	£14,820	£889,200
2017	80	60	£14,820	£1,185,600
2018	100	60	£14,820	£1,482,000
2019	120	60	£14,820	£1,778,400
2020	140	60	£14,820	£2,074,800
2021	160	60	£14,820	£2,371,200
2022	180	60	£14,820	£2,667,600
2023	200	60	£14,820	£2,964,000
2024	200	60	£14,820	£2,964,000
2025	200	60	£14,820	£2,964,000
2026	200	60	£14,820	£2,964,000
2027	200	60	£14,820	£2,964,000
2028	200	60	£14,820	£2,964,000
2029	200	60	£14,820	£2,964,000
2030	200	60	£14,820	£2,964,000
Total:				£36,753,600

Project Name: Smarter Network Storage **DNO:** UK Power Networks

Network Location:

Project Description: The project is exploring the commercial and regulatory barriers of storage when operated for multiple network and commercial applications; including industry-wide consultation on business model structures in July 2013

Methodology Employed: NPV Scenario Based (Full MW)

Costs: In NPV terms, the installed cost of the 6MW/10MWh storage solution, including all design, civil and electrical works is approximately £11.2 million.

Including estimates of lifetime operational expenditure, the NPV of the total system over 10 years is estimated to be £11.4 million.

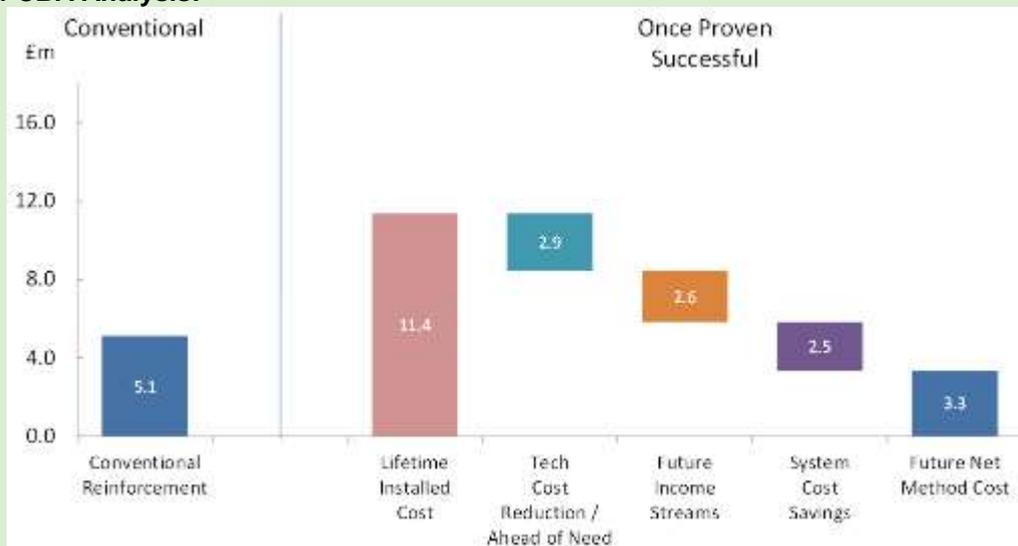
The breakdown of the design, civil and electrical aspects is shown in Appendix 1, Section A1.15.

Benefits: The NPV cost of the conventional solution, to solve the security of supply constraint, is approximately £5.1 million, (i.e. significantly lower than the storage lifetime costs above).

However, taking into account just the benefits of future income streams, and wider system operational savings and carbon reduction, the overall NPV cost once proven successful is equivalent to approximately £3.3 million (based on December 2014 project costs and analysis). The benefits included are as follows:

- ‘Tech Cost Reduction’ - Cost reductions anticipated in storage technology up to the point at which network intervention would otherwise be required (£2.9 million) – this adjustment accounts for the fact that strictly, the storage system was procured for the SNS LCNF project approximately 2 years ahead of need
- ‘Future Income Streams’ – The revenues available from providing additional system support through ancillary services (£2.6 million) – this income is assumed to come from a mix of STOR, FCDM and Fast Reserve only
- ‘System Cost Savings’ – The wider system benefits generated as a result of the relative reduction in peak demand & displaced peaking generation, reduced curtailment and carbon savings from 6MW of storage (£2.5 million)

Result of CBA Analysis:



This shows the difference between the conventional reinforcement solution (£5.1 million) and the Future Net Method Cost of EES (£3.3 million). The net benefit of the EES installation is therefore £1.8 million.

Project Name: Orkney Energy Storage Park **DNO:** SSE Power Distribution

Network Location: Connected to the 11kV distribution board at Kirkwall power station, Orkney Isles.

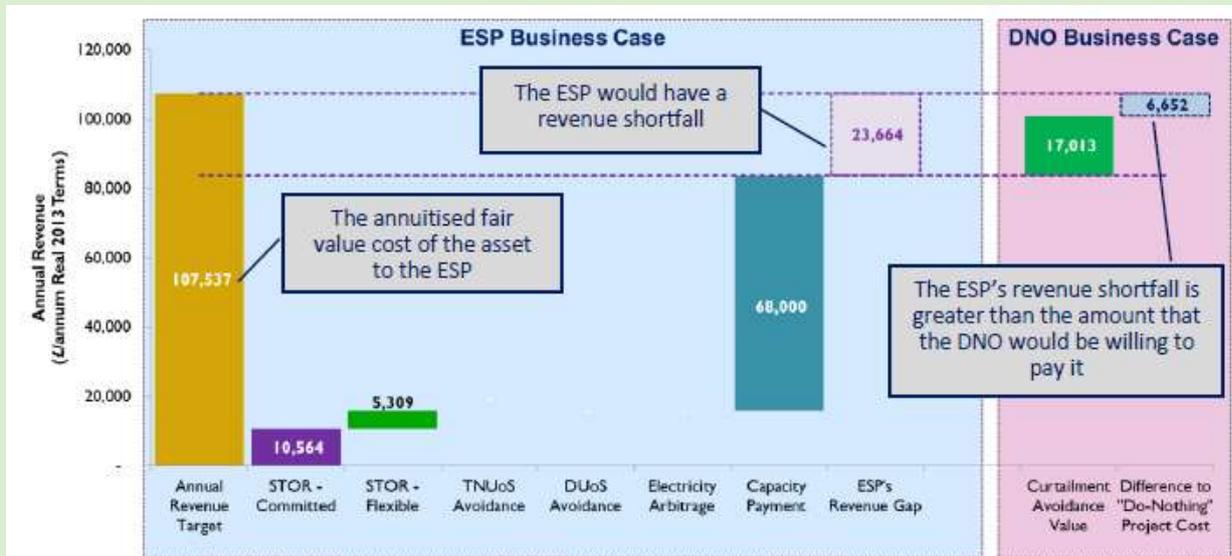
Project Description: This project is trialling DNO use of EES via the use of a '3rd party contracted services' business model. In this case SSEPD have entered into a contract with a third party to provide constraint management services in defined time windows. It is up to the discretion of the 3rd party whether they chose to operate the constraint management service or not.

Modelling work has been carried out to determine the potential business case in three scenarios: Today's Orkney Business Case, Generic Energy Storage System site (today) and Tomorrow's Orkney Business Case.

Methodology Employed: Revenue gap method (see Section 13.1.2)

Analysis Approach: The annual revenue target (for the Energy Storage Provider (ESP)) is set based on the totals costs of the unit (both capital and operating). The annual revenues available to the ESP from various applications (outside of providing services to the DNO) in the future have then been analysed – including STOR (both committed and flexible) and the Capacity Market.

Result of CBA Analysis:



Basic parameters were set in order to allow the business case to be built up, including setting the battery size to 2MW 500kWh, and the system operating from 2018 (i.e. for the 'future' scenario) for ten years. From this the annuitised project costs could be calculated. These came from literature as the project costs were unknown due to it being a 3rd party installation. One example of the literature used was Gruenewald et al 2011. The annuitised costs are shown by the orange bar on the graph above.

The revenue streams were built up via an appraisal of likely ancillary market during the project lifetime (2018 – 2028). The resulting revenue streams were STOR (both flexible and committed) and the Capacity Market. Comparing the total annual revenue available against the annuitised project costs shows a 'revenue gap' (grey column on the right hand side of the blue box). This 'revenue gap' is reduced further by considering the value of the constraint management service, which was quantified as the additional value the generators would receive by being able to export more energy. However, this model is economically imperfect as the DNO pays for the service, whilst the generators receive the benefits.

When all these costs and revenues are aggregated a 'revenue gap' still exists (far right hand column). This could be closed by changing location or details of some of the ancillary service contracts.

14 Concluding Remarks

The GPG has been developed by EA Technology, working with ESOF. Its aim is to consolidate the lessons from a range of EES projects in order to describe ‘good practice’ in deploying EES, and therefore to become a reference guide for others installing energy storage.

The Guide has been informed by a wide range of case studies, from both DNO led projects and those undertaken by system developers under the DECC Energy Storage Demonstration Competition. These case studies have been used to describe lessons and learnt and ‘good practice’ through the whole project life-cycle. The Guide can therefore be used as a reference at different stages of a project, or by different parties (e.g. procurement managers, commissioning engineers etc.). This is illustrated by Figure 14.1 below.



Figure 14.1: Use of the Good Practice Guide throughout the Project Lifecycle

The information contained in this Guide reflects the position at the time of writing, when a substantial number of the case study projects are ongoing. Further information (for example, network benefits and cost:benefit analysis) will be published in due course and a number of sources of further information are given in Section 15. The Guide has sought to describe ‘good practice’ rather than prescribe rigid standards. The knowledge gained by DNOs through their projects, and described in this Guide may feed into the development of Standards in the future, such as IEC-TC120 (as described in Section 6.7).

15 Further Reading

The previous sections of this Guide have referenced a range of projects and publications. The majority of these projects are ongoing at the time of writing, with further outputs to be published in due course. This section details the locations where these outputs will be published and other sources of further information.

15.1 GB Network Operator Sector

Northern Powergrid – Customer Led Network Revolution:

<http://www.networkrevolution.co.uk/resources/>

This website contains the outputs from the CLNR project (due to be completed in December 2014). This includes reports, videos, conference presentations and datasets from network trials. It will continue to be updated within the final outputs from the project.

SSEPD – Future Networks Innovation:

<https://www.ssepd.co.uk/FutureNetworks/>

This website links to portfolio of SSEPD energy storage projects described in this Guide, including links to various project outputs.

UK Power Networks – Short-Term Discharge Energy Storage:

<http://innovation.ukpowernetworks.co.uk/innovation/en/Projects/tier-1-projects/demonstrating-the-benefits-of-short-term-discharge-energy-storage/>

This website provides an outline of UK Power Network's LCN Fund Tier 1 project (completed in January 2014), along with the project outputs.

UK Power Networks – Smarter Network Storage:

[http://innovation.ukpowernetworks.co.uk/innovation/en/Projects/tier-2-projects/Smarter-Network-Storage-\(SNS\)/](http://innovation.ukpowernetworks.co.uk/innovation/en/Projects/tier-2-projects/Smarter-Network-Storage-(SNS)/)

Outputs from Smarter Network Storage (due to be completed in December 2016) are provided on this website, including reports (particularly on the commercial, regulatory and planning aspects of installing EES), presentations and images. The business case for SNS (presented in Section 13.2) will be updated and published on this website throughout the project, as the costs and revenues become clearer.

Western Power Distribution – Innovation Project Outputs:

[http://www.westernpowerinnovation.co.uk/Documents-\(1\).aspx](http://www.westernpowerinnovation.co.uk/Documents-(1).aspx)

Outputs from WPD's range of innovation projects (including FALCON and SolaBristol, described in this Guide) are published on the website above. This includes presentations from events and project reports.

National Grid – Future Energy Scenarios 2014:

<http://www2.nationalgrid.com/uk/industry-information/future-of-energy/future-energy-scenarios/>

This annual publication describes National Grid's analysis of credible future energy scenarios (to 2035 and 2050). It includes an assessment of the flexibility which will be required, and the relative costs and revenues available to a number of storage technologies.

Energy Networks Association – Smarter Networks Portal:

<http://www.smarternetworks.org/ProjectList.aspx?TechnologyID=7>

The ENA Smarter Networks Portal collates together outputs from each of the innovation projects being completed for both electricity and gas transmission and distribution networks. The link above relates to those projects investigating energy storage and demand response.

15.2 UK Government/Agency Reports and Projections

Electricity Networks and Storage Technology Innovation and Needs Assessment (Carbon Trust):

<http://www.carbontrust.com/our-clients/e/electricity-networks-and-storage-tina>

This report was completed in 2012 for the Low Carbon Innovation Coordination Group and reviews the potential future role of energy storage in the future energy system, areas for innovation and the case for UK public sector intervention.

Strategic Assessment of the Role and Value of Energy Storage Systems in the UK Low Carbon Energy Future (Imperial College London):

<http://www.carbontrust.com/resources/reports/technology/energy-storage-systems-strategic-assessment-role-and-value>

This report (published in 2012) reviews the future role of energy storage in the UK and analyses the potential of electricity storage to reduce the costs of electricity generation in the future GB energy system.

15.3 Other UK Reports

'Energy Storage: The Missing Link the UK's Energy Commitments' (Institution of Mechanical Engineers)

<http://www.imeche.org/docs/default-source/reports/imeche-energy-storage-report.pdf?sfvrsn=4>

This report provides a review of energy storage technologies for electricity, heat and transport and suggests a need for the UK government to prioritise the development and deployment of energy storage technologies.

Storage Business Models in the GB Market (Pöyry and Swanbarton):

http://www.poyry.com/sites/default/files/imce/374_elexon_storagebusinessmodelsandgbmarket_v2_0.pdf

This report (published in July 2014, for Elexon) examines the different business models for storage deployment, and their interactions with the trading and settlement arrangements. It also provides a number of recommendations in relation to the regulatory and commercial issues which currently exist.

15.4 Worldwide Information

International Energy Agency Technology Roadmap: Energy Storage

<http://www.iea.org/publications/freepublications/publication/TechnologyRoadmapEnergyStorage.pdf>

The IEA Technology Roadmap (published 2014) describes the range of applications for electricity and thermal energy storage throughout the energy system. It also discusses existing technology, policy and economic barriers which hinder deployment of energy storage.

U.S. Department of Energy Storage Systems Program (Sandia National Laboratories)

<http://www.sandia.gov/ess/>

The US DOE energy storage systems program aims to develop advanced energy storage technologies and systems in collaboration with industry, academia and government institutions. Various resources and tools, including the DOE/EPRI 2013 Electricity Storage Handbook and a review of codes and standards relevant to the US market are available via this website.

16 Acknowledgements

The support of a number of parties throughout the development of the GPG is acknowledged, as follows:

- The funding support provided by DECC under the Energy Storage Component Research and Feasibility Study Scheme, without which the production of this GPG would not be possible;
- Members of ESOF for their contribution to the development and review of the GPG, and provision of case study material;
- Other parties deploying EES as part of DECC/ETI funded demonstration projects for the provision of case study material; and
- Additional funding contributions provided by Electricity North West, National Grid, Northern Powergrid, Scottish and Southern Energy Power Distribution, SP Energy Networks, UK Power Networks and Western Power Distribution to support the DECC funding.

Appendix 1 Project Case Studies

Note: The case studies contained in this Appendix were compiled during the Summer of 2014 and reflect the individual project's status at the time of writing.

Each project is likely to have progressed further prior to the publication of this Guide. Sources of updated information for the various projects are given at the end of each case study and within Section 15.

A1.1 CLNR- Rise Carr (2.5 MW, 5 MWh)

Project Description:

Project Name:	Customer Led Network Revolution – Rise Carr
Principal Contact:	Ian Lloyd Northern Powergrid
Start Date:	Construction May 2012
End Date:	Commissioned November 2013
Project Status:	Commissioned
Project Highlights:	Multiple devices of various sizes interacting controlled within a large Smart Grid trial integrating multiple technologies.

Description of Technology:

Technology Employed:	A123 systems Inc. Lithium ion iron nanophosphate
System Supplier:	A123 for battery and system integration, Dynapower for PCS
Description of Technology:	Li-Ion Battery units 2500kWh x 2, 5000kWh, Batteries occupy two bespoke containers 14m x 4m x 3m (lxbxh) AC 6kV and LV AC/DC components installed in a constructed containment 14m x 4m x 5m (including air con systems) Transformer occupies a chamber 4m x 4m x 4m Overall footprint 11m x 21m
Description of PCS:	Dynapower : inverter between AC and DC bus
Previous track record:	First of a kind in GB
Number of Units Installed:	One three phase unit
Installation Location:	Rise Carr, Darlington, UK Connected directly via circuit breaker (CB) to a 6kV Primary substation bar at Rise Carr, Darlington, County Durham Existing primary substation compound.



Codes, Standards and Licensing:

Certification offered by equipment supplier in relation to energy storage module:	EU 2006/66/EC batteries must have crossed wheeled bin symbol. Li-ion batteries with electronic components subjected to EMC directive 93/97/EEC. Must have CE marking. Basic cells are approved according to UL 1642.
Codes considered in safety assessment:	Information provided by A123 and identified by Hazard and operability study completed by PB Power.
Planning Processes:	Permitted development schedule in coordination with county Durham authorities and Darlington Borough council via Northern Powergrid wayleave
Lessons learnt in relation to codes, standards and licensing:	There are very few standards for battery and PCS devices that can be quoted in the specification.

Procurement:

Process followed:	Rise Carr is part of an R&D project within the Customer Led Network Revolution project, with A123 commissioned to design, manufacture and install. Northern Powergrid to witness and commission interfaces to networks.
Scope of supply:	Design of system, delivery, installation and commission with service support
Associated BoP required for project:	The project was funded using CLNR awarded Tier 2 LCNF funding.
Process for development of specification:	Consideration of functionality of device required feeding into development of specification. Iterations with the supplier. Installed on a 6kV network in an urban environment.
Performance/select ion criteria and standards applied:	Full market procurement tender completed, specifics based on requested power and duration output, together with overall maximum footprint constraints and budgetary limitations
Acceptance tests employed:	Factory Acceptance Tests (FAT) on entire system separates completed by A123 and Dynapower Cold commissioning to prove functionality. Northern Powergrid witnessed A123 major component testing Northern Powergrid Network interface and G59 protection commission tests After final connections to 6kV network hot commissioning testing including charge and discharge onto network via primary source.
Warranty and after-sales support included:	Full Maintenance and Service support with the exception of consumables for three years after commission completion and site acceptance Maintenance arrangements include schedules of monthly visual live inspections, 6 monthly and annual arrangements, together with remote dial in support.
Lessons Learnt:	As the technology is still immature careful coordination with Procurement has to be maintained. Emerging market of Battery manufacturers in long duration and high density battery cells are vulnerable to low uptake and market variations making such companies susceptible to financial risk. Existing install base of large scale batteries is not yet global and testing, legislation, operational practice and distribution and transmission codes of practice and safety rules are not well defined to the manufacturers and designers.

Training:

Operational Training Provided:	Combination of classroom and on-site training.
Authorisations and Personal Competence:	45 (to date) specialist standby Senior Authorised Persons (SAPs) and Authorised Persons (APs) have attended the training for operational access/egress, fire suppression disarming, network isolation, Battery and PCS points of isolation. Sanctioned authorisation detailed and granted by safety in coordination with training certification.
Lessons Learnt:	Build the relationship with those who will operate the device as early as possible. Involve them in the safety procedure discussions.

Installation:

Roles and responsibilities:	Northern Powergrid Client PB Power as CDM coordinator A123 supplier
Application of CDM Regulations	Project required CDM notification >500 man days
Site selection process used:	Site selected due to network configuration, available footprint, urban characteristics and primary transformer loading.
Site work:	Existing Primary substation building and curtilage. Foundations, security, earthing, cabling, craneage, ground load bearing , flood defence, assembly, etc.
Engagement with external stakeholders regarding site:	Way leaves, local authorities, local emergency services, local businesses and residents, Darlington borough council and parish.
Electrical connection and interfaces:	Established 6kV CB remotely controllable with full G59 protection and inter tripping with battery control system.
Ancillary services required:	Auxiliary supplies from primary substation auxiliary transformer. Uninterruptible Power Supply (UPS) system for safe shutdown control Water + glycol cooling for the IGBTs Heating, Ventilation and Air Conditioning in battery and control rooms
Access requirements:	Special training pre requisite, Northern Powergrid locking policy applies Control instructed access
Installation procedure:	Full detailed construction and lifting plans completed, coordinated by Northern Powergrid and CDM site coordinator
Handover to operational team:	
Lessons learnt:	



Safety and Operational Assessment:

Failure Modes and Effects Analysis:	
Risk Assessment Process:	Hazard identification and Hazard operability study was completed
Mitigation Measures Employed against Residual Risks:	Control restricted access. 2.4m palisade fencing, Electrified 3m fencing; only trained staff access the control room. Sanctioned authorisation on completion of training
Information Provided by the manufacturer/ system supplier:	Training material and on-site familiarisation
Integration with Existing Safety Rules:	Engineering Operational Standard was written as a point of reference. Method of isolation and earthing.
Engagement with external stakeholders:	Site neighbours were told what we were doing throughout the installation.
Lessons Learnt:	DSR treat up to 1500V DC as LV. Test equipment has limits when detecting voltages below 60V. More robust alarming function when undertaking innovative projects, New alarms were created within the control system to provide more information.

Operating Regime:

Applications:	Peak shaving, voltage support, Thermal support of the primary transformers, Thermal support of the EHV underground 33kV feeder and demand reduction response coordinated by overarching control system
Control Architecture:	A123 Aeros control system allows monitoring and controlling the different devices (batteries, Zone control, DC breakers, AC breakers, integrated fire suppression and detection system). Siemens RDC (remote distributed controller) as interface to host
Despatch mechanism:	The unit is currently in trial operating under despatched command from a mix of central and distributed controllers. Central control coordinated network voltages in tandem with primary transformer loading, whereas local distributed control offers thermal support via local coordination algorithms and following a state of charge profile coupled with the network load profile. BaU Network Control have the ability to disable the storage platform by initiating its safe mode.
Operating regime:	During trialling periods the unit is in operation daily and depth of discharge varies dependent on the thermal support requirement of the Primary transformers, as configured for the ANM controller trial.
Benefits from operation:	Benefits yet to be calculated, coordination with central control system is still under trial.

Cost:Benefit Case:

Full Cost benefit analysis is under evaluation using actual costs and projected distribution utilising the TRANSFORM model. These results will be published in the project closedown reports.

Further Information:

Additional Information:	www.networkrevolution.co.uk
References:	

A1.2 CLNR – High Northgate (100 kW, 200 kWh)

Project Description:

Project Name:	Customer Led Network Revolution – High Northgate
Principal Contact:	Ian Lloyd Northern Powergrid
Start Date:	Construction May 2012
End Date:	Commissioned November 2013
Project Status:	Commissioned
Project Highlights:	Multiple devices of various sizes interacting controlled within a large Smart Grid trial integrating multiple technologies.

Description of Technology:

Technology Employed:	A123 systems Inc. Lithium ion iron nanophosphate
System Supplier:	A123 for battery and system integration, ABB for PCS
Description of Technology:	Li-Ion Battery units 100kWh x 2, 200kWh, Batteries and inverter occupy a bespoke container 3m x 3m x 3m (lxbxh) All LV AC/DC components installed in the container with separation between the batteries and the inverters Isolation transformer (TX) occupies a chamber within the inverter 480V:400V ratio Overall footprint 3m x 3m
Description of PCS:	ABB : inverter between AC and DC bus
Previous track record:	First of a kind in GB
Number of Units Installed:	One three phase unit
Installation Location:	High Northgate, Darlington, UK Connected directly to the LV bar at High Northgate, Darlington, County Durham Existing substation compound.



Codes, Standards and Licensing:

Certification offered by equipment supplier in relation to energy storage module:	EU 2006/66/EC batteries must have crossed wheeled bin symbol. Li-ion batteries with electronic components subjected to EMC directive 93/97/EEC. Must have CE marking. Basic cells are approved according to UL 1642.
Codes considered in safety assessment:	Information provided by A123 and identified by Hazard and operability study completed by PB Power.
Planning Processes:	Permitted development schedule in coordination with county Durham authorities and Darlington Borough council
Lessons learnt in relation to codes, standards and licensing:	There are very few standards for battery and PCS devices that can be quoted in the specification.

Procurement:

Process followed:	High Northgate is part of a R&D project within the Customer Led Network Revolution project, with A123 commissioned to design, manufacture and install. Northern Powergrid to witness and commission interfaces to networks.
Scope of supply:	Design of system, delivery, installation and commission with service support
Associated BoP required for project:	The project was funded using CLNR awarded Tier 2 LCNF funding.
Process for development of specification:	Consideration of functionality of device required feeding into development of specification. Iterations with the supplier. Installed on a 0.4kV network in an urban environment.
Performance/select ion criteria and standards applied:	Full market procurement tender completed, specifics based on requested power and duration output, together with overall maximum footprint constraints and budgetary limitations
Acceptance tests employed:	FAT on entire system separates completed by A123 Cold commissioning to prove functionality. Northern Powergrid witnessed A123 major component testing Northern Powergrid Network interface and G59 protection commission tests After final connections to 0.4kV network hot commissioning testing including charge and discharge onto network via source.
Warranty and after-sales support included:	Full Maintenance and Service support with the exception of consumables for three years after commission completion and site acceptance Maintenance arrangements include schedules of monthly visual live inspections, 6 monthly and annual arrangements, together with remote dial in support.
Lessons Learnt:	As the technology is still immature careful coordination with Procurement has to be maintained. Emerging market of Battery manufacturers in long duration and high density battery cells are vulnerable to low uptake and market variations making such companies susceptible to financial risk. Existing install base of large scale batteries is not yet global and testing, legislation, operational practice and distribution and transmission codes of practice and safety rules are not well defined to the manufacturers and designers.

Training:

Operational Training Provided:	Combination of classroom and on-site training.
Authorisations and Personal Competence:	45 (to date) specialist standby SAPs and APs having attended the training for operational access/egress, fire suppression disarming, network isolation, Battery and PCS points of isolation. Sanctioned authorisation detailed and granted by safety in coordination with training certification.
Lessons Learnt:	Build the relationship with those who will operate the device as early as possible. Involve them in the safety procedure discussions.

Installation:

Roles and responsibilities:	Northern Powergrid Client, A123 supplier
Application of CDM Regulations	Project not notifiable as less than 500 man days. Site Risk Assessment and Method Statement completed.
Site selection process used:	Site selected due to network configuration, available footprint, urban characteristics and transformer loading.
Site work:	Existing substation building and curtilage. Foundations, security, earthing, cabling, craneage, ground load bearing, assembly, etc.
Engagement with external stakeholders regarding site:	Way leaves, local authorities, local emergency services, local businesses and residents, Darlington borough council and parish.
Electrical connection and interfaces:	Established 0.4kV LV fuse board with additional fused protection in Northern Powergrid standard Industrial Service Unit (ISU) with full G59 protection and inter tripping with battery control system.
Ancillary services required:	Auxiliary supplies fed from LV distributor. UPS system for safe shutdown control Fan cooling for the IGBTs Heating, Ventilation and Air Conditioning in battery and control room
Access requirements:	Special training pre requisite, Northern Powergrid locking policy applies Control instructed access
Installation procedure:	Full detailed construction and lifting plans completed, coordinated by Northern Powergrid and site coordinator
Handover to operational team:	
Lessons learnt:	

Safety and Operational Assessment:

Failure Modes and Effects Analysis:	
Risk Assessment Process:	Hazard identification and Hazard operability study was completed
Mitigation Measures Employed against Residual Risks:	Control restricted access. 2m palisade fencing; only trained staff access the control room. Sanctioned authorisation on completion of training
Information Provided by the manufacturer/ system supplier:	Training material and on-site familiarisation
Integration with Existing Safety Rules:	Engineering Operational Standard was written as a point of reference. Method of isolation and earthing.
Engagement with external stakeholders:	Site neighbours were told what we were doing throughout the installation.
Lessons Learnt:	DSR treat up to 1500V DC as LV. Test equipment has limits when detecting voltages below 60V. More robust alarming function when undertaking innovative projects, New alarms were created within the control system to provide more information.

Operating Regime:

Applications:	Peak shaving, voltage support, Thermal support of the distribution transformer, Thermal support of the HV underground 6kV feeder and demand reduction response coordinated by overarching control system
Control Architecture:	A123 Aeros control system allows monitoring and controlling the different devices (batteries, Zone control, DC breakers, AC breakers, integrated fire suppression and detection system). Siemens RDC (remote distributed controller) as interface to host
Despatch mechanism:	The unit is currently in trial operating under despatched command from a mix of central and distributed controllers. Central control coordinated network voltages in tandem with transformer loading on upstream networks, whereas local distributed control offers voltage and thermal support via local algorithms or state of charge profiles coupled to the network load profile. BAU Network Control has the ability to disable the storage platform by initiating its safe mode.
Operating regime:	During trialling periods the unit is in operation daily and depth of discharge varies dependent on the thermal support requirement of the transformer, as configured for the ANM controller trial.
Benefits from operation:	Benefits yet to be calculated, coordination with central control system is still under trial.

Cost:Benefit Case:

Full Cost benefit analysis is under evaluation using actual costs and projected distribution utilising the TRANSFORM model. These results will be published in the project closedown reports.

Further Information:

Additional Information:	www.networkrevolution.co.uk
References:	

A1.3 CLNR – Wooler Ramsey (100 kW, 200 kWh)

Project Description:

Project Name:	Customer Led Network Revolution – Wooler Ramsey
Principal Contact:	Ian Lloyd Northern Powergrid
Start Date:	Construction May 2012
End Date:	Commissioned November 2013
Project Status:	Commissioned
Project Highlights:	Multiple devices of various sizes interacting controlled within a large Smart Grid trial integrating multiple technologies.

Description of Technology:

Technology Employed:	A123 systems Inc. Lithium ion iron nanophosphate
System Supplier:	A123 for battery and system integration, ABB for PCS
Description of Technology:	Li-Ion Battery units 100kVA, 200kWh Batteries occupy one bespoke container 5m x 3m x 2.5m (lxbxh) AC LV and LV AC/DC components installed in an existing container 5m x 3m x 2.5m (including air con system) Isolation TX occupies a chamber within the inverter 480V:400V ratio Distribution TX is outside the container Overall footprint as above
Description of PCS:	ABB : inverter between AC and DC bus
Previous track record:	First of a kind in GB
Number of Units Installed:	One three phase unit
Installation Location:	Wooler Ramsey Substation Connected directly via discrete fused protection to a new LV Feeder at, Wooler Ramsey, 16m W of 16 Broomey Road, Wooler, Northumberland, NE71 6NZ Existing distribution substation compound.



Codes, Standards and Licensing:

Certification offered by equipment supplier in relation to energy storage module:	EU 2006/66/EC batteries must have crossed wheeled bin symbol. Li-ion batteries with electronic components subjected to EMC directive 93/97/EEC. Must have CE marking. Basic cells are approved according to UL 1642.
Codes considered in safety assessment:	Information provided by A123 and identified by Hazard and operability study completed by PB Power.
Planning Processes:	Permitted development schedule in coordination with Northumberland authorities and Northumberland County Council via Northern Powergrid.
Lessons learnt in relation to codes, standards and licensing:	There are very few standards for battery and PCS devices that can be quoted in the specification.

Procurement:

Process followed:	Wooler Ramsey is part of a R&D project within the Customer Led Network Revolution project, with A123 commissioned to design manufacture and install. Northern Powergrid to witness and commission interfaces to networks.
Scope of supply:	Design of system, delivery, installation and commission with service support
Associated BoP required for project:	The project was funded using CLNR awarded Tier 2 LCNF funding.
Process for development of specification:	Consideration of functionality of device required feeding into development of specification. Iterations with the supplier. Installed on a 0.4kV network in a rural environment.
Performance/select ion criteria and standards applied:	Full market procurement tender completed, specifics based on requested power and duration output, together with overall maximum footprint constraints and budgetary limitations
Acceptance tests employed:	FAT on entire system separates completed by A123 and ABB Cold commissioning to prove functionality. Northern Powergrid witnessed A123 major component testing Northern Powergrid Network interface and G59 protection commission tests After final connections to 0.4kV network hot commissioning testing including charge and discharge onto network via primary source.
Warranty and after-sales support included:	Full Maintenance and Service support with the exception of consumables for three years after commission completion and site acceptance Maintenance arrangements include schedules of monthly visual live inspections, 6 monthly and annual arrangements, together with remote dial in support.
Lessons Learnt:	As the technology is still immature careful coordination with Procurement has to be maintained. Emerging market of Battery manufacturers in long duration and high density battery cells are vulnerable to low uptake and market variations making such companies susceptible to financial risk. Existing install base of large scale batteries is not yet global and testing, legislation, operational practice and distribution and transmission codes of practice and safety rules are not well defined to the manufacturers and designers.

Training:

Operational Training Provided:	Combination of classroom and on-site training.
Authorisations and Personal Competence:	45 (to date) specialist standby SAPs and APs having attended the training for operational access/egress, fire suppression disarming, network isolation, Battery and PCS points of isolation. Sanctioned authorisation detailed and granted by safety in coordination with training certification.
Lessons Learnt:	Build the relationship with those who will operate the device as early as possible. Involve them in the safety procedure discussions.

Installation:

Roles and responsibilities:	Northern Powergrid Client, A123 supplier
Application of CDM Regulations	Project not notifiable as the construction phase was less than 500 man days. Site Risk Assessment and Method Statement completed.
Site selection process used:	Site selected due to network configuration, available footprint, rural characteristics and secondary transformer loading.
Site work:	Existing substation building and curtilage. Foundations, security, earthing, cabling, craneage, ground load bearing, flood defence, assembly, etc.
Engagement with external stakeholders regarding site:	Local authorities, local emergency services, local businesses and residents, Northumberland County Council and local parish.
Electrical connection and interfaces:	Established 0.4kV LV fuse board with additional fused protection in Northern Powergrid standard Industrial Service Unit (ISU) with full G59 protection and inter tripping with battery control system.
Ancillary services required:	Auxiliary supplies from existing LV supply. UPS system for safe shutdown control Fan cooling for the IGBTs Heating, Ventilation and Air Conditioning in battery and control room
Access requirements:	Special training pre requisite, Northern Powergrid locking policy applies Control instructed access
Installation procedure:	Full detailed construction and lifting plans completed, coordinated by Northern Powergrid and Northern Powergrid site coordinator
Handover to operational team:	
Lessons learnt:	

Safety and Operational Assessment:

Failure Modes and Effects Analysis:	
Risk Assessment Process:	Hazard identification and Hazard operability study was completed
Mitigation Measures Employed against Residual Risks:	Control restricted access. 1.6m wooden palisade fencing, only trained staff access the EES enclosure. Sanctioned authorisation on completion of training
Information Provided by the manufacturer/ system supplier:	Training material and on-site familiarisation
Integration with Existing Safety Rules:	Engineering Operational Standard was written as a point of reference. Method of isolation and earthing.
Engagement with external stakeholders:	Site neighbours were told what we were doing throughout the installation. Local Council planners and street works officials
Lessons Learnt:	DSR treat up to 1500V DC as LV. Test equipment has limits when detecting voltages below 60V. More robust alarming function when undertaking innovative projects, New alarms were created within the control system to provide more information.

Operating Regime:

Applications:	Peak shaving, voltage support, Thermal support of the distribution transformer, Thermal support of the LV underground 0.4kV feeder and demand reduction response coordinated by overarching control system
Control Architecture:	A123 Aeros control system allows monitoring and controlling the different devices (batteries, Zone control, DC breakers, AC breakers, integrated fire suppression and detection system). Siemens RDC (remote distributed controller) as interface to host
Despatch mechanism:	The unit is currently in trial operating under despatched command from a mix of central and distributed controllers. Central control coordinated network voltages in tandem with transformer loading on upstream networks, whereas local distributed control offers thermal and voltage support via local algorithms or state of charge profiles coupled to the network load profile. BAU Network Control has the ability to disable the storage platform by initiating its safe mode.
Operating regime:	During trialling periods the unit is in operation daily and depth of discharge varies dependent on the thermal support requirement of the transformers, as configured for the ANM controller trial.
Benefits from operation:	Benefits yet to be calculated, coordination with central control system is still under trial.

Cost:Benefit Case:

Full Cost benefit analysis is under evaluation using actual costs and projected distribution utilising the TRANSFORM model. These results will be published in the project closedown reports.

Further Information:

Additional Information:	www.networkrevolution.co.uk
References:	

A1.4 CLNR – Maltby (50 kW, 100 kWh)

Project Description:

Project Name:	Customer Led Network Revolution – Maltby
Principal Contact:	Ian Lloyd Northern Powergrid
Start Date:	Construction May 2012
End Date:	Commissioned November 2013
Project Status:	Commissioned
Project Highlights:	Multiple devices of various sizes interacting controlled within a large Smart Grid trial integrating multiple technologies.

Description of Technology:

Technology Employed:	A123 systems Inc. Lithium ion iron nanophosphate
System Supplier:	A123 for battery and system integration, ABB for PCS
Description of Technology:	Li-Ion Battery units 50kVA 100kWh, Batteries and inverter occupy a bespoke container 3m x 3m x 3m (lxbxh) All LV AC/DC components installed in the container with separation between the batteries and the inverters Isolation TX occupies a chamber within the inverter 480V:400V ratio Overall footprint 3m x 3m
Description of PCS:	ABB : inverter between AC and DC bus
Previous track record:	First of a kind in GB
Number of Units Installed:	One three phase unit
Installation Location:	Connected directly to the LV distributed network at Maltby, Nr Rotherham, South Yorkshire New substation location.



Codes, Standards and Licensing:

Certification offered by equipment supplier in relation to energy storage module:	EU 2006/66/EC batteries must have crossed wheeled bin symbol. Li-ion batteries with electronic components subjected to EMC directive 93/97/EEC. Must have CE marking. Basic cells are approved according to UL 1642.
Codes considered in safety assessment:	Information provided by A123 and identified by Hazard and operability study completed by PB Power.
Planning Processes:	Permitted development and 5 year wayleave schedule in coordination with South Yorkshire council authorities
Lessons learnt in relation to codes, standards and licensing:	There are very few standards for battery and PCS devices that can be quoted in the specification.

Procurement:

Process followed:	Maltby is part of a R&D project within the Customer Led Network Revolution project, with A123 commissioned to design, manufacture and install. Northern Powergrid to witness and commission interfaces to networks.
Scope of supply:	Design of system, delivery, installation and commission with service support
Associated BoP required for project:	The project was funded using CLNR awarded Tier 2 LCNF funding.
Process for development of specification:	Consideration of functionality of device required feeding into development of specification. Iterations with the supplier. Installed on a 0.4kV network in an urban environment.
Performance/select ion criteria and standards applied:	Full market procurement tender completed, specifics based on requested power and duration output, together with overall maximum footprint constraints and budgetary limitations
Acceptance tests employed:	FAT on entire system separates completed by A123 Cold commissioning to prove functionality. Northern Powergrid witnessed A123 major component testing Northern Powergrid Network interface and G59 protection commission tests After final connections to 0.4kV network hot commissioning testing including charge and discharge onto network via source.
Warranty and after-sales support included:	Full Maintenance and Service support with the exception of consumables for three years after commission completion and site acceptance Maintenance arrangements include schedules of monthly visual live inspections, 6 monthly and annual arrangements, together with remote dial in support.
Lessons Learnt:	As the technology is still immature careful coordination with Procurement has to be maintained. Emerging market of Battery manufacturers in long duration and high density battery cells are vulnerable to low uptake and market variations making such companies susceptible to financial risk. Existing install base of large scale batteries is not yet global and testing, legislation, operational practice and distribution and transmission codes of practice and safety rules are not well defined to the manufacturers and designers.

Training:

Operational Training Provided:	Combination of classroom and on-site training.
Authorisations and Personal Competence:	45 (to date) specialist standby SAPs and APs having attended the training for operational access/egress, fire suppression disarming, network isolation, Battery and PCS points of isolation. Sanctioned authorisation detailed and granted by safety in coordination with training certification.
Lessons Learnt:	Build the relationship with those who will operate the device as early as possible. Involve them in the safety procedure discussions.

Installation:

Roles and responsibilities:	Northern Powergrid Client, A123 supplier
Application of CDM Regulations	Installation was not notifiable as it involved less than 500 man days of site work. Site Risk Assessment and Method Statements were completed.
Site selection process used:	Site selected due to network configuration, available footprint, urban characteristics and transformer pad loading.
Site work:	New substation building pad and security curtilage. Foundations, security, earthing, cabling, crane-age, ground load bearing, assembly, etc.
Engagement with external stakeholders regarding site:	Wayleave agreement for new site, local authorities, local emergency services, local businesses and residents, South Yorkshire council.
Electrical connection and interfaces:	Established 0.4kV LV fuse board with additional fused protection in Northern Powergrid standard Industrial Service Unit (ISU) with full G59 protection and inter tripping with battery control system.
Ancillary services required:	Auxiliary supplies fed from LV distributor. UPS system for safe shutdown control Fan cooling for the IGBTs Heating, Ventilation and Air Conditioning in battery and control room
Access requirements:	Special training pre requisite, Northern Powergrid locking policy applies Control instructed access
Installation procedure:	Full detailed construction and lifting plans completed, coordinated by Northern Powergrid and site coordinator
Handover to operational team:	
Lessons learnt:	

Safety and Operational Assessment:

Failure Modes and Effects Analysis:	
Risk Assessment Process:	Hazard identification and Hazard operability study was completed
Mitigation Measures Employed against Residual Risks:	Control restricted access. 2m palisade fencing; only trained staff access the control room. Sanctioned authorisation on completion of training
Information Provided by the manufacturer/ system supplier:	Training material and on-site familiarisation
Integration with Existing Safety Rules:	Engineering Operational Standard was written as a point of reference. Method of isolation and earthing.
Engagement with external stakeholders:	Site neighbours were told what we were doing throughout the installation. Local Council planners and street works officials
Lessons Learnt:	DSR treat up to 1500V DC as LV. Test equipment has limits when detecting voltages below 60V. More robust alarming function when undertaking innovative projects, New alarms were created within the control system to provide more information.

Operating Regime:

Applications:	Peak shaving, voltage support, thermal support of the distribution transformer, thermal support of the HV underground 0.4kV feeder and demand reduction response coordinated by overarching control system
Control Architecture:	A123 Aeros control system allows monitoring and controlling the different devices (batteries, Zone control, DC breakers, AC breakers, integrated fire suppression and detection system). Siemens RDC (remote distributed controller) as interface to host
Despatch mechanism:	The unit is currently in trial operating under despatched command from a mix of central and distributed controllers. Central control coordinated network voltages in tandem with transformer loading on upstream networks, whereas local distributed control offers voltage support via local algorithms or state of charge profiles coupled to the network load profile. BAU Network Control has the ability to disable the storage platform by initiating its safe mode.
Operating regime:	During trialling periods the unit is in operation daily and depth of discharge varies dependent on the thermal support requirement of the transformers, as configured for the ANM controller trial.
Benefits from operation:	Benefits yet to be calculated, coordination with central control system is still under trial.

Cost:Benefit Case:

Full Cost benefit analysis is under evaluation using actual costs and projected distribution utilising the TRANSFORM model. These results will be published in the project closedown reports.

Further Information:

Additional Information:	www.networkrevolution.co.uk
References:	

A1.5 CLNR – Wooler St. Mary (50 kW, 100 kWh)

Project Description:

Project Name:	Customer Led Network Revolution – Wooler, St Mary
Principal Contact:	Ian Lloyd Northern Powergrid
Start Date:	Construction May 2012
End Date:	Commissioned November 2013
Project Status:	Commissioned
Project Highlights:	Multiple devices of various sizes interacting controlled within a large Smart Grid trial integrating multiple technologies.

Description of Technology:

Technology Employed:	A123 systems Inc. Lithium ion iron nanophosphate
System Supplier:	A123 for battery and system integration, ABB for PCS
Description of Technology:	Li-Ion Battery units 50 kVA 100kWh, Batteries and inverter occupy a bespoke container 3m x 3m x 3m (lxbxh) All LV AC/DC components installed in the container with separation between the batteries and the inverters Isolation TX occupies a chamber within the inverter 480V:400V ratio Overall footprint 3m x 3m
Description of PCS:	ABB : inverter between AC and DC bus
Previous track record:	First of a kind in GB
Number of Units Installed:	One three phase unit
Installation Location:	Wooler, Northumberland Connected directly to the LV distributed network at Wooler, Northumberland Existing substation outside.



Codes, Standards and Licensing:

Certification offered by equipment supplier in relation to energy storage module:	EU 2006/66/EC batteries must have crossed wheeled bin symbol. Li-ion batteries with electronic components subjected to EMC directive 93/97/EEC. Must have CE marking. Basic cells are approved according to UL 1642.
Codes considered in safety assessment:	Information provided by A123 and identified by Hazard and operability study completed by PB Power.
Planning Processes:	Permitted development schedule in coordination with Northumberland authorities and Northumberland County Council via Northern Powergrid.
Lessons learnt in relation to codes, standards and licensing:	There are very few standards for battery and PCS devices that can be quoted in the specification.

Procurement:

Process followed:	Wooler St Mary is part of a R&D project within the Customer Led Network Revolution project, with A123 commissioned to design, manufacture and install. Northern Powergrid to witness and commission interfaces to networks.
Scope of supply:	Design of system, delivery, installation and commission with service support
Associated BoP required for project:	The project was funded using CLNR awarded Tier 2 LCNF funding.
Process for development of specification:	Consideration of functionality of device required feeding into development of specification. Iterations with the supplier. Installed on a 0.4kV network in an urban environment.
Performance/select ion criteria and standards applied:	Full market procurement tender completed, specifics based on requested power and duration output, together with overall maximum footprint constraints and budgetary limitations
Acceptance tests employed:	FAT on entire system separates completed by A123 Cold commissioning to prove functionality. Northern Powergrid witnessed A123 major component testing Northern Powergrid Network interface and G59 protection commission tests After final connections to 0.4kV network hot commissioning testing including charge and discharge onto network via source.
Warranty and after-sales support included:	Full Maintenance and Service support with the exception of consumables for three years after commission completion and site acceptance Maintenance arrangements include schedules of monthly visual live inspections, 6 monthly and annual arrangements, together with remote dial in support.
Lessons Learnt:	As the technology is still immature careful coordination with Procurement has to be maintained. Emerging market of Battery manufacturers in long duration and high density battery cells are vulnerable to low uptake and market variations making such companies susceptible to financial risk. Existing install base of large scale batteries is not yet global and testing, legislation, operational practice and distribution and transmission codes of practice and safety rules are not well defined to the manufacturers and designers.

Training:

Operational Training Provided:	Combination of classroom and on-site training.
Authorisations and Personal Competence:	45 (to date) specialist standby SAPs and APs having attended the training for operational access/egress, fire suppression disarming, network isolation, Battery and PCS points of isolation. Sanctioned authorisation detailed and granted by safety in coordination with training certification.
Lessons Learnt:	Build the relationship with those who will operate the device as early as possible. Involve them in the safety procedure discussions.

Installation:

Roles and responsibilities:	Northern Powergrid Client, A123 supplier
Application of CDM Regulations	Project not notifiable as construction phase was less than 500 man days. Site Risk Assessments and Method Statements completed.
Site selection process used:	Site selected due to network configuration, available footprint, urban characteristics and transformer pad loading.
Site work:	New substation building pad and security curtilage. Foundations, security, earthing, cabling, craneage, ground load bearing, assembly, etc.
Engagement with external stakeholders regarding site:	Local authorities, local emergency services, local businesses and residents, Northumberland County Council and local parish.
Electrical connection and interfaces:	Established 0.4kV LV fuse board with additional fused protection in Northern Powergrid standard Industrial Service Unit (ISU) with full G59 protection and inter tripping with battery control system.
Ancillary services required:	Auxiliary supplies fed from LV distributor. UPS system for safe shutdown control Fan cooling for the IGBTs Heating, Ventilation and Air Conditioning in battery and control room
Access requirements:	Special training pre requisite, Northern Powergrid locking policy applies Control instructed access
Installation procedure:	Full detailed construction and lifting plans completed, coordinated by Northern Powergrid and site coordinator
Handover to operational team:	
Lessons learnt:	

Safety and Operational Assessment:

Failure Modes and Effects Analysis:	
Risk Assessment Process:	Hazard identification and Hazard operability study was completed
Mitigation Measures Employed against Residual Risks:	Control restricted access. 1.6m palisade fencing; only trained staff access the control room. Sanctioned authorisation on completion of training
Information Provided by the manufacturer/ system supplier:	Training material and on-site familiarisation
Integration with Existing Safety Rules:	Engineering Operational Standard was written as a point of reference. Method of isolation and earthing.
Engagement with external stakeholders:	Site neighbours were told what we were doing throughout the installation. Local Council planners and street works officials
Lessons Learnt:	DSR treat up to 1500V DC as LV. Test equipment has limits when detecting voltages below 60V. More robust alarming function when undertaking innovative projects, New alarms were created within the control system to provide more information.

Operating Regime:

Applications:	Peak shaving, voltage support, thermal support of the distribution transformer, thermal support of the HV underground 0.4kV feeder and demand reduction response coordinated by overarching control system
Control Architecture:	A123 Aeros control system allows monitoring and controlling the different devices (batteries, Zone control, DC breakers, AC breakers, integrated fire suppression and detection system). Siemens RDC (remote distributed controller) as interface to host
Despatch mechanism:	The unit is currently in trial operating under despatched command from a mix of central and distributed controllers. Central control coordinated network voltages in tandem with transformer loading on upstream networks, whereas local distributed control offers voltage support via local algorithms or state of charge profiles coupled to the network load profile. BAU Network Control has the ability to disable the storage platform by initiating its safe mode.
Operating regime:	During trialling periods the unit is in operation daily and depth of discharge varies dependent on the thermal support requirement of the transformer, as configured for the ANM controller trial.
Benefits from operation:	Benefits yet to be calculated, coordination with central control system is still under trial.

Cost:Benefit Case:

Full Cost benefit analysis is under evaluation using actual costs and projected distribution utilising the TRANSFORM model. These results will be published in the project closedown reports.

Further Information:

Additional Information:	www.networkrevolution.co.uk
References:	

A1.6 CLNR – Harrowgate Hill (50 kW, 100 kWh)

Project Description:

Project Name:	Customer Led Network Revolution – Harrowgate Hill
Principal Contact:	Ian Lloyd Northern Powergrid
Start Date:	Construction May 2012
End Date:	Commissioned November 2013
Project Status:	Commissioned
Project Highlights:	Multiple devices of various sizes interacting controlled within a large Smart Grid trial integrating multiple technologies.

Description of Technology:

Technology Employed:	A123 systems Inc. Lithium ion iron nanophosphate
System Supplier:	A123 for battery and system integration, ABB for PCS
Description of Technology:	Li-Ion Battery units 50kVA, 100kWh Batteries occupy one bespoke area 3m x 1.6m x 2.5m (lxbxh) AC LV and LV AC/DC components installed in an existing substation building 10m x 4m x 2.5m (including air con system) TX is outside the building Overall footprint as above
Description of PCS:	ABB : inverter between AC and DC bus
Previous track record:	First of a kind in GB
Number of Units Installed:	One three phase units
Installation Location:	Harrowgate Hill Substation Connected directly via discrete fused protection to an existing LV Feeder at, 9m south of 39 Elmcroft, Darlington, County Durham, DL1 3EL, Existing distribution substation within compound.



Codes, Standards and Licensing:

Certification offered by equipment supplier in relation to energy storage module:	EU 2006/66/EC batteries must have crossed wheeled bin symbol. Li-ion batteries with electronic components subjected to EMC directive 93/97/EEC. Must have CE marking. Basic cells are approved according to UL 1642.
Codes considered in safety assessment:	Information provided by A123 and identified by Hazard and operability study completed by PB Power.
Planning Processes:	Permitted development schedule in coordination with Darlington authorities and Darlington Borough Council
Lessons learnt in relation to codes, standards and licensing:	There are very few standards for battery and PCS devices that can be quoted in the specification.

Procurement:

Process followed:	Harrowgate Hill is part of a R&D project within the Customer Led Network Revolution project, with A123 commissioned to design, manufacture and install. Northern Powergrid to witness and commission interfaces to networks.
Scope of supply:	Design of system, delivery, installation and commission with service support
Associated BoP required for project:	The project was funded using CLNR awarded Tier 2 LCNF funding.
Process for development of specification:	Consideration of functionality of device required feeding into development of specification. Iterations with the supplier. Installed on a 0.4kV network in a semi-urban environment.
Performance/select ion criteria and standards applied:	Full market procurement tender completed, specifics based on requested power and duration output, together with overall maximum footprint constraints and budgetary limitations
Acceptance tests employed:	FAT on entire system separates completed by A123 and ABB Cold commissioning to prove functionality. Northern Powergrid witnessed A123 major component testing Northern Powergrid Network interface and G59 protection commission tests After final connections to 0.4kV network hot commissioning testing including charge and discharge onto network via primary source.
Warranty and after-sales support included:	Full Maintenance and Service support with the exception of consumables for three years after commission completion and site acceptance Maintenance arrangements include schedules of monthly visual live inspections, 6 monthly and annual arrangements, together with remote dial in support.
Lessons Learnt:	As the technology is still immature careful coordination with Procurement has to be maintained. Emerging market of Battery manufacturers in long duration and high density battery cells are vulnerable to low uptake and market variations making such companies susceptible to financial risk. Existing install base of large scale batteries is not yet global and testing, legislation, operational practice and distribution and transmission codes of practice and safety rules are not well defined to the manufacturers and designers.

Training:

Operational Training Provided:	Combination of classroom and on-site training.
Authorisations and Personal Competence:	45 (to date) specialist standby SAPs and APs having attended the training for operational access/egress, fire suppression disarming, network isolation, Battery and PCS points of isolation. Sanctioned authorisation detailed and granted by safety in coordination with training certification.
Lessons Learnt:	Build the relationship with those who will operate the device as early as possible. Involve them in the safety procedure discussions.

Installation:

Roles and responsibilities:	Northern Powergrid Client, A123 supplier
Application of CDM Regulations	Not notifiable as the construction phase was less than 500 man days. Site Risk Assessments and Method Statements were completed.
Site selection process used:	Site selected due to network configuration, available footprint, semi-urban characteristics and secondary transformer loading.
Site work:	Existing substation building and curtilage. Foundations, security, earthing, cabling, craneage, ground load bearing , flood defence, assembly, etc.
Engagement with external stakeholders regarding site:	Local authorities, local emergency services, local businesses and residents, Darlington Borough Council and local parish.
Electrical connection and interfaces:	Established 0.4kV LV fuse board with additional fused protection in Northern Powergrid standard Industrial Service Unit (ISU) with full G59 protection and inter tripping with battery control system.
Ancillary services required:	Auxiliary supplies from existing LV supply. UPS system for safe shutdown control Heating, Ventilation and Air Conditioning in battery and control room
Access requirements:	Special training pre requisite, Northern Powergrid locking policy applies Control instructed access
Installation procedure:	Full detailed construction and lifting plans completed, coordinated by Northern Powergrid and NPG site coordinator
Handover to operational team:	
Lessons learnt:	



Safety and Operational Assessment:

Failure Modes and Effects Analysis:	
Risk Assessment Process:	Hazard identification and Hazard operability study was completed
Mitigation Measures Employed against Residual Risks:	Control restricted access. Existing 2.2m wall, only trained staff access the EES enclosure. Sanctioned authorisation on completion of training
Information Provided by the manufacturer/ system supplier:	Training material and on-site familiarisation
Integration with Existing Safety Rules:	Engineering Operational Standard was written as a point of reference. Method of isolation and earthing.
Engagement with external stakeholders:	Site neighbours were told what we were doing throughout the installation.
Lessons Learnt:	DSR treat up to 1500V DC as LV. Test equipment has limits when detecting voltages below 60V. More robust alarming function when undertaking innovative projects, New alarms were created within the control system to provide more information.

Operating Regime:

Applications:	Peak shaving, voltage support, Thermal support of the distribution transformer, Thermal support of the LV underground 0.4kV feeder and demand reduction response coordinated by overarching control system
Control Architecture:	A123 Aeros control system allows monitoring and controlling the different devices (batteries, Zone control, DC breakers, AC breakers, integrated fire suppression and detection system). Siemens RDC (remote distributed controller) as interface to host
Despatch mechanism:	The unit is currently in trial operating under despatched command from a mix of central and distributed controllers. Central control coordinated network voltages in tandem with transformer and underground cable rating and loading on upstream networks, whereas local distributed control offers voltage support via local algorithms or state of charge profiles coupled to the network load profile. BAU Network Control has the ability to disable the storage platform by initiating its safe mode.
Operating regime:	During trialling periods the unit is in operation daily and depth of discharge varies dependent on the thermal support requirement of the transformer and cable, as configured for the ANM controller trial.
Benefits from operation:	Benefits yet to be calculated, coordination with central control system is still under trial.

Cost:Benefit Case:

Full Cost benefit analysis is under evaluation using actual costs and projected distribution utilising the TRANSFORM model. These results will be published in the project closedown reports.

Further Information:

Additional Information:	www.networkrevolution.co.uk
References:	

A1.7 LV Connected Storage – Chalvey (3 off 25 kW, 25 kWh)

Project Description:

Project Name:	LV Connected Batteries
Principal Contact:	FutureNetworks@sse.com
Start Date:	2011
End Date:	2014
Project Status:	Complete
Project Highlights:	Operation of a fleet of LV connected energy storage units with renewable generation

Description of Technology:

Technology Employed:	<p>Lithium Cobalt Manganese Nickel Oxide</p> <p>Negative Electrode : Carbon</p> <p>Positive Electrode : Lithium Cobalt Manganese Nickel Oxide (LiMnNiCoO₂)</p> <p>Electrolyte : Solution of lithium hexafluorophosphate (LiPF₆) in a mixture of organic solvent: Ethylene Carbonate(EC) and Ethymethyl Carbonate(EMC)</p> <p>Nominal Cell Voltage : 3.7V</p>
System Supplier:	S&C Electric product with Dow Kokam battery
Description of Technology:	25kVA / 25kWh units
Description of PCS:	Full 4 quadrant power converter 25kVA capacity switching at 5kHz
Previous track record:	<p>A number of previous installations in the U.S. with utility American Electric Power (AEP).</p> <p>This connection arrangement is slightly different – units are not connected in a UPS mode to the domestic loads, this is a 'street' type battery. A step up transformer is employed to comply with UK voltage.</p>
Number of Units Installed:	3 x single phase units
Installation Location:	<p>Chalvey, Slough, Berkshire</p> <p>Installed via a T-off from the main feeder approx. three quarters of the way down the LV feeder</p> <p>Installed within a substation compound with multiple isolation points within a distribution cabinet to allow for detailed testing monitoring etc.</p>



Codes, Standards and Licensing:

Certification offered by equipment supplier in relation to energy storage module:	CE Marking of complete system approved by TUV with technical file Declaration of Conformity under the Low Voltage Directive EMC Directive fully compliant. Multiple US standards
Codes considered in safety assessment:	Full details of the codes and standards addressed in Section 6. 'Codes, Standards and Related Considerations' of the Safety review document produced by EA Technology.
Planning Processes:	The site was agreed to be completed under permitted development. This stemmed from detailed discussions and the submission of drawings etc. to Slough Borough Council. The process took approx. 2 months to agree. There was significant debate as permitted development relates to critical electrical infrastructure e.g. distribution substations. Although we were treating this like a substation it was an R&D project to learn about batteries and not critical to keeping the lights on.
Lessons learnt in relation to codes, standards and licensing:	There appears to be a grey area with the CE Marking of bespoke R&D products – the simplest way to address this is to ensure the manufacture complies with this requirement as early as possible. A minimum requirement is to issue a declaration of conformity under the EMC and Low Voltage Directive. This puts the responsibility firmly on the manufacturer and not the utility.

Procurement:

Process followed:	N/A
Scope of supply:	The system supplied by S&C Electric was an integrated PCS and battery with associated communications. SSEPD specified the auxiliary transformer
Associated BoP required for project:	N/A
Process for development of specification:	SSEPD took what was available on the market and made some significant bespoke alterations to the design: Integration with Current Group monitoring equipment No load connection (UPS mode) – operating as 'street' batteries' not point of use Auxiliary transformer to step up voltage Integration with SCADA system – bespoke DNP points list
Performance/select ion criteria and standards applied:	N/A
Acceptance tests employed:	Attendance at Factory Acceptance Testing for CES units <ul style="list-style-type: none"> - Manufacturer had a detailed test plan which was complete, however SSEPD had a number of additional tests requested one of which actually led to a minor design change (delay between charge / discharge) Site acceptance testing completed under G59/2 (islanded network) Manufacturers site acceptance testing (islanded network) Site safety / operational testing completed Multiple charge / discharge cycles run to establish efficiency
Warranty and after-sales support included:	S&C offered a full warranty for the lifetime of the project (4 years). The support has mainly been U.S. based and there have been numerous problems, however support has been quick and pretty good. All 3 batteries were replaced in 2012 under warranty. Replacement parts have been sent to the UK and it has always taken less than 5 working days from the U.S. As this is the first in the UK installation for S&C there is significant interest in the project progress. Regular discussions are held on performance etc with S&C logging in remotely to check parameters etc.

Lessons Learnt:	Taking a product specifically built for the US market and modifying it for the UK is always going to have some issues with integration etc. The main difficulties in this installation were with the communications side e.g. the link to the SCADA system / remote access. A significant amount of time was spent on this issue – more time should be allocated and the right experts from all sides should be present for this element of the project.
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Training:

Operational Training Provided:	Project is still run by Future Networks team. Training on operation was provided by manufacturer. Any problems / issues are investigated by the manufacturer remotely.
Authorisations and Personal Competence:	The units can only be operated at present by Future Networks staff. The system has 100 Amp MCCBs in a distribution panel to allow trained SSE staff to isolate units. The LV fuses within the 200 Amp cut out can only be operated by appropriately authorised personnel.
.Lessons Learnt:	Remote access is key to supporting the project and should be arranged prior to installation

Installation:

Roles and responsibilities:	SSEPD took responsibility for setting up the site e.g. electrical connection to the network, distribution cabinet with isolation points, all civil works and transformer specification, installation and commissioning. S&C Electric were responsible for installation of the 3x CES units installation / connection up to the auxiliary transformer. The communications testing / integration was a joint effort between SSEPD and S&C. SSEPD put the units through G59/2 testing operating on an islanded network with a 100kVA generator, 100kVAr and 100kW load banks. Upon completion of this testing the generators were connected to the network. The project test programme was completed with EA Technology and SSEPD.
Application of CDM Regulations	Not notifiable under CDM regulations, but legislation complied with.
Site selection process used:	Site was selected as it was on the same LV feeder as the Low Carbon Homes and SSE owned land was available. After detailed network study to confirm the batteries could be connected work began to progress the site selection.
Site work:	Significant civil works were completed to establish the site. As the battery element of the system is located underground, the site had to be excavated and a number of services had to be removed: Telecoms cables Live LV cables had to be pot ended HV cables had to be spiked before removal A water sump had to be filled in A large perimeter wall was constructed which had to be in keeping with the surrounding buildings and rendered appropriately. The site was treated in the same manner as an SSEPD distribution substation e.g. signage / records / fencing etc.
Engagement with external stakeholders regarding site:	Detailed engagement with Slough Borough Council. Engagement with the Murco petrol station to ensure access and detail the potential hazards, location of underground tanks etc.

Electrical connection and interfaces:	<p>Electrical connection provided by SSEPD depot under the normal demand connection arrangements. SSE Contracting completed the site cabling / earthing and the distribution board etc.</p> <p>SSEPD completed the electrical design and earthing requirements / voltage set-points etc with the help of engineers from S&C.</p>
Ancillary services required:	None required
Access requirements:	<p>The site is treated as a distribution substation and access is only permitted by authorised staff. Full PPE is required on site:</p> <ul style="list-style-type: none"> • Hard hat • High vis • Glasses • Ankle support boots with steel toe caps • Gloves – appropriate to task
Installation procedure:	<p>The nature of the underground battery vaults meant a crane had to be used to deploy the batteries and this was completed before the perimeter fence was constructed on 2 sides to allow easier access.</p> <p>When the batteries were replaced the crane had to access the site from the garage side.</p> <p>The units were installed within a day e.g. battery + PCS. The site works took approx 3 weeks. The electrical works 2 weeks and the final perimeter fence took an additional 2 weeks to complete.</p>
Handover to operational team:	Project is still operated by Future Networks team.
Lessons learnt:	Some minor delays with the weather on the civil side, however everything was fairly straightforward.

Safety and Operational Assessment:

Failure Modes and Effects Analysis:	Full safety case completed by EA Technology in conjunction with manufacturer.
Risk Assessment Process:	SSE PEAR system completed as stage 1 by EA Technology. Stage 2 & 3 completed before entering site.
Mitigation Measures Employed against Residual Risks:	<p>Multiple mitigation measures employed within the design of the system detailed within the safety case.</p> <p>Additional requirements enforced on manufacturer – full CE Marking and survey from TUV.</p> <p>Alterations to the remote inhibit procedure via SCADA.</p> <p>Alterations to battery casing to seal units from water ingress</p> <p>Alterations to alarm priorities / self reset commands</p>
Information Provided by the manufacturer/ system supplier:	Detailed in Risk Assessment above.
Integration with Existing Safety Rules:	The site is treated as a live substation at all times. To complete any work on the units 2 points of isolation must be employed. To work on the PCS the battery (DC) connections must be disconnected.
Engagement with external stakeholders:	Site has been registered with the local fire authority - data sheets sent and stored on their database.
Lessons Learnt:	Completing a full safety case for a new project is costly and takes a great deal of time / resource. This is not feasible going forward for every new project; there needs to be more responsibility on the manufacturer to provide an adequate assurance the system is safe. DNOs need to have the appropriate knowledge to assess this based on the number of live projects in this area as this technology progresses into business as usual.

Operating Regime:

Applications:	Testing functionality of peak shaving, solar power absorption, voltage support, phase balancing and aggregated demand reduction on a low voltage feeder circuit with significant deployment of low carbon technologies.
Control Architecture:	Bespoke S&C control hub connected to SSE SCADA system - utilises S&C SpeedNet radios to communicate with control hub. Control hub is connected to 'Current Group' substation monitor to enable real time values to be used as set-points for demand schedules. System can be accessed remotely to alter charge-discharge parameters / fault diagnosis / software updates etc.
Despatch mechanism:	The project is a test set up and hence the schedules are annually set for a period of time and the results recorded. The system has the capability to respond automatically to real or reactive power set points based on measurements at the substation in order to peak lop both demand and generation and also balance phases. The system can be set to run basic charge / discharge schedules to dispatch fixed power at certain times of the day to support network operation.
Operating regime:	System has completed more than 500 cycles on each units
Benefits from operation:	Benefits have been in line with the application section. Up to 100 amp peak demand reduction and +/- 7V maximum voltage manipulation.



Further Information:

Additional Information:	
References:	Closedown report available from: https://www.ofgem.gov.uk/ofgem-publications/89553/sset1008lvconnectedbatteriesclosedown2ndsubmission.pdf

A1.8 Orkney Energy Storage Park (2 MW, 500 kWh)

Project Description:

Project Name:	SSET 1007 Orkney Energy Storage Park & SSET1009 Trial of Orkney Energy Storage Park
Principal Contact:	Future Networks, SSEPD, future.networks@sse.com
Start Date:	2011
End Date:	2015
Project Status:	In progress
Project Highlights:	First MW scale grid supporting battery in the UK First service contract trialled for constraint management First load to be controlled by an Active Network Management (ANM) scheme in the UK

Description of Technology:

Technology Employed:	Lithium-ion Battery (Nickel Manganese Cobalt)
System Supplier:	Mitsubishi Heavy Industries (MHI) and Mitsubishi Hitachi Power System Europe (MPSE) for full system
Description of Technology:	2MW 500kWh 3 phase
Description of PCS:	
Previous track record:	First installation outside at MHI Nagasaki factory (1MW 250kWh Li-Ion)
Number of Units Installed:	1 x three phase unit Consisting of 2 x 40ft Battery container and 1 x 40ft PCS container
Installation Location:	Kirkwall Power Station, Great Western Road, Kirkwall, Orkney, Scotland, KW15 1AN Feeds directly into 11kV board at Kirkwall Primary Substation Within a fenced off compound inside 3 x ISO 40 foot containers



Codes, Standards and Licensing:

<p>Certification offered by equipment supplier in relation to energy storage module:</p>	<ul style="list-style-type: none"> • UN Recommendation on the Transportation of Dangerous Goods Manual of Tests and Criteria Part III, Section 38.3 Lithium Metal and Lithium Ion Batteries • REACH Directive • CE Marking • WEEE Directive • CSC Marking (convention of safe containers)
<p>Codes considered in safety assessment:</p>	<p><u>Required Compliance ESS Standards</u></p> <ul style="list-style-type: none"> • The Batteries and Accumulators and Waste Batteries and Accumulators Directive (2006/66/EC) • BS EN 50272-2:2001 Safety Requirements for Secondary & Batteries and Battery Installations – Part 2: Stationary Batteries • Pressure Systems Regulations • DSEAR and ATEX (Reference) • COMAH • Low Voltage Directive • EMC Directive <p><u>Required Compliance Fire Suppression System Standards</u></p> <ul style="list-style-type: none"> • BS EN 15004-1:2008 • BS 6266:2011 • BS 7273-1:2006 • BS 5839-1:2002+A2:2008
<p>Planning Processes:</p>	<p>The supplier was required by the tender conditions to submit a full planning permission application. Upon receipt of this the local planning department stated that it could be covered under permitted development as the company submitting the claim was SSE Generation.</p>
<p>Lessons learnt in relation to codes, standards and licensing:</p>	<p>Few overarching codes and standards apply to Li-Ion systems. This means that a far more in-depth safety case is required to demonstrate compliance. CE marking using the EMC directive and the LV Directive goes some way to helping on this but more exact standards are required for Li-Ion. If these existed then engagement with external stakeholders would result in more consistent results.</p>



Procurement:

Process followed:	Prequalification round followed up by full invitation to tender. All completed through Achilles.
Scope of supply:	Full energy storage system that would allow connection to 11kV distribution network.
Associated BoP required for project:	n/a
Process for development of specification:	Undertook analysis to determine extent of curtailed energy available to absorb, which defined the minimum capacity of the required system. Then looked at how the system would be dispatched, which led to the definition of response times. Finally looked at site to be used, which led to the maximum footprint requirement.
Performance/select ion criteria and standards applied:	Selection criteria were based on: <ul style="list-style-type: none"> • safety of the full system; • experience of supplier; • existing reference system; • meeting technical requirements; • least project cost
Acceptance tests employed:	Majority n/a as system not purchased. Only system test completed were those required under G59/2 and also to commission system to ANM control.
Warranty and after-sales support included:	n/a as SSEPD not operators
Lessons Learnt:	G59/2 has implications for non stable networks

Training:

Operational Training Provided:	Supplier led training sessions
Authorisations and Personal Competence:	Operators must have had supplier training. Must also hold operational and access authorisations as defined through SSE Generation Operational Safety Rules
Lessons Learnt:	n/a as SSEPD not operators

Installation:

Roles and responsibilities:	SSE Generation designer Hedde Construction Principal Contractor SSE Contracting Electrical Contractor
Application of CDM Regulations	Project not notifiable, all regulations followed.
Site selection process used:	Site chosen because: <ul style="list-style-type: none"> • to expedite installation • ANM core zone constraint affects all generators (thus placed in core zone) • Enhanced site security as within power station grounds • More resilient comms as located on same site as ANM system
Site work:	Foundation required for containers as built on reclaimed ground. Compound also fenced off for additional security and to reinforce operational boundaries.
Engagement with external stakeholders regarding site:	Full planning application submitted to local planning body
Electrical connection and interfaces:	System monitored and possible constraint management despatch by Orkney ANM system. ESS connected to 11kV board at Kirkwall Primary substation. All supplies fed through single connection.
Ancillary services required:	Yes to ensure PCS and FSS are kept on supply
Access requirements:	Standard access procedures for SSEG sites
Installation procedure:	Crane required to put 3 containers into place. Site works took 1 year from start to completion of commissioning
Handover to operational team:	System handed over commercially in August 2013 to SSE Generation Wind Operations. Unaware of any issues as SSEPD removed from process.
Lessons learnt:	n/a

Safety and Operational Assessment:

Failure Modes and Effects Analysis:	FMEA provided by supplier up to what they considered as realistic possibilities.
Risk Assessment Process:	<ul style="list-style-type: none"> • Literature review to see what incidents have been reported worldwide • Assessment of applicable codes and standards to ESS • Assessment of supplier design package • Assessment of suitability of Fire Suppression System (FSS) • Stakeholder engagement • Site visit and review
Mitigation Measures Employed against Residual Risks:	<p>Defence in depth approach taken by supplier with several layers of protection including cell design, monitoring and protection systems and a fire suppression system.</p> <p>Additional measures were the certification of CE marking via the LV and EMC directives and the involvement of EA Technology to provide the safety appraisal.</p>
Information Provided by the manufacturer/ system supplier:	Supplier provided their FMEA as well as some results from their failure testing
Integration with Existing Safety Rules:	Site is treated as live SSEG site at all times thus operational safety rules and safe systems of work apply.
Engagement with external stakeholders:	Through the project the SSEPD and SSEG teams engaged with the local emergency services, who were also the site neighbours, as well as the local council emergency planning officer. Further engagement was had with SEPA and the local planning bodies.
Lessons Learnt:	<ul style="list-style-type: none"> • Engage with the local emergency services early and consistently • Explain the installation by referencing it to existing types of installations and applications already deployed which they would be familiar with • Ensure that people attending the meetings are suitably senior enough to understand the overall picture/application • No explicit requirement to engage with local emergency services thus they may not provide project approval to allow continuation rather just encompass site to existing emergency plans

Operating Regime:

Applications:	Initially constraint management but other markets targeted e.g. ancillary services contract for STOR or frequency response either indirectly by the operator or via an aggregator.
Control Architecture:	For constraint management service request dispatched by ANM. Whilst system is operating in any other market then output controlled by ANM to ensure network stays within limits. Renewable Operations Centre (SSE Generation Control Room) receives all alarms for system but have no remote control. Network Management Centre (SSEPD Control Room) control interface circuit breaker. Local Human Machine Interface (HMI) allows for remote operation of the battery systems as well as giving remote indication of system status.
Despatch mechanism:	Constraint management service will be managed by the ANM system. The ANM system monitors the network monitoring points and if applicable it requests the storage to provide the service if the device is available. For other ancillary services the decision how and when to operate is made by the 3 rd party operator.
Operating regime:	As the system is operated by a 3 rd party then SSEPD aren't privileged to this information.
Benefits from operation	At this moment no direct operational benefits have been achieved. However numerous other benefits have been achieved around safety cases and general learning around the operation of storage in general.

Cost:Benefit Case:

As the system is operated by a 3rd party then SSEPD aren't privileged to the relevant information, i.e. unit, installation, operation & maintenance costs necessary to pull together a CBA.

Further Information:

Additional Information:	
References:	SSET1007 closedown report http://www.ssepd.co.uk/HaveYourSay/Innovation/Portfolio/OrkneyPhase1/ SSET1009 closedown report to follow in 2015

A1.9 NINES – Shetland NaS Battery (1 MW, 6 MWh)

Project Description:

Project Name:	SSET1001 1MW battery, Shetland (NaS)
Principal Contact:	future.networks@sse.com
Start Date:	2010
End Date:	2012
Project Status:	Complete.
Project Highlights:	First MW scale grid supporting battery procurement UK Largest grid supporting battery installation in Europe Design and build of a bespoke battery building

Description of Technology:

Technology Employed:	Sodium Sulphur (NaS) NaS battery active materials are molten sulphur at the positive electrode and molten sodium at the negative electrode. A solid beta alumina (a sodium ion conductive ceramic) separates both electrodes.
System Supplier:	Contract placed with S&C Electric Europe. Battery System – NGK Insulators Ltd PCS – S&C Electric Europe
Description of Technology:	The system comprises of 20 x 50kW/300kWh modules. Each module contains 384 cells, operating at a temperature in excess of 300°C. Giving a total capacity of 1MW/6MWh The battery system is approximately 5m x 4m x 5m, weighing 86 tonnes.
Description of PCS:	The major components are in four sections (bays). Sections are the DC interface bay, the inverter bay, the AC interface bay and the control bay. The DC interface bay has the DC circuit breakers, DC filter capacitor and DC inductors. The inverter bay has the inverter controls, DC/DC converter controls, DC/AC inverter, DC/DC converter, and AC inductor. The AC interface bay has the AC filter capacitors, AC circuit breakers, and input bus bar connections. The control bay has the system controls and HMI computer. The PCS is approximately 6m x 1m x 2m, weighing 14 tonnes
Previous track record:	No previous installations in the UK. One other installation in Europe (0.5MW/3MWh) Over 300MW of NaS batteries installed world wide primarily in Japan and the United States of America at over 215 sites. The largest of these is a 34MW/220MWh battery array connected to a 51MW wind farm in Rokkasho, Aomori prefecture in Japan.
Number of Units Installed:	1 x three phase unit
Installation Location:	Lerwick Power Station, Lerwick, Shetland, ZE1 0PS Connected to dedicated 11kV breaker at Gremista Primary substation Within a dedicated building, to house the battery system, PCS and transformer. Additional storage space for battery module. SSEPD control room located between the PCS and Battery room, to provide a thermal buffer.
Applications:	Peak Shaving, Frequency Support, Voltage Support (PCS), Increasing renewable generation output, increasing LPS thermal generation efficiency

Control Architecture:	<p>Touch screen HMI built into the SMS, which provides local control of both the SMS and the battery system. Physical switch on the Storage Management System (SMS) to move from local to remote control.</p> <p>Dedicated battery control system developed, to allow scheduling and profiling. This is connected to the battery system through a Local Interface Controller.</p> <p>Key alarms and controls are connected to the existing LPS SCADA system. Commands from this system, override those from the battery control system.</p> <p>11kV breaker is controlled directly from the LPS SCADA system.</p> <p>Telemetry, but not control, is provided to the Power Systems control room in Perth.</p>
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Codes, Standards and Licensing:

Certification offered by equipment supplier in relation to energy storage module:	<ul style="list-style-type: none"> • ISO9001
Codes considered in safety assessment:	<ul style="list-style-type: none"> • The Batteries and Accumulators and Waste Batteries and Accumulators Directive • BS EN 50272: 2001 Safety Requirements for Secondary Batteries and Battery Installations. Stationary Batteries. • The Pressure Systems Safety Regulations 2000 • The Supply of Machinery (Safety) Regulations • Low Voltage Directive • Electromagnetic Compatibility (EMC) Directive • COSHH Regulations (Control of Substances Hazardous to Health)
Planning Processes:	<p>All of the equipment was located within a dedicated building, on the existing Lerwick Power Station (LPS) site. SHEPD were able to construct the building under permitted development.</p>
Lessons learnt in relation to codes, standards and licensing:	<ul style="list-style-type: none"> • Clarification from discussions with the HSE as to the application of CE marking to grid scale battery systems • Majority of regulations covering battery systems are aimed at specific technologies, but do not exclude others. • No codes and standards which are directly applicable/relevant to this technology. • Importance of stakeholder engagement, when using permitted development (not a full consultation planning process)

Procurement:

Process followed:	Prequalification round followed up by full invitation to tender. All completed through Achilles.
Scope of supply:	Turnkey contract placed for Battery, PCS and transformer with S&C Electric Europe.
Associated BoP required for project:	Contract placed for Civil, Electrical and Building works with Powerteam through existing framework contract. Building design – McGregor McMahon Associates, through existing framework contract
Process for development of specification:	Analysis work by the University of Strathclyde indicated that the connection of a 1MW battery to the electrical network on Shetland would allow the connection of 0.44MW of additional renewable generation. Indicative size ranges, based on network peaks and troughs. Size to be sufficient to represent 'grid scale'. Lessons learned from earlier projects, relating to minimum number of reference installations, experience of the UK market and electrolyte containment measures.
Performance/selection criteria and standards applied:	Selection criteria were based on: <ul style="list-style-type: none"> • Safety and Environmental • Cost and Efficiency; • Compliance with specification • Programme • Technical merit
Acceptance tests employed:	Factory acceptance tests/Factory visits were completed for both the PCS and the battery The battery visit provided useful information on how the modules were manufactured, but in the absence of defined standards, it was difficult to conduct acceptance tests, The PCS completed a rigorous test schedule.
Warranty and after-sales support included:	5-year, all inclusive, maintenance agreement provided with original tender. Option to extend this to 15 years (full life of battery system)
Lessons Learnt:	<ul style="list-style-type: none"> • Difficulty in defining and performing acceptance tests for new technology • The very low market maturity in terms of systems of this scale with previous installations. • Include minimum system efficiency as a contractual limit

Training:

Operational Training Provided:	Training to be provided by both the PCS and battery system manufacturers. Minimum interaction expected, due to the all inclusive maintenance contract.
Authorisations and Personal Competence:	<ul style="list-style-type: none"> • Hold suitable SSEPD switching authorisation • Have been trained by the manufacturer on the equipment • Follow agreed work instruction
Lessons Learnt:	<ul style="list-style-type: none"> • How isolation will be achieved and safety locks applied, is an important design consideration.

Installation:

Roles and responsibilities:	SHEPD – Customer and CDM co-ordinator Powerteam – Principal contractor S&C Electric Europe – Principal Contractor
Application of CDM Regulations	Full CDM project for all site works. Powerteam were principal contractor for the building construction, this transferred over to S&C for the battery and PCS works.
Site selection process used:	
Site work:	<ul style="list-style-type: none"> • Clear building site, move earth screen • Complete building construction, including extensive forced ventilation • Installation of 200m of 11kV cable • Upgrade to existing 11kV breaker (protection)
Engagement with external stakeholders regarding site:	<ul style="list-style-type: none"> • Permitted development discussed with local planners • Ambulance and Police service notified • Site meeting and tour with the fire service • Meeting with HSE • Meeting with SEPA, leading to PPC regulation 12 notification
Electrical connection and interfaces:	<ul style="list-style-type: none"> • Electrically connected to Gremista primary substation (HV) and LPS electrical network (LV)
Ancillary services required:	Damage can occur to the NaS cells if the internal heaters cannot maintain the sodium and sulphur electrodes in their liquid state. The primary auxiliary supply was taken from the 11kV connection (using a step down transformer), a backup supply was provided from the LPS LV network (using a transformer to match the voltages). An LV generator connection point was also included as a backup.
Access requirements:	The building was designed to provide access for a forklift truck to install or replace modules. The manufacturer used a bespoke tool to physically install the modules, the access requirements were however similar, as the module needs to be lifted on to the tool.
Installation procedure:	<p>The SMS was fully assembled at the factory and shipped to site, it was skidded into place in the building.</p> <p>The battery enclosure was shipped in component parts and assembled on site using a Hiab. Once the enclosure was complete, a bespoke tool supplied by the manufacturer was assembled beside the enclosure. A frame is fitted to the battery module and it is then lifted onto the tool, using the Hiab. Once on the tool, very fine adjustments can be made to ensure correct positioning. The module is then slid into position on rollers, using nitrogen to reduce friction.</p> <p>All 20 modules were installed in three days.</p>
Handover to operational team:	N/A – Project did not reach this stage
Lessons learnt:	<ul style="list-style-type: none"> • Difficulties in proving suitability and competence for the installation method, when this was first of its kind for the UK. • Issues with providing back up to the system as it uses non-standard LV for auxiliary supplies

Safety and Operational Assessment:

Failure Modes and Effects Analysis:	Information on destructive testing was provided at tender stage.
Risk Assessment Process:	<ul style="list-style-type: none"> • A review of relevant codes, standards and legislation • A review of documentation provided by the supplier • The preparation of Risk Assessments • Seeking specialist input from an independent 3rd party
Mitigation Measures Employed against Residual Risks:	<p>Defence in depth approach taken by supplier with several layers of protection including cell design, module design, monitoring and multiple protection systems</p> <p>Additional fire detection system, emergency stops and CCTV monitoring employed.</p>
Information Provided by the manufacturer/ system supplier:	Destructive testing information provided and material safety data sheets.
Integration with Existing Safety Rules:	Standard operational rules applied to construction
Engagement with external stakeholders:	<ul style="list-style-type: none"> • Permitted development discussed with local planners • Ambulance and Police service notified • Site meeting and tour with the fire service • Meeting with HSE • Meeting with SEPA, leading to PPC regulation 12 notification
Lessons Learnt:	

Further Information:

Additional Information:	<p>On the 30th September 2011, just two weeks before the scheduled energisation date of the battery, SHEPD were notified of a fire at a NaS battery installation in Japan. NGK recommended that all NaS battery installations worldwide shut down until the root cause of the fire had been established. Following a period of investigation and reporting, it was concluded that if a fire were to occur, it would burn for a significant period of time and would involve evacuating Lerwick Power Station and potentially switching off the electricity supply to the whole of Shetland for a number of days. Whilst the likelihood of a fire occurring is extremely low, the associated consequence would be catastrophic. For these reasons and without a suitable resolution to allow a fire to be extinguished in an acceptable timescale, SHEPD concluded that the NaS battery was no longer fit for purpose at the power station site.</p>
References:	<p>SSET1001 interim closedown report: https://www.ofgem.gov.uk/ofgem-publications/83393/sset10011mwbatterysketlandinterimclosedownreportsep2013.pdf</p>

A1.10 NINES – Shetland Pb-Acid Battery (1 MW, 3 MWh)

Project Description:

Project Name:	SSET1001 1MW battery, Shetland (VRLA)
Principal Contact:	future.networks@sse.com
Start Date:	2010
End Date:	2018
Project Status:	In progress.
Project Highlights:	First VRLA grid supporting battery in the UK Largest VRLA battery in Europe Re-design and retrofit of battery technology into an existing building.

Description of Technology:

Technology employed:	Valve Regulated Lead Acid (VRLA)
System supplier:	Contract placed with S&C Electric Europe Battery System – GS Yuasa PCS – S&C Electric Europe
Description of technology:	The system is comprised of 3168 x 1000Ah cells. Cells are arranged in modules (rows) of six. Four modules are stacked to form a rack with 11 racks – all in series – forming a string. 12 parallel strings provide a total capacity of 1MW / 3MWh The batteries cover an area approximately 14m x 11m x 1.5m. Total weight is in excess of 200 tonnes
Description of PCS:	The PCS consists of one inverter rated at 1MW / 1.25 MVA. Output is 480V delta. The major components are in four sections (bays): The DC interface bay – contains the DC circuit breakers, DC filter capacitor and DC inductors The inverter bay – the heart of the PCS contains the primary power electronics: DC/DC boost converter (choppers), a three phase DC/AC inverter and AC filter inductor. The AC interface bay has the AC filter capacitors, AC circuit breakers, and input bus bar connections. The control bay – system controls and HMI computer The PCS is approximately 6.5m x 1m x 2.5m, weighing 7.5 tonnes
Previous track record:	In the UK, Yuasa sell 1.2 million cells per annum, equivalent to over 1GW of energy storage. Yuasa provided high level details of six recent UK installations; primarily used in data centres as an uninterruptible power supply (UPS). SSE Telecoms own and operate a similar small asset at the Fareham data centre in Hampshire
Number of units installed:	1 x three phase unit
Installation location:	Housed within a dedicated building at: Lerwick Power Station, Gremista, Lerwick, Shetland, ZE1 0PS Grid connection is via a dedicated 11kV breaker at Gremista primary substation

Codes, Standards and Licensing:

<p>Certification offered by equipment supplier in relation to energy storage module:</p>	<p>The battery is compliant with 'JIS C 8704 Stationary Lead-Acid Batteries'. This is the Japanese equivalent to IEC 60896-21 and IEC 60896-22, Stationary Lead-Acid Batteries – Valve Regulated Types. The standards set out a comprehensive method of test and requirements for VRLA batteries. The manufacturer results have been shared with SHEPD</p> <ul style="list-style-type: none"> • EN 50272-1:2010 Safety requirements for secondary batteries and battery installations- Part 1 General safety information. • EN 50272-1:2001 Safety requirements for secondary batteries and battery installations- Part 2 Stationary batteries • The Batteries Directive 2006/66/EC
<p>Codes considered in safety assessment:</p>	<p>The codes and standards identified in the initial review for the NaS battery were used as a benchmark for the VRLA technology</p>
<p>Planning processes:</p>	<p>All of the equipment was located within an existing dedicated battery building</p>
<p>Lessons learnt in relation to codes, standards and licensing:</p>	<p>Codes and standards for lead acid battery systems are mature and robust; this is a significant advantage in building a safety case and proving compliance</p>



Procurement:

Process followed:	Alternative technology offered under the original contract
Scope of supply:	Replacement battery technology including Battery Management System Internal building modifications New hydrogen detection and fire suppression system
Associated BoP required for project:	N/A
Process for development of specification:	Criteria set for the replacement battery were: Established safety case Fit within the existing battery building footprint Deliverable within a reasonable timescale to allow suitable learning to be obtained Deliverable with no additional cost to customers Alternative solutions were limited, with the required timescales being the most restrictive factor. Pb-Acid emerged as the sole alternative technology with two manufacturers able to meet the delivery schedule. The first of these utilised valve-regulated Pb-Acid (VRLA) and became the preferred supplier. This is because the second option utilised a more traditional flooded cell design. The former could be racked four cells high whereas the latter was limited to a single level. This would have required significant modifications to the battery building and therefore resulted in a greater overall cost
Performance/select ion criteria and standards applied:	SHEPD sent out a request for information (RFI) to fulfil the requirements of a technical assessment and basis for the safety case. S&C maintained a good dialogue with Yuasa during this period and subcontracted Thamesgate for their prior experience of installing battery rooms in data centres
Acceptance tests employed:	No FAT was conducted for the cells, due to the 'mass production' nature of the manufacturing
Warranty and after-sales support included:	Five year (whole life), or 1500 cycles, maintenance agreement for the battery and associated systems
Lessons learnt:	Successful use of Achilles register to invite tenders Screening and evaluation criteria established Prompted further research into ownership models of energy storage

Training:

Operational Training Provided:	Basic on site training provided for phase 1 system, full training to be provided after phase 2 installation.
Authorisations and Personal Competence:	<ul style="list-style-type: none"> • Hold suitable SSEPD switching authorisation • Have been trained by the manufacturer on the equipment • Follow agreed work instruction
Lessons Learnt:	



Installation:

Roles and responsibilities:	SHEPD – Customer and CDM Co-ordinator S&C Electric Europe – Principal Contractor
Application of CDM Regulations	Full CDM project, S&C were Principal Contractor
Site selection process used:	N/A
Site work:	Removal of internal wall (to extend battery hall), fill in cable trenches, suspended ceiling and cladding of roller doors to improve insulation. Installation of full hydrogen detection and fire suppression system
Engagement with external stakeholders regarding site:	Meeting with HSE Meeting with SEPA, leading to revised PPC regulation 12 notification
Electrical connection and interfaces:	Electrically connected to Gremista primary substation (HV) and LPS electrical network (LV)
Ancillary services required:	LV supply for auxiliary systems. Heating to maintain 20°C room temperature. Forced ventilation if hydrogen is detected
Access requirements:	Access required to the front of each battery rack, cells are removed horizontally using a trolley arrangement, so only 'walkway' width requirements
Installation procedure:	Where space allowed, cells were installed in the module frames off-site and then lifted into position on site
Handover to operational team:	In progress
Lessons learnt:	In comparison to the NaS battery, installation time was significantly longer. However the method utilised off-site construction, was highly repetitive and therefore resulted in a much simpler installation

Safety and Operational Assessment:

Failure modes and effects analysis:	Buro Happold produced a quantified fire engineering assessment for the Pb-Acid battery. This concluded that there was an extremely low likelihood of a fully developed fire occurring and it was not considered credible that a fire in the battery storage building could develop to a size large enough to spread to adjacent buildings
Risk assessment process:	A review of relevant codes, standards and legislation A review of documentation provided by the supplier Preparation of risk assessments
Mitigation measures employed against residual risks:	S&C have installed a very early smoke detection apparatus (VESDA) with a hydrogen gas detection system. This is connected to an inert gas fire suppression system and forced ventilation to respond to a fire or build-up of hydrogen respectively
Information provided by the manufacturer / system supplier:	Safety statement and safety data sheet, explanation of gas production in VRLA batteries, ventilation requirements, faulty cell replacement guide
Integration with existing safety rules:	Standard operational rules applied to construction
Engagement with external stakeholders:	Meeting with HSE Meeting with SEPA, leading to revised PPC regulation 12 notification
Lessons learnt:	It was concluded that the Shetland Pb-Acid batteries are defined as "articles" under the Registration, Evaluation, Authorisation and restriction of Chemicals (REACH) regulations and Classification, Labelling and Packaging (CLP) regulations and therefore do not meet the definition of "dangerous substances" in COMAH

Operating regime:

Applications:	Peak shaving Frequency response Voltage support (PCS) Increasing renewable generation output Increasing LPS thermal generation efficiency
Control Architecture:	Touch screen HMI built into the SMS, which provides local control of both the SMS and the battery system. Physical switch on the SMS to move from local to remote control. Integration with the full NINES ANM system, which performs generation and demand forecasting, load scheduling and real time system control. The ANM system is fully integrated with the power station control system, which provides control and alarms to the local operators. 11kV breaker is controlled directly from the LPS SCADA system. Telemetry, but not control, is provided to the Power Systems control room in Perth
Despatch mechanism:	Battery operation is primarily managed via an ANM system. An HMI in Lerwick Power Station control room currently provides the means for manually scheduling the battery. Once operators have gained experience and confidence in the technology and system, the battery may be scheduled autonomously by the ANM system. This will be exploited further once new renewable generation connections connect under the NINES project
Operating regime:	Limits specified in the software permit a maximum discharge of 3MWh per day. The battery charges during the night and is scheduled to discharge during peak times through the day
Benefits from operation:	Current benefits from operation include a 1MW reduction in peak demand. This equates to an average of 3.2%. Whilst charging at 1MW, the battery may increase the minimum demand by an average of 5.2%

Cost:Benefit Case:

A full cost benefit analysis will be undertaken during the 'operate and evaluate' phase of the project
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Further Information:

Additional Information:	
References:	SSET1001 close-down report: https://www.ofgem.gov.uk/ofgem-publications/89496/sset10011mwbatterysketland-closedownreport20141.1.pdf

A1.11 Nairn Flow Battery Trial

Project Description:

Project Name:	IFIT 2007_02_Flow Battery Trial
Principal Contact:	FutureNetworks@sse.com
Start Date:	2007
End Date:	2011
Project Status:	Complete
Project Highlights:	<p>This was one of the first flow battery projects in the UK and the first venture into advanced battery systems from a GB DNO. The system was never operational to the extent that SSE were satisfied in spite of multiple iterations of the technology.</p> <p>The project did however help to inform numerous advanced battery projects in the UK and provided a significant amount of learning to the industry despite not delivering the original project aims.</p>

Description of Technology:

Technology Employed:	Zinc- Bromine flow battery
System Supplier:	Premium Power Corporation
Description of Technology:	Single, fully contained outdoor unit, 100kW peak power, 150kWh
Description of PCS:	
Previous track record:	No previous UK installs – although with some previous installs outside of UK
Number of Units Installed:	Three phase unit – 3 phase operation only
Installation Location:	Unit was installed as a trial at a Nairn grid substation (132kV to 33kV).

Codes, Standards and Licensing:

Certification offered by equipment supplier in relation to energy storage module:	UL1778 (Uninterruptible Power Systems) FCC Part 15 Class A (addressing EMC aspects) NFPA 1 (National Fire Code), via the provision of an integrated approach to fire code regulation and hazard management. NFPA 70 (National Electrical Code, addressing safe electrical design, installation, and inspection aspects)
Codes considered in safety assessment:	
Planning Processes:	
Lessons learnt in relation to codes, standards and licensing:	

Procurement:

Process followed:	
Scope of supply:	Complete integrated system
Associated BoP required for project:	Footing to specification provided by Premium Power Corporation.
Process for development of specification:	n/a
Performance/select ion criteria and standards applied:	n/a
Acceptance tests employed:	Test and monitoring programme developed by EA Technology, such as allow for the demonstration and evaluation of system capability.
Warranty and after-sales support included:	
Lessons Learnt:	

Training:

Operational Training Provided:	
Authorisations and Personal Competence:	
Lessons Learnt:	Requirement to carefully supervise installation staff unfamiliar with UK regulations and operating environment.

Installation:

Roles and responsibilities:	DNO took responsibility in conjunction with the manufacturer to complete the installation
Application of CDM Regulations	CDM Regulations followed, project was not notifiable.
Site selection process used:	Site was selected as there was sufficient free space / access and within Inverness depot area.
Site work:	The containerised solution made the installation fairly straightforward. A plinth was created with multiple ducts to house the required comms & electrical cabling.
Engagement with external stakeholders regarding site:	The substation was not close to any housing developments and as such no engagement was required. Local field unit teams made aware of equipment + highlighted on control room diagrams.
Electrical connection and interfaces:	Connection made to the LV board within substation. Additional connection made to a resistive load bank for testing.
Ancillary services required:	
Access requirements:	
Installation procedure:	A grab loader was used to install and remove the device.
Handover to operational team:	Testing was always completed in the presence of the manufacturer.
Lessons learnt:	

Safety and Operational Assessment:

Failure Modes and Effects Analysis:	
Risk Assessment Process:	Standard SSEPD Risk Assessment process, with peer review by EA Technology.
Mitigation Measures Employed against Residual Risks:	Spill kit deployed in substation (Acid resistant PPE, pH testing equipment, neutralising compounds)
Information Provided by the manufacturer/ system supplier:	Firefighting procedures, safety data etc.
Integration with Existing Safety Rules:	SAP present during all testing – only attended testing was carried out.
Engagement with external stakeholders:	
Lessons Learnt:	Significant learning generated, including that in relation to the challenges involved in “anglicising” a non-indigenous product, for operation in a GB DNO operating environment.

Operating Regime:

Applications:	The unit was operated within the context of a contrived test programme only, as a precursor to possible future network related applications.
Control Architecture:	
Despatch mechanism:	
Operating regime:	
Benefits from operation:	

Cost:Benefit Case:

The intention was to investigate advanced batteries in general not just the replacement for substation batteries to provide auxiliary supplies.

Further Information:

Additional Information:	IFI Closedown Report available to GB DNOs
References:	SSEPD Transmission Innovation Funding Incentive (IFI) Report 2012 - 2013. Available from http://www.ssepd.co.uk/Innovation/IFIAndRPZ/ (accessed 23 rd July 2014).

A1.12 FALCON (5 off 50 kW, 100 kWh)

Project Description:

Project Name:	FALCON
Principal Contact:	Philip Bale, WPD. wpdinnovation@westernpower.co.uk
Start Date:	December 2011
End Date:	September-2015
Project Status:	Equipment is installed and commissioning is underway.
Project Highlights:	Installation of batteries in a secondary substation environment. First UK installation of Durathon™ batteries.

Description of Technology:

Technology Employed:	Sodium Nickel Chloride
System Supplier:	GE Durathon Batteries, Princeton Power Invertors
Description of Technology:	100kWh, 50kVA units
Previous track record:	New to the UK
Number of Units Installed:	5 x 3ph units
Installation Location:	Milton Keynes Within a distribution secondary substation environment

Codes, Standards and Licensing:

Certification offered by equipment supplier in relation to energy storage module:	U.S. National Electrical Code (NEC) EMC: FCC Class A, CISPR 22 Class A, ETSI 300 386, and NEBS Level 3 EMC IEEE - Guide 1679.2 IEC 61000-4-2
Codes considered in safety assessment:	Information from Suppliers WPD internal fire Risk Assessment process
Planning Processes:	Planning notified to MKC using permitted development.
Lessons learnt in relation to codes, standards and licensing:	Most codes are US-based and few manufacturers offer certification to UK specific codes.



Procurement:

Process followed:	PQQ and ITT both used following an Achilles search.
Scope of supply:	Single contractor for all components
Associated BoP required for project:	Funded using LCNF Tier 2 money
Process for development of specification:	Outline of physical size constraints and where the devices where to be connected to the network. Use cases developed and shared to tendering companies on what product functionality is required.
Performance/select ion criteria and standards applied:	Device selected based on company performance, timescales to deliver, functionality match as per the specification
Acceptance tests employed:	FAT for device limits and operation Site Acceptance Test (SAT) for full operation of equipment – 5 days full commissioning testing per device once connected to the live network
Warranty and after-sales support included:	Warranty as per WPD/GE framework agreement
Lessons Learnt:	Certain functionality can be hard to prove outside of a test environment Technology still very immature Degradation of the batteries over time still unclear

Training:

Operational Training Provided:	Onsite training for staff using the equipment. Remote training for monitoring the device
Authorisations and Personal Competence:	LV AP for disconnecting the device.
Lessons Learnt:	Disconnection of the device to fit BAU as closely as possible. Wider implications of training if the device is replicated around the business



Installation:

Roles and responsibilities:	WPD Delivery teams GE to support installation
Application of CDM Regulations	CDM regulations followed. Project was not notifiable.
Site selection process used:	Site selected due to size constraints and proximity to customers
Site work:	New Glass Reinforced Plastic (GRP) housing required, concrete plinth work and earthing extensions from existing substation mat
Engagement with external stakeholders regarding site:	MK Council, Housing trusts both extensively consulted until legal acceptance of site work complete.
Electrical connection and interfaces:	LV connection to existing LV board
Ancillary services required:	All systems run off incoming way to facilitate disconnection
Access requirements:	WPD Substation access requirements
Installation procedure:	HIAB required to position into site. Electrician required to assist with DC wiring.
Handover to operational team:	Units still being commissioned.
Lessons learnt:	Protection of the equipment via G59 is essential and overlooked by US suppliers. For trial equipment, making interfaces familiar for Business as Usual (BaU) staff is important. Size of equipment can make retrofitting at some sites very difficult. Density of energy in standard batteries is not compatible with existing distribution substation space.

Safety and Operational Assessment:

Failure Modes and Effects Analysis:	WPD fire Risk Assessments Site Risk Assessments.
Risk Assessment Process:	Internal validation of risks
Mitigation Measures Employed against Residual Risks:	Signing on equipment for fire fighting procedures. Additional fire fighting equipment placed on site. Sites fenced to prevent unauthorised access
Information Provided by the manufacturer/ system supplier:	Training material and on-site familiarisation
Integration with Existing Safety Rules:	Standard Techniques for disconnection and monitoring of the device written
Engagement with external stakeholders:	Local fire fighting department will be invited to site for training once commissioned.
Lessons Learnt:	Site suitability can significantly help eliminate risks Using BAU procedures to disconnect the equipment allows any authorised staff member to remove the device from the network, and leave any fault-finding to more suitably qualified staff.

Operating Regime:

Applications:	Manual and time/day/date scheduled discharge (P&Q adjustable) to support network, Peak shaving, voltage support.
Control Architecture:	GE Management System
Despatch mechanism:	The control system provides local and remote dispatch, of manual or time schedule charge/discharge or advanced control functions of peak shaving, voltage control and frequency control.
Operating regime:	Following commissioning a wide variety of operating regimes will be tested as part of the LCNF Falcon Project
Benefits from operation:	Benefits of operation will be assessed as part of LCNF Falcon Project

Cost:Benefit Case:

Cost Benefit Case will be assessed as part of the LCNF Falcon Project

Further Information:

Additional Information:	
References:	



A1.13 Sola Bristol (31 installations, a total of 100 kW, 279kWh)

Project Description:

Project Name:	Sola Bristol
Principal Contact:	Mark Dale WPD. wpdinnovation@westernpower.co.uk
Start Date:	1 st Dec 2011
End Date:	15 th Jan 2016
Project Status:	26 domestic installs are complete and commissioned along with 11 substation monitors. 6 commercial properties are also installed and commissioned.
Project Highlights:	All data for connected properties is available and analysis is underway

Description of Technology:

Technology Employed:	GEL filled Pb-Acid batteries. Siemens control unit with Moixa comms
System Supplier:	FIAMM Battery & sonnenschein SOLAR battery, Siemens & PE Control and DC/DC converters, 4 Quadrant Studer Inverter/charger, Moixa Comms.
Description of Technology:	4X130Ah batteries (4kWh) in each home. Charged by PV Panels or off peak mains. Discharged at peak times. Network requests controlled by DNO
Description of PCS:	DC/AC Inverter- 2.4kW Studer Xtender DC/DC Converter 2kW Siemens/PE 200V to 600V input 27V to 30V output
Previous track record:	None
Number of Units Installed:	26 homes Installed along with 5 schools and an office. 11 Substation monitors installed and Commissioned
Installation Location:	Knowle, West Bristol LV Feeder for home installation Power Quality meter and battery control unit in Distribution Sub station

Codes, Standards and Licensing:

Certification offered by equipment supplier in relation to energy storage module:	Full system CE Tested. LVD and EMC tests complete. CTs comply with IEC6044-1 Batteries IEC60896-22 compliant
Codes considered in safety assessment:	OHSAS 18001 Workplace Health & Safety EN 50 272-2 G59 Protection
Planning Processes:	N/A
Lessons learnt in relation to codes, standards and licensing:	Full system CE marking takes time for bespoke R&D projects



Procurement:

Process followed:	N/A
Scope of supply:	Deep discharge Pb-Acid batteries chosen.
Associated BoP required for project:	
Process for development of specification:	Siemens working with PE designed system that could be charged by PV or mains. Batteries could run internal DC network and/or export to the grid. LV connection manager communicates with LV Network manager to optimise storage use for DNO and Customer.
Performance/select ion criteria and standards applied:	N/A
Acceptance tests employed:	Attendance at full FAT at NAREC Facility in Blyth. Complete system tested. Variable DC power supply proved not to be representative of a PV Panel. Issues found on initial install required further testing. Site commissioning tests as per G59
Warranty and after-sales support included:	On-site support from Siemens for the duration of the project. Bristol City Council support for DC Network in homes
Lessons Learnt:	FAT testing needs to replicate PV on site. Lead in time for some DC (24V) equipment can be lengthy

Training:

Operational Training Provided:	Installation guide produced. Installers personally trained by Siemens.
Authorisations and Personal Competence:	Trained and authorised council electricians. No DNO authorisation, as on customer side of the meter.
Lessons Learnt:	Refresher courses required due to time delays between installs and the innovative nature of the installations i.e. not your usual every day work.



Installation:

Roles and responsibilities:	Siemens produced an installation guide and helped train installers BCC electricians undertook install work Knowle West Media Centre (KWMC) responsible for Customer Engagement University of Bath responsible for setup and Data capture
Application of CDM Regulations	N/A
Site selection process used:	BCC council homes with existing PV installed and in the project area. Local workshop held by KWMC to showcase the project and invite tenants to take part.
Site work:	Minor support work for roof trusses following structural survey. Working platform and walkway in all lofts.
Engagement with external stakeholders regarding site:	Engagement with BCC & KWMC for most suitable properties
Electrical connection and interfaces:	All domestic installs on customers side of the meter. Sub monitors have voltage take off from bus bar and split CTs (400/1) on each feeder.
Ancillary services required:	
Access requirements:	Small loft hatches. Walkways and working platforms required in lofts
Installation procedure:	Structural and electrical surveys carried out pre installation. Specialist lift for batteries into loft area (4x48kg units)
Handover to operational team:	Council electricians support installations. Council call centre have a list of participating properties so that Sola Trained staff only attend any issues.
Lessons learnt:	Logistically boarding out of lofts and lifting batteries needs to be completed as a separate task in case of delays. Customers have bespoke lighting that cannot be converted to DC.

Safety and Operational Assessment:

Failure Modes and Effects Analysis:	Aside from CE & EMC testing, a report from ERN was commissioned into the effects of using existing AC wiring to run DC lighting. No issues raised.
Risk Assessment Process:	Siemens Installation Guide covers Risk Assessment, Isolation and PPE etc All batteries compliant with IEC60896-22
Mitigation Measures Employed against Residual Risks:	Electrical protection in the DC/DC Battery Transfer Box via CBs and fuses. G59 relay tested by independent test body and checked against mains failure. DC MCCBs in LV Connection distribution box. Full system CE tested Additional drip tray for battery box despite using Gel filled batteries. Minor structural re-inforcement of roof joists.
Information Provided by the manufacturer/system supplier:	All contained in Installation guide. Document control to ensure latest versions of guides and associated drawings available
Integration with Existing Safety Rules:	Domestic works outside of DSRs as on the customer's side of meter. Sub installs work in live substation environment
Engagement with external stakeholders:	As the homes are all local authority owned, the BCC call centre staff have been briefed on the project
Lessons Learnt:	Voltage take off in the substation aimed to use adapted Schneider fuse carriers. Some LV boards were non-standard so an alternative bus bar clamp was used. 400/1 CTs were not suitable for current levels below 20A requiring reprogramming of PQ monitors

Operating Regime:

Applications:	Peak shaving, voltage control, Demand side Management, customer savings, Time of use Tariffs
Control Architecture:	Bespoke Siemens /PE LV Connection manager unit communicates to home Studer inverter and DC/DC converter. Also communicates with LV Network Manager in substation.
Despatch mechanism:	<p>The system is capable of managing and maintaining the SOC of the batteries by exporting to the grid on demand.</p> <p>The grid-side demand comes from sub-station depending on voltage levels (statutory limits)</p> <p>Network related Tariff based information is also used to manage the Battery SOC.</p> <p>Primary drivers are the surplus to requirement PV-on-the-day and calculated target-SOC.</p> <p>The data paths are through GPRS connectivity and the data is deposited at the repository at University of Bath.</p> <p>Associated substations within the area have Siemens power quality monitoring equipment installed on every feeder, linked to the individual homes.</p>
Operating regime:	How often a system charges and discharges will be dependent on the individual property's demand and generation profile, coupled with the network requests and tariff information. An early operational learning report is due in December 2014.
Benefits from operation:	<p>We have identified 4 areas where customers could benefit from the proposed solution</p> <p>Keeping the lights on: Through the installation of the BRISTOL system, the batteries will be used to provide enhanced resilience during power outages. Lighting, computing, telecommunications and potentially central heating pumps will be available from the battery storage even during network power outages.</p> <p>Lower energy bills through a better control of energy; a Variable Tariff rewarding customers for reducing their peak energy demand, passing on the cost savings. Clearer, more transparent energy bills through the LV connection manager using energy efficiency, better use of PV</p> <p>Improved energy efficiency: Supplying DC equipment using a high quality AC/DC converter and PV panels powering the DC network instead of a large number of inefficient AC/DC converters will reduce electricity losses.</p> <p>Quicker and cheaper connections: Conventional network reinforcement can not only be costly, but also require significant scheduling; the BRISTOL solution is one that could be implemented much faster and cost effectively.</p> <p>DNO Benefits</p> <ul style="list-style-type: none"> • The project will test the benefits of storage located at customer premises, rather than at substations, providing the additional LV feeder load and voltage control support. • By oversizing the battery in the customers' premises, the project will explore the business case for DNOs operating a virtual partition of distributed storage. • BRISTOL will test how batteries can be used with demand response by customers to take advantages of variable retail tariffs. From this DNOs will gain an insight into the residual impact of LCTs on the distribution networks. • The project will provide insight into how customers perceive innovative solutions such as the BRISTOL solution.

	<ul style="list-style-type: none"> • BRISTOL will create an intelligent self managing network linking together the substation with multiple properties with battery storage and demand response to reduce voltage rise and reduced peak demand. • This project will use intermittent generation and battery storage when making network planning assumptions for the connection of other customers. • BRISTOL will explore lower harmonic distortions on the network voltage by solving the problem, reducing power quality issues • The Project will provide better use of the existing distribution assets.
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Cost: Benefit Case:

The projection below is taken from the original project submission. It should be noted that the final cost of the Bristol solution will be analysed at project end in Jan 2016.

BRISTOL costs per substation - £48,900

One LV Network Manager (£2,400) and thirty properties per substation (£1,550) assuming the properties are on average located over three LV feeders.

Conventional network reinforcement costs per substation - £63,720

Based on 120m LV overlay and Harmonic Filtering on three LV feeders.

Year	Connected microgeneration			
	Estimated number of locations	Average micro-generation (kWe)	Cost savings per substation	Cost savings per year
2015	40	60	£14,820	£592,800
2016	60	60	£14,820	£889,200
2017	80	60	£14,820	£1,185,600
2018	100	60	£14,820	£1,482,000
2019	120	60	£14,820	£1,778,400
2020	140	60	£14,820	£2,074,800
2021	160	60	£14,820	£2,371,200
2022	180	60	£14,820	£2,667,600
2023	200	60	£14,820	£2,964,000
2024	200	60	£14,820	£2,964,000
2025	200	60	£14,820	£2,964,000
2026	200	60	£14,820	£2,964,000
2027	200	60	£14,820	£2,964,000
2028	200	60	£14,820	£2,964,000
2029	200	60	£14,820	£2,964,000
2030	200	60	£14,820	£2,964,000
				£36,753,600

Further Information:

Additional Information:	Project Progress reports can be found at www.westernpowerinnovation.co.uk
References:	

A1.14 Hemsby (200 kW, 200 kWh)

Project Description:

Project Name:	Hemsby
Principal Contact:	Peter Lang, UK Power Networks
Start Date:	Construction May 2010
End Date:	Commissioned April 2011
Project Status:	Complete - Operational
Project Highlights:	First electrical energy storage device connected to a distribution network*.

Description of Technology:

Technology Employed:	SAFT's Intensium Flex Li-ion battery Electrodes Lithiated Nickel oxide coated on aluminium foil, Carbon coated on copper foil. Electrolyte Lithiated salt with organic solvent
System Supplier:	SAFT for battery, ABB for PCS and system integration
Description of Technology:	Intensium FLEX Li-Ion Battery unit 200kW, 200kWh, Batteries occupy a room 3m x 4m x 3m (lxbxh) AC 11kV and 2.2kV components installed in an outside compound 6m x 10m PCS occupies a room 3m x 5m x 3m Overall footprint 15m x 15m
Description of PCS:	ABB's SVC-Light : inverter between AC and DC bus
Previous track record:	First of a kind in GB
Number of Units Installed:	One three phase unit
Installation Location:	Hemsby near Great Yarmouth Connected to an 11kV normal open point of a feeder supplied from Martham and Ormesby primary substations. Newly established substation compound.

Codes, Standards and Licensing:

Certification offered by equipment supplier in relation to energy storage module:	EU 2006/66/EC batteries must have crossed wheeled bin symbol. Li-ion batteries with electronic components subjected to EMC directive 93/97/EEC. Must have CE marking. Basic cells are approved according to UL 1642.
Codes considered in safety assessment:	Information provided by SAFT
Planning Processes:	Planning permission involving the approval of the visuals was granted by Great Yarmouth Borough Council
Lessons learnt in relation to codes, standards and licensing:	There are very few standards for battery and PCS devices that can be quoted in the specification.

*: In current round of IFI/LCN Fund demonstration projects

Procurement:

Process followed:	Hemsby was part of a R&D project with ABB who carried out the installation as a turn-key contract.
Scope of supply:	ABB was a turnkey contractor
Associated BoP required for project:	The project was funded using IFI funding.
Process for development of specification:	Consideration of functionality of device required feeding into development of specification. Iterations with the supplier. Installed on an 11kV network, with wind farm on the same feeder.
Performance/selection criteria and standards applied:	No selection process. The device was as big as the funding could afford.
Acceptance tests employed:	FAT on MACH2 control system and other individual components. Type test certificates were made available on off the shelf components, e.g. cooling system Cold commissioning to prove functionality. After final connections to 11kV network hot commissioning testing the device at rating i.e. after full charge 200kW discharge for one hour, recharge and short time discharge at 600kW. The testing process took several weeks after snagging.
Warranty and after-sales support included:	Warranty requires the supplier to remedy any and all defects in the Works (including Latent Defects) within 5 (five) business days of such defects arising or such longer period as may be agreed between the parties for a period of 60 months. Availability of troubleshooting (time to site)- normally next working day. Maintenance arrangements includes schedules of monthly visual live inspections, 6 monthly and annual arrangements.
Lessons Learnt:	As the technology is still immature careful coordination with Procurement has to be maintained. Still unclear whether it is better to choose a battery supplier who subcontracts a PCS supplier or vice versa or an integrator who subcontracts both major components.

Training:

Operational Training Provided:	Combination of classroom and on-site training. Annual refresher training during the annual maintenance shutdown.
Authorisations and Personal Competence:	11kV SAP and having attended the training.
Lessons Learnt:	Build the relationship with those who will operate the device as early as possible. Involve them in the safety procedure discussions.



Installation:

Roles and responsibilities:	UK Power Networks - Client and CDM coordinator ABB - Supplier Freedom - Principal contractor
Application of CDM Regulations	Project required CDM notification as construction phase was greater than 500 man days.
Site selection process used:	Site selected to be close to a wind farm to assess potential benefits
Site work:	Previous agricultural land, All works necessary to install and connect to an 11kV network. Foundations, security, earthing, cabling, craneage, assembly, etc.
Engagement with external stakeholders regarding site:	Land owner via an agent
Electrical connection and interfaces:	Established new substation with RMU with all switches and CB remotely controllable. Second CB in series to be controlled by MACH2.
Ancillary services required:	Two auxiliary supplies from independent sources. Automatic changeover system Water + glycol cooling for the IGBTs Heating, Ventilation and Air Conditioning in battery and control rooms
Access requirements:	Special key to enter control room Castell interlocks to prevent unauthorised access.
Installation procedure:	Cranes were required
Handover to operational team:	Operational procedures were included in an Engineering Operational Standard that allowed the operational team to operate and work on the equipment safely.
Lessons learnt:	<p>Make sure smoke detectors are kept clean. A mis-fire of a smoke detector caused the CO₂ fire suppressant system to operate. Have two smoke detectors in series to trigger the CO₂ fire suppressant system.</p> <p>Make sure the auxiliary load (heating, cooling, lighting, etc.) is not disproportionate to the size of the battery store. E.g. assuming a 1kW standing demand, each day would be equivalent to 24kWh consumption.</p> <p>Only connect the installation to the network when the contractor has completed all cold commissioning. Once connected it becomes part of the network and bound by DSR and DNO safety procedures. This means a SAP is required each time to release the equipment for inspection.</p> <p>Protection co-ordination of the DC side can be challenging. Special DC rated fuses were required to protect the DC cables from the batteries to the PCS and DC busbars. Routing the DC cables from the battery room to the PCS room along a safe route. (not passing through the control room).</p> <p>200kW is better connected to a LV network, avoiding the need for step-up transformers, etc.</p>



Safety and Operational Assessment:

Failure Modes and Effects Analysis:	
Risk Assessment Process:	Hazard elimination management log (HEML) was completed
Mitigation Measures Employed against Residual Risks:	Unauthorised access. 2.4m palisade fencing, castell interlocks, only trained staff access the control room.
Information Provided by the manufacturer/ system supplier:	Training material and on-site familiarisation
Integration with Existing Safety Rules:	Engineering Operational Standard was written as a point of reference. Methods of isolation and earthing. Approved voltage detection testing device.
Engagement with external stakeholders:	Site neighbours were told what we were doing throughout the installation. They do keep a neighbourly eye on the site.
Lessons Learnt:	Distribution Safety Rules treat up to 1500V DC as LV. Test equipment has limits when detecting voltages below 100V. More robust alarming function when undertaking innovative projects, New alarms were created within the control system to provide more information.

Benefit Case:

The installation at Hemsby was not intended to have a strong financial return (given its relatively small scale), but to be an opportunity to further understand the effects of energy storage on the 11kV network and hence the potential for future larger scale devices, with sufficient economy of scale, to be economically viable as network support devices. As such, the main outcomes of this project have been learning and understanding.

The learning from Hemsby informed UK Power Networks' Smarter Network Storage project that was proposed and awarded funding under the LCNF Tier 2. This project aims to carry out a range of technical and commercial innovation to tackle these challenges, and facilitate more efficient and economic adoption of storage. See Appendix 1 Section A1.15.

Further Information:

Additional Information:	Demonstrating the benefits of short-term discharge energy storage on an 11kV distribution network, Close down report, UK Power Networks, June 2014 that can be accessed from http://innovation.ukpowernetworks.co.uk/ or the Ofgem website.
References:	[1] N. Wade, P. Taylor, P. Lang, J. Svensson, "Energy storage for power flow management and voltage control on an 11 kV UK distribution network," CIRED paper 0824, Prague, Czech Republic, June 2009. [2] P. Lang, N. Wade, P. Taylor, P. Jones, T. Larsson, "Early findings of an energy storage practical demonstration," CIRED paper 0413, Frankfurt, Germany, June 2011. [3] P. Lang, M. Michel, N. Wade, R. Grünbaum, T. Larsson, "Dynamic Energy Storage – A UK first, IET ACDC conference, Birmingham Dec. 5-6 2012 [4] "Early learning from an electrical storage installation on an 11 kV distribution network", Report, UK Power Networks, October 2012 [5] Feature Article for Transmission and Distribution World Magazine [6] Demonstrating the benefits of short-term discharge energy storage on an 11kV distribution network, Close down report, UK Power Networks, June 2014

	Other references and presentations are referred to in the close down report available on the ENA smarter networks portal and Ofgem websites.
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A1.15 Smarter Network Storage, Leighton Buzzard (6 MW, 10 MWh)

Project Description:

Project Name:	Smarter Network Storage (Leighton Buzzard)
Principal Contact:	innovation@ukpowernetworks.co.uk
Start Date:	January 2013
End Date:	December 2016
Project Status:	Commissioned
Project Highlights:	<p>A building-housed facility, SNS is the first battery energy storage facility to go through a full planning consents process with a regional local authority – granted in June 2013</p> <p>The project is exploring the commercial and regulatory barriers of storage when operated for multiple network and commercial applications; including industry-wide consultation on business model structures in July 2013</p> <p>SNS is the largest distribution network connected battery energy storage system in Europe, and the first battery to be incorporated in the Transmission System Operator's (TSO) portfolio of balancing plant;</p>

Description of Technology:

Technology Employed:	Lithium ion, lithiated metal oxide / intercalation graphite electrodes.
System Supplier:	Samsung SDI for batteries, Younicos for battery management system and S&C Electric for Power Conversion System (PCS) & installation/integration.
Description of Technology:	Samsung SDI lithium ion batteries 6MW, 10MWh S&C Electric Europe Ltd – Power Conversion system (Lead Supplier) Yunicos – Battery Management & Control System Building housed installation; footprint 39mx19m
Description of PCS:	S&C Electric 3 x 2MW / 2.5MVA PCS, for 480V AC connections
Previous track record:	<p>S&C have other small-scale PCS systems in UK, including part of "LV Connected Batteries" project, and a 1MW installation on Shetland". >24MWh installed storage worldwide</p> <p>Samsung SDI have >25MW utility solutions installed worldwide (April 2013), but SNS will be the first in UK for Samsung SDI</p>
Number of Units Installed:	Single installation comprising 3x 3 phase units, each 2MW / 2.5MVA / ~3.3MWh
Installation Location:	Leighton Buzzard Connection to 11kV primary substation busbar, site adjacent to existing primary substation



Codes, Standards and Licensing:

<p>Certification offered by equipment supplier in relation to energy storage module:</p>	<p>EU 2006/66/EC batteries must have crossed wheeled bin symbol. Li-ion batteries with electronic components subjected to EMC directive 93/97/EEC. Must have CE marking. Basic cells are approved according to UL 1642.</p>
<p>Codes considered in safety assessment:</p>	<p>Information was provided by S&C Electric.</p> <p>The following codes and standards were considered in the contract specification:</p> <ul style="list-style-type: none"> • Health and Safety at Work etc. Act 1974 and the Management of Health and Safety at Work Regulations 1999 and Amendments • Construction (Design and Management) Regulations 2007 • ANSI/IEEE C2-1997, National Electrical Safety Code • IET Wiring Regulations 17th Edition (BS 7671:2008 incorporating amendment number 1:2011) • Energy Networks Association (ENA) Engineering Recommendation G5/4-1 in October 2005 • Control of Major Accident Hazards Regulations 1999 (COMAH) • Control of Substances Hazardous to Health Regulations 2002 (COSHH) • Planning (Hazardous Materials) Act 1990 • Regulation (EC) No 1272/2008 of 16 December 2008 on classification, labelling and packaging of substances and mixtures • ANSI C57.12.28, Pad-Mounted Equipment Enclosure Integrity • UL 1741 for Distributed Resources • IEEE Standard 1547-2003, IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems • IEEE P1547.1/D6, Draft Standard Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems. • IEEE P2030.3 Standard for Test Procedures for Electric Energy Storage Equipment and Systems for Electric Power Systems Applications • BS EN ISO 9001 Quality Management Systems – Requirements • Directive 2004/108/EC of 15 December 2004 Electromagnetic Compatibility (EMC) • The UN Recommendations on the Transport of Dangerous Goods, Manual of Tests and Criteria. 5th Revised Edition (Issued December 2009) Section 38.3 • Material Safety Data Sheet for battery cell

<p>Planning Processes:</p>	<p>Full Planning consent was required for the site from Central Bedfordshire Council.</p> <p>This included multiple site investigations, alternative site scenario analysis, full design of the external appearance of the facility and consultation with local residents.</p> <p>The location of the development within the floodplain meant it was necessary to convey the importance for the development in terms of supporting network requirements. From robust analysis and presentation of alternative scenarios, it was agreed the proposal constituted essential infrastructure which, in the Technical Guidance to the National Planning Policy Framework, is acceptable within flood zones.</p> <p>There was also a conflict with South Bedfordshire Local Plan Review policy R7, and this was overcome by the general need for the development, and the offer of the remainder of the land for amenity use, and the transfer of some land for a planned cycleway/footway and other general environmental improvements through landscaping and replacement fencing.</p> <p>It was considered that the proposed development would not have any significant adverse impact on the character and appearance of the area or general or residential amenity to such an extent to warrant refusing planning permission. The proposal did not raise any highway, biodiversity or other issues which cannot be overcome by conditions or through the legal s106 agreement implemented.</p> <p>The proposal was therefore granted planning permission subject to 15 planning conditions.</p> <p>Further information about this process, and learning obtained is available from the project deliverable report SNS1.2 - Design & Planning Considerations Report (SDRC 9.1), available from: http://www.smarternetworks.org/Files/Smarter_Network_Storage_(SNS)_130930165806.pdf</p>
<p>Lessons learnt in relation to codes, standards and licensing:</p>	<p>There are very few standards for battery and PCS devices that can be quoted in the specification.</p> <p>Securing planning consents at the trial site, Leighton Buzzard, has required a significant amount of effort, and additional time, engagement and costs than initially anticipated – even taking into account guidance from planning consultants at the start of the process.</p> <p>Initial pre-application guidance from the council was however invaluable in identifying early, the key areas that required addressing, and guiding the focus of this work, but a broad range of specialist studies and investigations have still been required to satisfy the requirements, most of which have not been possible to carry out in house.</p> <p>From the public consultation exercise it was learnt that the top three areas of interest for local residents were the overall visual appearance of the development, the plans for the surplus land at the site, and plans for preventing additional flood-risk at the site – these were perhaps unsurprisingly specific to the locality of the trial site, but highlighted the nature of the technology was of relatively little concern to local residents.</p> <p>This learning suggests it is important to consult early with local authorities when considering sites for storage and understand the specific nuances and local issues relevant to the area. Incorporating feedback from consultation responses from local residents in the design is important to show that concerns have been taken on board and attempted to be incorporated in the design.</p>

Procurement:

Process followed:	<p>Intensive internal market research, followed by Invitation To Tender followed by reviews and detailed discussions with preferred suppliers. Credit and other checks were carried out including Achilles/Bravo registration.</p> <p>A technology-agnostic approach was taken, and functional specification used to outline the particular applications and functions that were required from the overall storage solution.</p>
Scope of supply:	<p>Scope of supply covered:</p> <ul style="list-style-type: none"> - Power Conversion Systems - Battery Cell and Systems - Control Systems (excluding 'Smart Optimisation & Control' platform) - Fire Suppression Systems - Cooling and Ventilation systems - Step-up transformers (with option for free-issue) - Cabling between battery systems - 11kV switchboard
Associated BoP required for project:	<p>Panel-clad building to house the facility, raised out of flood plain. Switchgear panel extension to connect to 11kV busbars. Automatic Voltage Control upgrade. Smart Optimisation & Control (scheduling) platform, developed by AMT-SYBEX.</p>
Process for development of specification:	<p>A functional specification was developed based on previous experience of the Hemsby project, other technical LCNF storage projects, and existing network equipment specifications. Additional functional requirements covering the various market applications and services required were developed based on information from National Grid</p>
Performance/select ion criteria and standards applied:	<p>Specific procurement criteria applied were:</p> <ul style="list-style-type: none"> - Safety, Health and Environmental Factors (18%) - Product Quality and Technical Compliance (18%) - Cost (18%) - Service Levels, Lead Times and Management Information Provisions (18%) - Technology Readiness, ease of deployment and experience (18%) - Value Adding Services (5%) - Alignment to the Carbon Plan and Project Objectives (5%) <p>The capacity of the device was defined in a range determined by the network requirements at the specified site. The specific capacity was determined from the proposal and further discussions with the chosen supplier.</p>
Acceptance tests employed:	<p>Test Strategy included 8 separate stages for the full end-to-end system:</p> <ul style="list-style-type: none"> • System (Unit) Testing • Attendance at Factory Acceptance Tests • Site Acceptance Tests • System Integration Tests • User Acceptance Tests • Non-Functional Tests • Operational Acceptance Tests • Cut-Over Process Test
Warranty and after-sales support included:	<p>2 year warranty.</p>

<p>Lessons Learnt:</p>	<p>An initial Achilles search was substituted with intensive internal market search as it was deemed that Achilles did not have a robust or up to date view of the relevant market for grid-scale energy storage systems, and lacks many appropriate categories for such a solution.</p> <p>The supply chain for energy storage systems, and battery storage in particular, has been found to be relatively immature and a complex supply chain of second-tier suppliers is required for a fully integrated storage system – covering, for example, power-conversion equipment, battery cells and assemblies, advanced control systems, fire-suppression and cooling systems. Currently there are examples of players with a history in each of these areas who are targeting the market for fully-integrated systems, and all have the potential to be lead suppliers. It is not yet clear however which segment of the supply chain will eventually dominate in the supply of integrated systems, and so it is likely there will be further shake-ups and consolidation in the coming years.</p> <p>This creates procurement challenges for energy storage systems and it was found that procurement databases, such as Achilles, do not necessarily capture the best or latest view of the potential supplier landscape. To overcome this, it is suggested that alongside existing procurement approaches, further market research is carried out to identify and capture additional emerging players, as was carried out in the bid-phase of the SNS project.</p> <p>Notwithstanding this, the nature of the market and sensitivity to other global markets, such as Electric Vehicles, increases the risk of supplier failure and delivery issues for these systems therefore it is prudent to identify and engage alternatives, even at the subcontractor level.</p>
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Training:

<p>Operational Training Provided:</p>	<p>Classroom and on-site training.</p>
<p>Authorisations and Personal Competence:</p>	<p>It is proposed that those who have been through the training will be able to operate the storage device up to their normal operational competency. No specific training is required for site access, sufficient information is provided on site to ensure those who are competent to enter substations can avoid danger inside.</p>
<p>Lessons Learnt:</p>	<p>None to date</p>



Installation:

Roles and responsibilities:	<p>A Principal Contractor managing the civil & electrical build, procured independently, oversees the entire construction site and electrical works to connect the storage facility to the 11kV network.</p> <p>The Principal Contractor oversees and manages S&C Electric and their subcontractors onsite who offload, install and commission the storage technology equipment in the finished building, as summarised below:</p> <p>Battery Management System suppliers, Younicos, are responsible for the final commissioning works of the battery management system.</p> <p>Client: UK Power Networks, Future Networks Principal Contractor: Morrison Utility Services Supplier / installer: S&C Electric</p>
Application of CDM Regulations	Project notifiable under CDM
Site selection process used:	<p>A number of sites were chosen based on substations reaching capacity limits and where reinforcement was scheduled that could be meaningfully deferred by installing storage. These sites were then filtered by looking at other relevant issues such as alternative solutions and available space.</p> <p>The storage is providing real network support for maintaining security-of-supply limits at the Leighton Buzzard site, and defers conventional reinforcement otherwise planned for the site.</p> <p>Alternative sites considered had similar constraints, but lower cost conventional interventions that could be deferred.</p>
Site work:	<p>The site used was previously scrub land adjacent to the existing 33/11kV substation. In order to accommodate the construction site facilities the whole site was levelled and prepared to be able to manage and provide welfare for [up to 40] people on site at any time. Approximately half of this land will be returned as a useable green space upon completion of the works.</p> <p>The storage device is housed in a custom designed single storey building raised above the potential site flood level. It is a steel framed building based on a piled foundation with the first floor construction being a reinforced concrete slab formed on pre-cast concrete planks to provide sufficient strength. The frame was clad with Kingspan insulated panels with similar panels being used for the roof and the walls. These are insulated metal clad panels that have established their place in the UK construction industry. With an A+ energy rating they enable energy efficient buildings to be built quickly and efficiently, reducing construction costs.</p> <p>Once the building was completed the majority of work was carried out inside with the construction of the internal walls, installation of the building services and primary electrical assets. This included 14 shipping containers of equipment for the batteries and delivery of the Power Conversion Systems, step-up transformers, 11kV switchgear and other items.</p> <p>Connections into the neighbouring 11kV primary substation were also required. The 11kV switchboard was extended to connect in the storage device and new 11kV cables were installed. The Remote Terminal Unit and Automatic Voltage Control system were both replaced and the ancillary supplies (AC and DC) were upgraded to support the storage device. This included installation of two new LV unit substations.</p> <p>Further information about the building design is available from the project deliverable report SNS1.2 - Design & Planning Considerations Report (SDRC 9.1), available from: http://www.smarternetworks.org/Files/Smarter_Network_Storage_(SNS)_1309301_65806.pdf</p>

Engagement with external stakeholders regarding site:	<p>Detailed engagement with Central Bedfordshire Council, local residents and other stakeholders was required as part of the planning application process, including letter drops to local residents, consultation meeting, full planning permission process engaging with local council and discussions with environment agency.</p> <p>Visits to both the local primary and secondary schools have been carried out to talk about electrical safety and the project.</p> <p>On-going engagement with nearby residents during the construction and installation phase was carried out through newsletters and emails. Although there was concern when the building first took shape the overall responses from the residents have been positive with several compliments received.</p> <p>Some large infographics have been installed on the construction hoarding providing insight into why the project is taking place and links to UK Power Networks innovation website where more detail is available. The project team have also engaged with the Leighton Buzzard Society with some of their members attending a knowledge dissemination event for the project. The SNS project team are also scheduled to present at one of their regular meetings on the work.</p>
Electrical connection and interfaces:	11kV duplicated dedicated circuits to new circuit breakers (CBs) in the existing primary substation.
Ancillary services required:	2x 415V supplies with change-over system for security of supply. Building heating, ventilation and air conditioning required.
Access requirements:	24h access, system secured using standard UK Power Networks operational locks.
Installation procedure:	<p>All major equipment was offloaded onto a dedicated loading bay, to allow sliding into the building. An interim level and static scissor lift were installed to speed up the process.</p> <p>Battery modules were offloaded from containers using fork-lifts, and transferred to the loading bay.</p> <p>General, high level procedure:</p> <ul style="list-style-type: none"> • Step-Up transformers positioned • Overhead busbars installed • Rack assemblies installed • Battery trays installed using custom frame that allowed trays to be raised and slid in at correct height (see image) • Battery rack switchgear installed • PCS Units positioned • Cabling • Comms & IT installation
Handover to operational team:	<p>Maintenance to be carried out by manufacturer during project lifetime.</p> <p>A number of UK Power Networks Directorates are involved with the operation of the storage system.</p> <p>The Commercial operation is carried out by Future Networks team, within Strategy & Regulation, for the project duration due to the first-of-a-kind nature of the activities involved in operating the storage in ancillary markets. Ultimately new functions may need to be established in future 'Distribution System Operators' that would take on these activities surrounding shared-use assets and commercial management of flexible capacity.</p> <p>Technical operation of the storage asset for network security is handed over to Control room teams within Network Operations.</p>



Lessons learnt:	<p>Due to the large quantity of goods to be brought out of lorry mounted containers (at one height) and offloaded into the building (at another height) a temporary interim loading bay was designed and built to enable this process to be done quickly and efficiently. This could be replicated for installations at ground level if required.</p> <p>The different component parts of the storage system have different environmental requirements. In order to improve the efficiency of the building overall the internal walls were insulated to minimise the energy requirements of maintaining different room temperatures.</p>
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Safety and Operational Assessment:

Failure Modes and Effects Analysis:	<i>n/a</i>
Risk Assessment Process:	Standard UK Power Networks design Risk Assessment procedures with addition of specific “So, what if?” (SWIFT) test.
Mitigation Measures Employed against Residual Risks:	Argon-based fire suppression system installed, backup electrical protection systems.
Information Provided by the manufacturer/ system supplier:	<p>Manufacturer carried out extensive tests on battery cells, to our requirements including:</p> <ul style="list-style-type: none"> - COSHH Assessment - Testing Risk Assessment - CDM Design Risk Assessment - Waste Batteries procedure - Material Safety Data Sheets - Fire Cascade Testing Results and Video - Information on cell safety measures - Drop Tests
Integration with Existing Safety Rules:	Engineering Operational Standard written as a point of reference
Engagement with external stakeholders:	Site neighbours engaged as above.
Lessons Learnt:	Additional site safety inductions were needed once batteries were present on site due to the residual stored energy, despite not being connected to the network.

Operating Regime:

Applications:	<p>Project objective is to explore the multi-purpose application of storage, and how value can be maximised across other applications alongside network deferral to improve the economic case. Applications that the storage will be used for include (but not limited to):</p> <ul style="list-style-type: none"> • Peak Shaving – Primary reason for storage at this network location is reduction of peak demand to maintain demand within security-of-supply limits. • Reactive Power (& Voltage) Support - to improve the distribution system efficiency and maintain the receiving voltage of the Leighton Buzzard Primary substation within limits • Dynamic Firm Frequency Response • Static Firm Frequency Response • Frequency Control by Demand Management • Short Term Operating Reserve (STOR) • Long Term Market Optimisation (Tolling) • TRIAD avoidance • Fast Reserve • Combinations of the above applications are being explored
Control Architecture:	<p>Units are controlled through Younicos-supplied 'Battery Energy Storage System Manager' (BESSM) and a custom-designed Smart Optimisation and Control System, developed by AMT-SYBEX (Part of Capita Plc).</p> <p>UK Power Networks operational teams will have access to these systems although key parameters and control functionality will be available through the network control system GE PowerOn Fusion, used by system control engineers.</p>
Despatch mechanism:	<p>The SNS facility has been designed to operate as autonomously as possible, once configured with a portfolio of available services & network applications. (See Applications above)</p> <p>The exact despatch mechanism is dependent on the particular service scheduled by the 'Forecasting & Optimisation System' (FOSS).</p> <p>Peak shaving is scheduled, based on a site-specific demand forecast, which is carried out on a range of timescales. If site demand is forecasted to exceed firm capacity, the peak shaving mode is scheduled for this period, including any pre-charge needed to cover the estimated energy required. During this mode, the on-site battery management system then reacts to measured demand at site, despatching the storage in real time to maintain overall site demand below the firm capacity threshold.</p> <p>When there is forecast headroom available, the FOSS system performs an optimisation to determine the best combination of services from the available portfolio to maximise the value from the storage facility.</p> <p>Depending on the services selected and scheduled, the following other despatch mechanisms are supported:</p> <ul style="list-style-type: none"> - Automatic despatch based on local frequency measurement - Automatic despatch based on measured voltage or reactive power - Despatch via messaging system by Aggregator's control room system (KiwiPower) - Manual/scheduled despatch to provide tolling contracts, TRIAD avoidance and future applications.

Operating regime:	<p>The operating philosophy is based around the site-specific demand forecast, which prioritises the need for peak shaving to maintain security of supply.</p> <p>Periods when peak shaving is needed are effectively reserved, and sufficient energy automatically charged into the storage to cover the peak. A safety margin can be factored in to account for the error margin in the forecasting.</p> <p>This service is expected to cycle the battery approximately once per day, over the seasons of high demand.</p> <p>For most other commercial services, the cycling regime tends to be less onerous, with the storage held at a fixed state of charge, ready to despatch in case of a system stress event, or any other trigger defined for each service/application..</p> <p>Dynamic Frequency response involves more frequent cycling, and involves the storage responding in real time to frequency deviations outside a deadband. These tend to be far shallower than a full charge/discharge cycle. Future trials will assess the relative cycling and degradation of this application.</p>
Benefits from operation:	<p>The storage is able to provide a number of benefits due to its application across a number of different services. Main benefits expected are:</p> <ul style="list-style-type: none"> - Reduction in peak demand of around 18% (7.5 MVA), ensuring security of supply is maintained - Deferral of over £6m of 33kV reinforcement as a result of peak demand reduction - Benefits of c£2.6m over 10 years from system reserve support and frequency regulation <p>Other secondary benefits are:</p> <ul style="list-style-type: none"> - Extension of outage season by providing additional support, allowing faster connection of DG customers - Losses reduction, through use of reactive power to improve power factor - Support to the TSO through reserve and response services provision and testing using storage devices. - Supporting storage of renewable electricity generation - Increased optionality and flexibility for long term network investment at Leighton Buzzard

Cost/Benefit Case:

One of the key purposes of the SNS project is to identify the general business case for the economic use of grid scale storage on the distribution network, when leveraged for additional benefit across the full electricity system under different business models.

This generic business case will be dependent upon the form of business model which is chosen for storage, and the assumptions that are made regarding all of the current unknowns. This project is looking to identify and quantify many of these unknowns and apply them to the various different business model structures to help drive forward the adoption of storage.

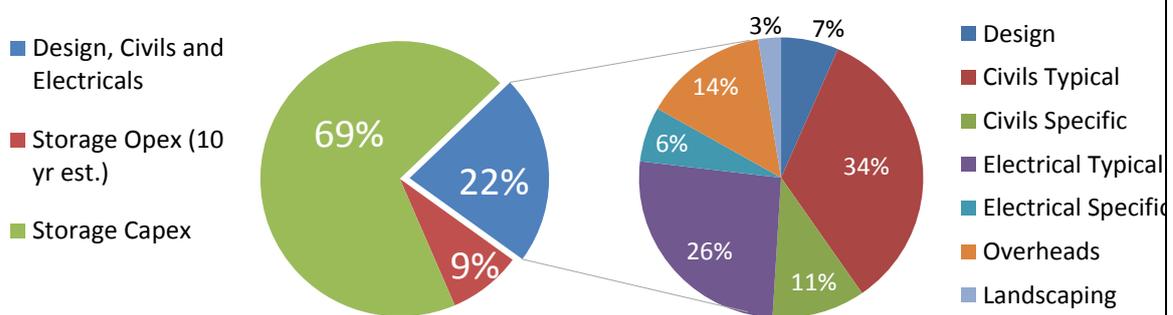
To date, the project has been tracking changes to all the main drivers of the business case, and has incorporated detailed costing of the procurement and installation costs of the SNS installation. The estimates of operational costs and revenues will be validated as further learning emerges.

Installed costs (as at June 2014)

In NPV terms, the installed cost of the 6MW/10MWh storage solution, including all design, civil and electrical works is approximately £11.2m.

Including estimates of lifetime operational expenditure, the NPV of the total system over 10 years is estimated to be £11.5m

The breakdown of the design, civil and electrical aspects is shown below:



Source: UK Power Networks analysis. All values in 2013 prices. Capex and design, civil and electrical costs specific to Leighton Buzzard

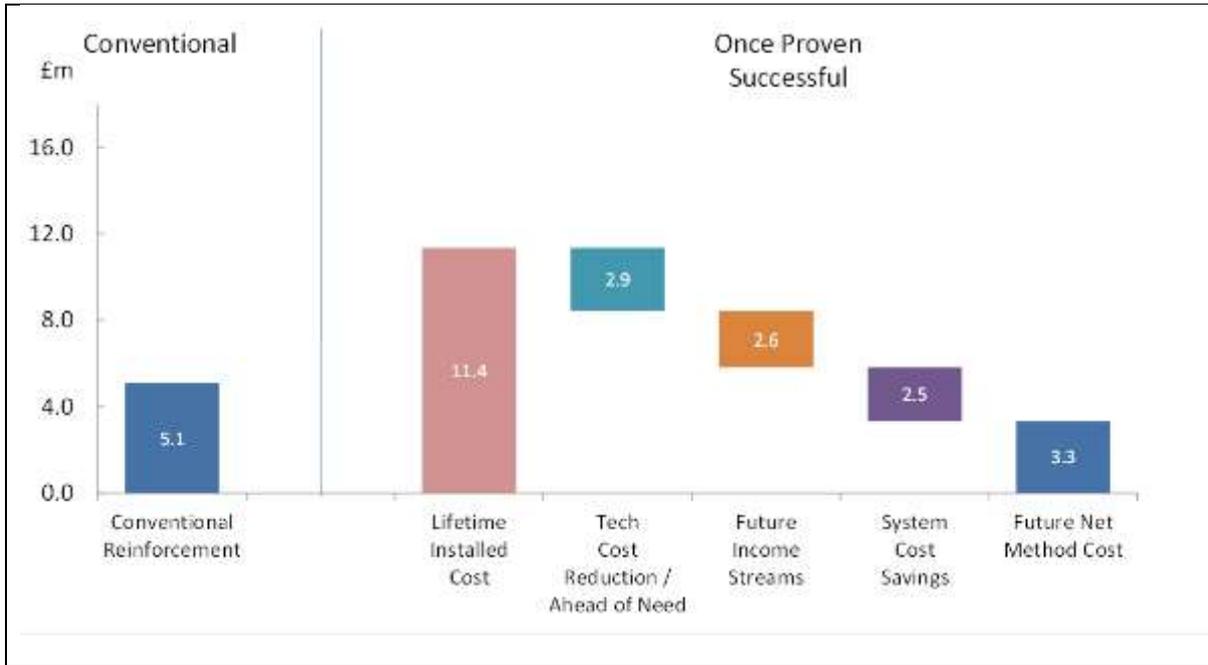
Benefits (as at December 2014)

The NPV cost of the conventional solution, to solve the security of supply constraint, is approximately £5.1m, which is obviously significantly lower than the lifetime cost of the storage of £11.4m.

However, taking into account just the benefits of future income streams, and wider system operational savings and carbon reduction, the overall NPV cost once proven successful is equivalent to approximately £3.3m.

These benefits, illustrated further below, include:

- 'Tech Cost Reduction' - Cost reductions anticipated in storage technology up to the point at which network intervention would otherwise be required (£2.9m) – this adjustment accounts for the fact that strictly, the storage system was procured for the SNS LCNF project approximately 2 years ahead of need
- 'Future Income Streams' – The revenues available from providing additional system support through ancillary services (£2.6m) – this income is assumed to come from a mix of STOR, FCDM and Fast Reserve only
- 'System Cost Savings' – The wider system benefits generated as a result of the relative reduction in peak demand & displaced peaking generation, reduced curtailment and carbon savings from 6MW of storage (£2.5m)



Further Information:

Additional Information:	http://innovation.ukpowernetworks.co.uk/innovation/en/Projects/tier-2-projects/Smarter-Network-Storage-(SNS)/
References:	Business Model Consultation SDRC 9.1 – Planning Considerations SRDC 9.2 – SOCS Design Interim Report on Legal & Regulatory Barriers

A1.16 Liquid Nitrogen Cryogenic Energy Storage Demonstration Project (DECC Energy Storage Technology Demonstration Competition)

Project Description:

Project Name:	Pilsworth Landfill Site – Liquid Nitrogen Cryogenic Energy Storage Demonstration Project
Principal Contact:	Site host: Viridor Waste Management Limited Technology provider: Highview Enterprises Limited trading as Highview Power Storage
Start Date:	January 2014
End Date:	September 2016
Project Status:	In progress. Planned to commence site works January 2015. Planned to commence operation October 2015.

Installation Description:

Installation Location:	Pilsworth North Landfill Gas Power Generation Plant, Bury, Lancashire Within landfill gas power generation plant compound.
Installation Capacity	5.5MW (gross) 4.5MW (net) 15MWh
Number of Units Installed:	One unit
Description of PCS:	Not applicable – the power recovery generator is a process gas expansion turbine driving a synchronous 4 pole generator
Principal Application for the Storage Demonstration	National Grid ancillary services, specifically Short Term Operating Reserve (STOR), TRIAD and peaking operation

Description of Technology:

Technology Employed:	Cryogenic (liquid nitrogen) energy storage
Technology Supplier:	Highview Power Storage
Description of Technology:	<p>Highview's liquid air/liquid nitrogen energy storage system can be described as a thermo-mechanical system. In its complete form Highview's liquid air/liquid nitrogen energy storage system comprises three subsystems:</p> <ol style="list-style-type: none"> 1. A liquefier, which functions as the charging device by using electrical power to produce liquid air (or in this case liquid nitrogen); 2. The energy store, low pressure storage vessels containing liquid air or nitrogen; and 3. The power recovery system which by pumping to high pressure, adding heat and expanding the resultant high pressure gas in a turbine, recovers the stored energy from the liquid air or nitrogen. <p>The system uses proven components, mature technology and/or subsystems from the industrial gas sector, utility sector and chemical process plant. This provides longevity and low technology risk around the introduction and deployment of the technology, in addition to scalability (up to 100MW/1,000MWh is achievable now). Using liquid air or nitrogen as the storage medium allows for good energy density compared to other non-fossil based storage systems (10 tons of liquid air/nitrogen stores approximately 1MWh of electricity during the discharge cycle). The technology can be located where it is required rather than adjacent to suitable geographical features as is required by pumped hydro or cavern based compressed air storage systems.</p> <p>Highview's liquid air energy storage technology offers a large scale, long duration storage solution which can be deployed at near commercial scale to meet the UK's electricity storage needs, particularly with respect to:</p> <ul style="list-style-type: none"> • National Grid ancillary services, specifically Short Term Operating Reserve (STOR); • Black start and industrial back up generation for the technology in the format used in the current project; • Demand side management and industrial peaking; • Managing network constraints; • Firming intermittent renewable generation (including wind and solar), when coupled with an on-site liquefier providing on-site charging capability. <p>The current project is demonstrating subsystems 2 and 3 only, due to DECC funding constraints and to minimise the on-site systems; the liquefaction side of the cycle will be carried out off-site at a merchant industrial gas plant, with liquid nitrogen being bought in and delivered by road tanker.</p> <p>Together, steps 2 and 3 function as a generation system with on-site energy store, but without the controllable demand side characteristics of a typical storage system, although the system is self-evidently rechargeable by refilling with liquid nitrogen.</p> <p>The project will demonstrate the benefits of adding cryogenic energy storage to a LFG generation installation, where it will utilise waste heat available and convert it into power, harvesting of waste heat, providing the ability to ramp up power output on demand and provide reserve type services at relatively low load factor (<100 hours per year). The demonstration of storage functions which involve the use of a controllable demand will not be practicable.</p>

Codes, Standards and Planning:

<p>Safety Certification:</p>	<p>As the system comprises existing mature technologies as its subsystems, comprehensive safety certifications and standards are already in place for its deployment.</p> <p>Design and works will be carried out in compliance with the following UK and European Union health and safety legislation.</p> <ul style="list-style-type: none"> • Health and Safety at Work Act 1974 • Construction (Design and Management) Regulations 2007 • Management of Health and Safety at Work Regulations 1999 • Workplace (Health, Safety and Welfare Regulations) 1992 • Supply of Machinery (Safety) Regulations 1992 • The Regulatory Reform (Fire Safety) Order 2004 • Provision and Use of Work Equipment Regulations 1998 • Lifting Operations and Lifting Equipment Regulations 1998 • Electricity at Work Regulations 1989 • Electrical Equipment (Safety) Regulations 1994 • Gas Appliances (Safety) Regulations 1992 • Gas Safety (Installation and Use) Regulations 1998 • Pressure Systems Safety Regulations 2000 • Pressure Equipment Directive (97/23/EC) • Machinery Directive (2006/42/EC) • Electro Magnetic Compatibility (2004/108/EC) • Low Voltage Directive (93/68/EC) • Industrial Noise (2002/49/EC) • Control of Substances Hazardous to Health Regulations 2002 • Dangerous Substances and Explosive Atmospheres Regulations 2002 • Control of Noise at Works Regulations 2005 • Control of Vibration at Work Regulations 2005 • Construction (Head Protection) Regulations 1989 • Personal Protective Equipment at Work Regulations 1992 • Confined Spaces Regulations 1997 • Health and Safety (First Aid) Regulations 1981 • Reporting of Injuries, Diseases and Dangerous Occurrences Regulations 1995 • Working at Height Regulations 2005 • Manual Handling Operations Regulations 1992 • Health and Safety (Safety signs and signals) Regulations 1996 • Health and Safety (Consultation with Employees) Regulations 1996 • Information for Employees Regulations 1989 • Employers Liability (Compulsory Insurance) Act 1969 and Regulations 1998 <p>The plant will conform with the European Industrial Gases Association guidelines, covering:</p> <ul style="list-style-type: none"> • Operation of Static Cryogenic Vessels (IGC Doc 114/09/E) • Environmental Impacts of Customer Installations (IGC Doc 117/11/E) • Noise Management (IGC Doc 85/02/E) • Unmanned Air Gas Plants: Design and Operation (IGC Doc 132/05/E) <p>These lists are not exhaustive.</p>
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Codes considered in safety assessment:	See above.
Regulatory considerations (other than safety)	Include Distribution Code, Grid Code, Embedded generation engineering recommendations, planning guidelines and building regulations (if appropriate). Environment Agency to be consulted regarding noise emissions and storage of materials.
Planning Process:	Planning application to be filed (Sept 2014). We do not however expect any issues, as there were none on the pilot project (permitted twice)
Lessons learnt in relation to codes, standards and planning:	Not yet available – to be reported at project conclusion.

Installation:

Application of CDM Regulations	Notifiable project. Site host nominated as Client and appointed an external consultant as CDM-C. Technology provider (Highview) named as Designer and Principal Contractor.
Site selection process used:	Initial site deselected due to elevated cost and extended duration for network connection by local DNO. Final site selected due to improved network connection offer, availability of waste heat and space.
Site work:	Civil design underway. Mechanical subcontract in preparation. Further detail to follow.
Engagement with external stakeholders regarding site:	Local Authority as part of planning process. Environment Agency. Important to liaise with the DNO to ensure full understanding of likely operating regime.
Electrical connection and interfaces:	Maximum export capacity 4.5MVA. Site connection voltage 6.6kV. Ancillary demand 400V, 150kVA.
Ancillary services required:	Heating, ventilation, cooling Pumping load (heat transfer fluid) Control system No fire suppression required
Access requirements:	Access for maintenance and liquid nitrogen delivery (similar access as would be required for back-up diesel generator).
Installation procedure:	100 – 200 tonne crane to position major plant items on site. Initial fill of liquid nitrogen will be required.
Commissioning process:	In addition to site owner and technology provider, organisations involved include main turbine OEM, DNO (for protection testing/witnessing) and control system supplier. Detail of commissioning programme to follow.
Lessons learnt:	Not yet available – to be reported at project conclusion.

Safety and Operational Assessment:

Risk Assessment Process:	HAZOP and SIL studies initiated. Outcomes and further studies to follow.
Mitigation Measures Employed against Residual Risks:	To follow.
Engagement with external stakeholders:	HSE for CDM Notification.
Lessons Learnt:	Not yet available – to be reported at project conclusion.

Operating Regime:

Control Architecture:	Not yet available – to be reported at project conclusion.
Operating regime:	Not yet available – to be reported at project conclusion.

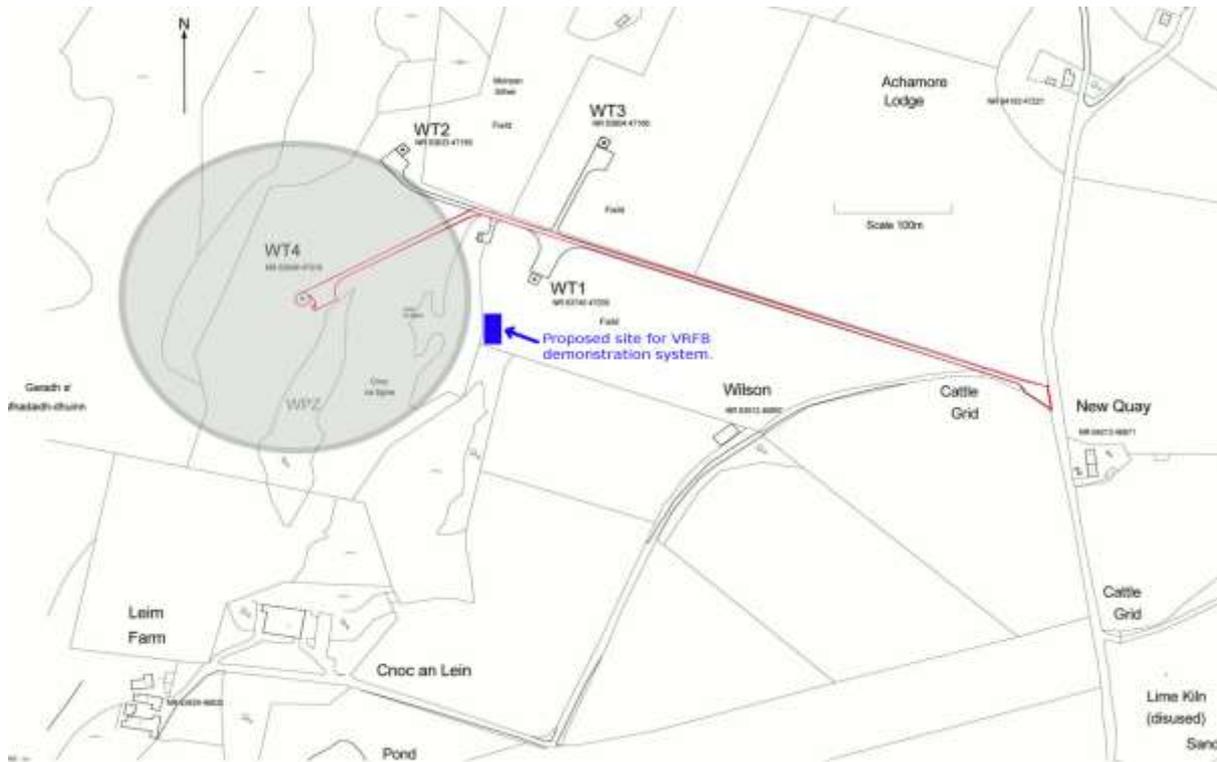
A1.17 Vanadium Redox Flow Battery Demonstration Project (DECC Energy Storage Technology Demonstration Competition)

Project Description:

Project Name:	DECC Energy Storage Technology Demonstration Competition–Phase 2
Principal Contact:	Gary Simmonds – Renewable Energy Dynamics Technology UK Ltd. (REDT)
Start Date:	15.10.13
End Date:	31.03.16
Project Status:	<ul style="list-style-type: none"> - Revised, containerised system design to be completed by end Sept. 2014 (end Milestone 4). - SEPA approval obtained 18.08.14. - Gigha installation site planning permission approval obtained 15.09.14. - VRFB system testing at PNDC planned to commence in March 2015 (end Milestone 6). - Site preparations for VRFB system installation planned to commence around April 2015 (during Milestone 6). - Shipping to, installation and commissioning of VRFB on site in Gigha planned for June 2015 (end Milestone 7). - Fully functional demonstration planned for June 2015 to end March 2016.

Installation Description:

Installation Location:	<ul style="list-style-type: none"> - The Isle of Gigha is located 3 miles off the west coast of the Kintyre peninsula in Argyll, Scotland. - The site selected for the installation is on farmland in the corner of the field that contains the no. 1 wind turbine (WT1) within the established Gigha wind farm estate which is located in the southern half of the island – please see the diagram overleaf. - This site was selected because it is well out of the way of the other wind turbines and associated equipment, and is bordered by a copse and a high stone ridge which will provide additional shelter from the elements. - As a revised, containerised design has now been adopted for the system, the requirement for an expensive building has been eliminated. Eight specially designed and adapted ISO 20ft containers will sit within a prepared compound measuring approx. 30m x 10m which will be surrounded by a protective and aesthetically blending fence. - The grid connection point is located at the 11kv transformer approx. 250m down the adjacent field next to WT4, and a cable will be installed from the VRFB to connect with the transformer. - Subject to further discussions with the local Planning Officer regarding arrangements for the site to become permanent rather than temporary, it is possible that the proposed fence may be replaced by a simple agricultural building to cover the container compound.
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Installation Capacity	<ul style="list-style-type: none"> - Stored energy capacity: 1.26MWh (= 12 hours duration) - System power: 105kW
Number of Units Installed:	<ul style="list-style-type: none"> - The basic module will be a 20ft ISO container with 15kW power (3 x 5kW stacks) and 180kWh (i.e. 12 hours duration) storage capacity with 2 x 7,000 litre electrolyte storage tanks. - In order to achieve the full system capacity required 7 of these container modules will be installed together with a 8th service module.
Description of PCS:	<ul style="list-style-type: none"> - TBA
Principal Application for the Storage Demonstration	<ul style="list-style-type: none"> - The deployment is on a wind farm on a remote Scottish Isle. The site has a wind turbine of 330kW rated capacity, constrained to 225kW. The goal of the ESS is to charge from energy that would otherwise be wasted when the wind is sufficient to generate more than 225kW. Energy can be discharged when power drops below 225kW and, thereby, augment the Gigha community's income from exported power that would, otherwise, be lost. The turbine will, by default, be constrained to 225kW and will be un-constrained by a signal transmitted from the Power Conversion System (PCS) Controller when the ESS is available for charge. - There will be three modes of operation other than the Test and Service Modes: <ul style="list-style-type: none"> • Primary: Allow 4th turbine (330 kW, constrained to 225 kW) to operate unconstrained when the ESS is available • Secondary: Arbitrage profile based upon peak/off-peak tariff times and durations • Tertiary: Voltage support using remaining PCS capacity

Description of Technology:

Technology Employed:	- Vanadium Redox Flow Battery (VRFB)
Technology Supplier:	- Renewable Energy Dynamics Technology UK Ltd. (REDT)
Description of Technology:	<ul style="list-style-type: none"> - Key differentiators: <ul style="list-style-type: none"> • Separation of power (kW) and storage capacity / duration (kWh) which can be individually scaled. • Capable of regular, deep discharge and repeated cycling with minimal performance degradation. • Long life of 10,000 cycles - subject to the daily duty cycle of a system, this is equivalent to up to 20 years. • Inherently safe operation with minimal management and maintenance. • Zero emissions. • Potentially lowest cost of storage over lifetime compared with any other energy storage technology. - Projected applications: <ul style="list-style-type: none"> • Grid support in the forms of capacity reserve, renewable intermittency management, relief of otherwise constrained energy, and capital deferral. • Enhanced efficiency and productivity of renewable energy generation sources such as wind farms by relieving and releasing otherwise constrained energy, and with solar PV generation by storing and time-shifting surplus power generation at peak times of the day for use beyond sunset. • Use in conjunction with wind and solar renewable generation sources and diesel gensets in off-grid mobile BTS locations to improve genset efficiency and / or eliminate the need for diesel fuel consumption and emissions entirely.

Codes, Standards and Planning:

Safety Certification:	Codes and Standards/Safety Certifications have been reviewed as part of the design stage, working with the project partners.
Codes considered in safety assessment:	
Regulatory considerations (other than safety)	<ul style="list-style-type: none"> - Local planning permission/approval for use of site and installation. - SEPA approval - CDM regulations. - Report prepared by GGPL, EATL and CES for submission to OFGEM (29.08.14) in order to clarify and confirm GGPL's FIT eligibility and accreditation with the added complexity of the VRFB system installation. - IGHT/REDT site lease is applicable through to the official end of the project in March 2016 and then subject to renegotiation.
Planning Process:	<ul style="list-style-type: none"> - Planning application and approval for Gigha site use processed through the local Planning Officer at Argyll and Bute Council via the Principal Contractor, McFadyens Ltd. (Campbeltown). - Environmental Management Plan for the system installation and operation submitted to and approved by the Scottish Environment Protection Agency (SEPA) on 18.08.14 - Planning approval/permission for the installation of the VRFB system at the proposed site (as outlined earlier) for the demonstration project through to end March 2016 was confirmed on 15.09.14. - Discussions are under way with the local Planning Officer regarding the possibility of, eventually, making the site permanent rather than temporary in order to avoid the necessity for decommissioning and re-siting at an alternative location within the wind farm estate.
Lessons learnt in relation to codes, standards and planning:	<ul style="list-style-type: none"> - Essential to consult all relevant parties at the earliest opportunity. The need to implement changes after the commencement of a project costs time and money. - All the advice and co-operation provided has been of considerable assistance in the thorough planning and execution of the project.

Installation:

Application of CDM Regulations	<ul style="list-style-type: none"> - Local, qualified CDM Co-Ordinator (Fox Safety, Clachan) appointed at the outset of the project to manage and oversee compliance with all CDM Regulations and health and safety requirements associated with the design, testing, installation, on-site commissioning and operation of the VRFB system, and all site preparation and construction works.
Site selection process used:	<ul style="list-style-type: none"> - Initial visit in April 2013 by REDT personnel for meetings with Gigha community representatives, and viewings of potential sites within the wind farm estate. Decision on preferred site location (as outlined earlier) confirmed and approved by both parties, subject to planning approval/permission (also now confirmed).
Site work:	<ul style="list-style-type: none"> - The laying of 240m² of hard core for to create an access track running from the main wind farm entrance across the top of the WT1 field to the selected VRFB site. - Ground preparation works and the laying of 300m² of hard core for the foundation of the compound to accommodate the 8 x 20ft containers. - Supply and installation of 32 (i.e. 4 per container) 0.5m x 0.5m concrete pad foundations at container landing corner points including excavation, shuttering, formwork and supply and laying of concrete. - Supply and installation of 80m² of 2.4m high vertical timber boarded fence and posts to surround and encompass the container compound.

	<ul style="list-style-type: none"> - Excavation of a 250m cable connection track between the VRFB site and the grid transformer at WT4, laying and connection of cable and backfilling of track. - Excavate 25m track for water pipe connection to local supply, instal pipework, stopcock and water meter.
Engagement with external stakeholders regarding site:	<ul style="list-style-type: none"> - Principal Project Partners involved in all discussions and decision making process. - Principal Contractor (McFadyens Ltd., Campbeltown) appointed at the outset for management of planning application/site approval with local Planning Officer at Argyll and Bute Council. - SEPA consulted and an Environmental Management Plan for the system installation and operation was submitted and approved 18.08.14. - Constant liaison and communication with the landowners, Isle of Gigha Heritage Trust (IGHT), for permission to use the farmland designated for the site, including preparation of a formal lease/contract with REDT for legal access for the duration of the project. - IGHT also managed communication and sub-lease arrangements with their local tenant farmer regarding the use of, and access to, the farmland. - Initial consultation with the owner/operator (Caledonian MacBrayne) of the local ferry service between the mainland and Isle of Gigha regarding logistics and scheduling of transport and deliveries to/from the site, with special consideration for regulations and requirements for the transport of "hazardous goods" (i.e. large volumes of electrolyte). This will be followed up with more detailed planning in early 2015 prior to the commencement of shipments/deliveries as the service consists of a single, small craft with limited, single truck carrying capacity.
Electrical connection and interfaces:	<ul style="list-style-type: none"> - Main 250m cable connection between the VRFB site and the grid connection transformer at WT4 which will also supply mains power to the site. - Interconnections between the 7 x 20ft container modules and the 8th service module. Design /specification still being worked on and not yet finalised. - Multiple meter installations to monitor power consumption from the grid, renewable power generation, storage and export to the grid. - Control/data interface connection between the VRFB system control unit and WT4. - Satellite communication for remote system operational management and control.
Ancillary services required:	<ul style="list-style-type: none"> - Suitable ventilation and cooling facilities designed and built into each 20ft container module to suit the known, local weather and temperature variations and extremes. - System efficiency losses are in the form of heat generation which are calculated to maintain required operational temperatures within each 20ft container module. Supplementary heating not required. - Fire containment measures designed and built into each 20ft container module. - Fresh water supply. - Mains electricity supply. - Back-up ambulance and fire control emergency services on Gigha briefed and on stand-by to assist with any unforeseen accidents or events.
Access requirements:	<ul style="list-style-type: none"> - Main access to the site will be via the existing wind farm site entry road and then across the WT1 field via the new spur access road that is to be installed. - The fence (or possibly building) surrounding the container compound will incorporate a lockable access gate.

	<ul style="list-style-type: none"> - The individual 20ft container modules have been designed and built for full access to all elements of the system that may require maintenance and/or repair/replacement.
Installation procedure:	<ul style="list-style-type: none"> - Installation is not planned to take place until June 2015 but: <ul style="list-style-type: none"> • The ground works and site preparations for the container compound are planned to commence in April 2015 in readiness for delivery and installation of the system containers following pre-shipment testing on the mainland. • The 8 x 20ft pre-fabricated and complete system containers will be delivered via standard flat-bed, HIAB equipped trucks, and lifted/dropped into position on-site. • A suitably qualified LV electrical contractor will be employed to manage all electrical connections. • Multiple meters to be supplied and installed by SSE contractors. • Once the system containers have been off-loaded into place, the electrolyte will be delivered in 76 x 1,000 litre IBCs and, transferred by pumps into the main storage tanks in each of the 7 container modules. • A thorough on-site system commissioning and testing programme will then be undertaken, overseen by SSEPD and EATL.
Commissioning process:	<ul style="list-style-type: none"> - A detailed pre-shipment testing and on-site commissioning and proving programme has been prepared by project partners EATL and REDT. - SSE and EATL will oversee the commissioning and proving programme prior to the system demonstration continuing through to project completion.
Lessons learnt:	<ul style="list-style-type: none"> - Not yet available – to be reported at project conclusion.

Safety and Operational Assessment:

Risk Assessment Process:	<p>A Risk Assessment for the operation of the system has been developed by REDT and the project partners, detailing the mitigation measures which should be employed.</p> <p>A functional FMEA for the system has been produced.</p>
Mitigation Measures Employed against Residual Risks:	
Engagement with external stakeholders:	<ul style="list-style-type: none"> - Early meetings with HSE for knowledge/information exchanges, advice and guidance. - Appointment of a full-time CDM Co-ordinator and H&S expert. - Planning application for site and installation submitted to and approved by local (Argyll & Bute) council. - Consultation with SEPA and approval obtained. - Following consultation, special insurance policies arranged with brokers, AON (Glasgow) – a specific requirement for approval from the Gigha community and IGHT to proceed with the installation. - Local landowner (IGHT) and sub-tenant farmer fully appraised for approval and co-operation. - Local Gigha ambulance and fire services briefed. - Consultation with local ferry operator, Caledonian MacBrayne.
Lessons Learnt:	<ul style="list-style-type: none"> - VRFB energy storage technology is relatively unknown so it has been necessary to inform and educate all organisations consulted before relevant risks could be properly assessed. - Again, such consultations very early in the project programme have proven to be invaluable.

Operating Regime:

Control Architecture:	<ul style="list-style-type: none"> - The day-to-day function of the VRFB system will be managed by the integral control system that has been designed into the 8th service module. - Operational performance monitoring and any necessary adjustments/updates will be managed remotely by REDT at their Wokingham office via a secure internet link. - The control/data interface connection between the VRFB system control unit and WT4 will manage the charge and discharge commands depending on the conditions prevailing at any given time.
Operating regime:	<ul style="list-style-type: none"> - Frequency of charge/discharge cycles is difficult to predetermine as this will, largely, be dependent on the prevailing weather conditions and wind speeds. - The WT4 Enercon unit has been commissioned and accredited at 330kW but, due to constraints on the network, it will be limited to 225kW. - The purpose of the VRFB system is to relieve and make use of the constrained 105kW. So, when the wind speed is strong and WT4 is producing more than 225kW (and up to 330kW), the control system will instruct the VRFB to start charging from the up to 105kW that would, otherwise, be lost to constraint. - Similarly, when wind speed weakens and power generation at the site reduces, the control system will instruct the VRFB to export its stored energy through the grid connection when such opportunity permits.

A1.18 Isentropic Pumped Heat Energy Storage (ETI Supported Demonstration Project)

Project Description:

Project Name:	Isentropic Pumped Heat Energy Storage
Principal Contact:	Philip Bale, Western Power Distribution James Macnaghten, Isentropic Ltd
Start Date:	March 2012
End Date:	March 2018
Project Status:	<p>The project has two main elements, the design, build and testing of both a Scaled Validation System (SVS) and a Field Test Article FTA.</p> <p>The SVS design has been finalised, key SVS components have been manufactured and the SVS is in the build stages. The SVS commissioning is expected to commence in Q2 2015, with testing following the completion of commissioning.</p> <p>The learning from the SVS will influence the FTA device and subsequent build.</p>
Project Highlights:	<ul style="list-style-type: none"> • How PHES energy storage could be integrated into a number of existing DNO substations; • The benefits PHES energy storage could offer DNO networks, how this drives where energy storage could be located; • At different DNO substations, how PHES energy storage could be used as an alternative conventional reinforcement and what would its functional specification need to be (MW, MWh, reliability...); and • The standards, designs, and safety requirements of a DNO siting PHES within a Distribution substation. • The impacts of energy storage operating for different markets at different times of the year under different network conditions



PHES SVS stores

Description of Technology:

Technology Employed:	Thermal - Pumped Heat Energy Storage
System Supplier:	The energy storage device is being designed and built by Isentropic Ltd. <u>SVS</u> Motor/Generator – Cummins. Thermal vessel & sub systems – Built by Isentropic with sub-contractors. <u>FTA</u> Motor/Generator – TBD. Thermal vessel & sub systems – Built by Isentropic with sub-contractors
Description of Technology:	The energy storage device is being designed and built by Isentropic Ltd. The Isentropic PHES technology is a highly reversible gas cycle machine that works as both an engine and a heat pump. It is the first time that a reversible system has been developed to both store and recover electricity using a thermodynamic approach. <u>SVS</u> Motor/Generator - 200kVA, Thermal vessel - 600kVAh <u>FTA</u> Motor/Generator – 1.5MVA, Thermal vessel – 6MVAh
Description of PCS:	Power is converted from thermal energy to rotational energy through an engine being developed and manufactured by Isentropic.
Previous track record:	First of a kind technology demonstration of Isentropic® PHES.
Number of Units Installed:	SVS - One three phase unit, installed in Hampshire UK, Q2 2015, with commissioning starting in Q2 2015. FTA - One three phase unit, installed in WPD East Midlands Primary substation 2017.
Installation Location:	The installation is within WPD's East Midlands licence area. The PHES device will be installed within an existing 33kV substation compound and connected at 11kV to the primary substation distribution board. Toton and Harbury primary substations have been identified as potential locations for the Isentropic trial.

Codes, Standards and Licensing:

Certification offered by equipment supplier in relation to energy storage module:	Codes and practices for pressure vessels – Underwritten by RSA
Codes considered in safety assessment:	Codes and practices for pressure vessels PD5500 Codes and practices for rotating machines. Machinery Directive Codes and practices for engines. Machinery Directive Codes and practices for electrical connection to grid. G59/2 and G59/3 Codes and practices for standard electrical construction.17 th Edition
Planning Processes:	Isentropic Ltd making an application for full planning permission, supported by Western Power Distribution. Planning permission will be applied for at two different WPD substations to help mitigate risk.
Lessons learnt in relation to codes, standards and licensing:	<ol style="list-style-type: none"> 1. Pressure vessels are a well-established technology with a number of associated relevant codes and standards, however it is not an area often encountered by a DNO. 2. The relevant codes and standards from the chemical industry are probably the most appropriate to PHES. 3. It is possible for a custom design to be under-written by a number of bodies to reduce risk.

Procurement:

Process followed:	Isentropic led a consortium with Western Power Distribution, applying for funding through the ETI call, Distribution scale energy storage in April 2012.
Scope of supply:	Isentropic Ltd are providing the FTA PHES, installing within a separate compound within one of WPD's existing substations, operating and maintain the Energy Storage device before decommissioning in Q1 2018. Western Power Distribution are providing a separate compound within an existing 33kV substation, an 11kV supply to the existing distribution network and support through the design and operating phases.
Associated BoP required for project:	Apart from PHES device – requires concrete plinth, steel frame building, electrical connection (breakers etc..), security
Process for development of specification:	Early stage project where simple cases, such as load shifting from off-peak to peak are proposed.
Performance/select ion criteria and standards applied:	75% efficiency, 1.5MW electrical output for 4 hours.
Acceptance tests employed:	Under development
Warranty and after-sales support included:	Not relevant at this stage
Lessons Learnt:	Ongoing

Training:

Operational Training Provided:	Under development
Authorisations and Personal Competence:	Isentropic Ltd. Health and Safety policy, which involved nominated operators and electrical lock out system.
Lessons Learnt:	Ongoing

Installation:

Roles and responsibilities:	Isentropic Ltd. for SVS, TBD for FTA
Application of CDM Regulations	CDM Regulations will be followed during the design/installation stage.
Site selection process used:	Ongoing
Site work:	TBD
Engagement with external stakeholders regarding site:	Planning Surveys and Conversations
Electrical connection and interfaces:	11kV – clean feed to primary substation
Ancillary services required:	None
Access requirements:	Separate Compound with own breaker on site
Installation procedure:	TBD
Handover to operational team:	TBD
Lessons learnt:	Ongoing

Safety and Operational Assessment:

Failure Modes and Effects Analysis:	TBD for FTA
Risk Assessment Process:	
Mitigation Measures Employed against Residual Risks:	
Information Provided by the manufacturer/ system supplier:	
Integration with Existing Safety Rules:	
Engagement with external stakeholders:	
Lessons Learnt:	Ongoing

Operating Regime:

Applications:	Peak Shaving – Intention is to charge 4 hours off peak and then discharge at peak for 4 hours. Charge Power is greater than discharge power. Intention is also to look at providing some reactive power.
Control Architecture:	Isentropic Control with SCADA connection
Despatch mechanism:	TBD for FTA
Operating regime:	Intention is daily charge/discharge for FTA

Benefits from operation:	Depends upon the site chosen
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Cost: Benefit Case:

<ul style="list-style-type: none"> • The Isentropic PHES device does not include large amounts of rare or expensive raw materials and thus, has the potential to significantly reduce the capital costs of energy storage. • Can demonstrate a round trip efficiency of 72-80% • Expected to operate for 20,000+ cycles with no overall loss in efficiency assuming that the maintenance programme is followed • Targeting an installed capital cost of \$200/kWh (≈ £130/kWh)

Further Information:

Additional Information:	www.isentropic.co.uk
References:	

Appendix 2 Applications of Electrical Energy Storage Systems

A2.1 Arbitrage

Presented with the concept of energy storage, arbitrage is often the application that a lay-person identifies first, 'buy-low, sell-high'. In the pre-market/trading era, this was implemented by various pumped storage systems by filling the upper reservoirs ('charging'), at night time (low demand) and discharging water to the lower reservoirs at periods of daytime peak demand.

However, the ability of any individual EES operator to exploit this application/revenue stream is dependent on how they are able to trade in the energy market. A suitable commercial arrangement is typically required via an Energy Supplier which passes on significant price variability. Experience of developing the necessary arrangements for EES systems of the scales described in the present GPG in the UK is currently at an early stage. The ability to obtain the commercial arrangements required may vary between suppliers, system rating and capacity, certainty in its operating regime, and the price volatility in the market.

A form of energy arbitrage (long term market optimisation, tolling) is being explored in UK Power Network's Smarter Network Storage project (see Appendix 1, A1.15).

A2.2 Peak Shaving

Peak shaving is the term given to the use of storage or demand-response to reduce peak demand. Electricity network investment and the cost of generation depends upon the magnitude of peak demand, hence value is realised through peak shaving, even down to the level of industrial and commercial consumers, which find that a portion of their bill depends upon their maximum demand.

A2.3 Deferral and Avoidance of Network Asset Reinforcement

In the unbundled electricity system of GB, transmission and distribution networks provide the ability to transport energy between generators and consumers via retail markets. In normal circumstances, network companies have no influence over the location or characteristics of the electricity that is transferred between producers and consumers; these regulated monopolies are separate from the competitive retail market.

Provision of network capacity is therefore subject to the risk that the energy market and the characteristics of generation change such that power flows on transmission and distribution networks change. The transmission and distribution of electricity entails the deployment, operation and maintenance of high-value assets that must be in-service for long asset lives to realise economic value.

Network operating companies therefore expend effort to understand the nature and factors involved in power flows, to predict duty on assets over their lives; to enable cost-efficient selection of the nature and capability of those assets. As for any prediction, the real outcome is uncertain - this leads to some assets requiring replacement before their condition warrants replacement and conversely, for other assets to be operated long after their economic lives, until their condition warrants replacement.

The former condition, whereby increasing power flow through the assets drives replacement, is a concern since if replacement is carried out, then assets with usable service-life are removed from service. These become 'stranded assets' and if they cannot be put back into service, the cost of operating electricity networks is increased as a result

There is a low likelihood of creating stranded assets when change is slow and the main factor in change is predictable. Conversely when change happens, especially if it causes increased amounts of energy to be transmitted and distributed and if there is greater transmission/distribution during peak times; the potential for creating stranded assets increases. Many technologies that are categorised under the banner of 'Smart' allow assets to continue in-service when they would otherwise have been replaced. These Smart technologies include, amongst others: Active Network Management (ANM), Demand-Side Management (DSM), Enhanced Automatic Voltage Control (EAVC) and Energy Storage¹⁰.

Most network assets that are not close to significant sources of generation are subject to diurnal cyclic power flow. Engines of work create industrial demand during the day; when that workforce arrives home it creates the evening 'domestic' peak. These two main factors combine to form a period of network congestion typically lasting 2-4 hours which drives most of a network company's 'load-related' investment requirements.

The contribution of energy storage in deferring or avoiding load-related investment is in reducing power flow through those assets such as to reduce the effective peak load and therefore the need for replacement. It can either provide a long-term solution to the asset replacement problem, i.e. until the end of the asset's service-life, a short-term solution while preparations are being made for a long-term solution, or a short-term solution for a short-term increase in power flow. The energy storage asset can be owned-and-operated by the network operating company or the services of a third-party operator can be procured through a service contract.

From the point-of-view of minimising the capital investment in energy storage and the risk that the storage device itself becomes a stranded asset, the latter service contract route appears a good solution today. It allows the storage operator to pursue additional sources of revenue including participation in the retail and ancillary services markets, which are barred to network operating companies.

Examples of applications of energy storage to defer the need for investment in network assets are at:

- Smarter Network Storage (Leighton Buzzard, Bedfordshire): The primary role of the device is to defer the need for reinforcement to cater for load growth.
- Orkney (Orkney Storage Park): A secondary role of the device is to provide 2 MW of generation capacity, which would be deployed in the case of a sub-sea cable fault.

A2.4 Renewable Energy Constraint Management

A constrained network has one or more assets that are required to operate at their maximum capacity or would, under circumstances that are not under the control of a network operator, be required to operate at their maximum capacity. One or a few assets might typically comprise this bottleneck. Constraints rarely arise from growth in load, since effort has been expended to predict it and companies have built-in excess capacity to cater for reasonably foreseeable load-growth over the life of an asset.

The majority of constraints arise today from the need to provide connection capacity for generation. Distribution networks in particular were built to supply demand. Their capacity to absorb generation can be less than that available to supply demand, particularly where voltage limits as opposed to thermal limits, define the constraint. Voltage limits to customers are dictated by Statutory Instrument whereas a power-flow limit imposed by an asset's rating can sometimes be exceeded if it is economic to trade this against the deleterious effect on asset lifetime and there is no impact on safety.

Generators connected to networks have Firm or non-Firm connection agreements, the latter meaning that there is a network constraint that prevents absorption of the full connection capacity under all combinations of load and generation that might exist, or there is a network asset for which full availability cannot be guaranteed. It should be noted that even generators with a 'Firm' connection may be prevented from generating occasionally due to network outages. Non-firm connections therefore imply a degree of communication, this being chosen as suitable for the task e.g. to protect against submarine cable faults a high-availability 'private-wire' connection with fast response might be appropriate while to cater for the planned maintenance of a transformer, telephone contact with a month's notice could be appropriate. The response required of a generator would be to curtail output to a lower level or altogether, for the necessary duration.

Where constraint schemes are in place and curtailment is either predicted or experienced, the application of energy storage to provide additional generation or demand can be used to reduce the frequency and severity of curtailment. Some situations may have associated penalty payments that could be reduced by deployment of energy storage.

Location of the energy storage device close to either the constraining or the constrained assets could allow it to make the essential measurement and control action necessary, though most applications would probably require the device to receive its commands from a governing system, operated by a network operator with greater knowledge of the constraint and its causal factors, e.g. an Active Network Management System¹⁹⁵. Again as for Asset Deferral, network operators have a choice whether to own-and-operate the energy storage device or procure the services of an operator.

Examples of applications of energy storage to manage constraints are at:

- Orkney (Orkney Storage Park): The primary role of the device is to provide additional demand, with which to reduce the level of curtailment of wind generators in the island's ANM scheme. The stored energy is then dispatched to support demand when network capacity is available.
- Shetland (Lerwick Power Station): The primary role of the device is to raise the island's minimum demand, which presently prevents the connection of additional wind generation. The stored energy is then dispatched at periods of peak demand, as shown in Case Study 1, Section 11.3.

A2.5 Power System Optimisation

Power system optimisation comprises the fine-tuning of power flow that allows additional capacity for load or generation to be released on existing networks. Without energy storage, optimisation possibilities are the control of reactive power, changes to network configuration and the tap-settings of transformers.

¹⁹⁵ Currie et al, Operating the Orkney Smart Grid: Practical Experience, Paper 1187, 21st International Conference on Electricity Distribution (CIRED), Frankfurt, 6-9 June 2011

A2.5.1 Control of Power Flow, Power Factor and Voltage

Possibilities for changing power flow using network configuration changes or adjustments to tap-settings are limited from considerations of fault levels, circulating currents and requirements for maintenance. More-flexible control can be exercised by the generation and absorption of reactive power at nodes, allowing power factor or voltage to be controlled. Technologies include static and switched passive components (inductance and capacitance) as well as dynamic devices employing power electronics components.

By virtue of the integral power conversion necessary to convert from DC energy sources to AC, properly specified energy storage devices are able to dynamically despatch the voltage and power factor control necessary to subsume nodal control of reactive power. Indeed, to provide a further degree of control, they are also able to despatch real power to affect voltage control (subject to sufficient energy being stored in the system). Practical application of this capability is usually limited to Low Voltage networks where the resistance dominates the reactance and where voltage rise occurs due to local sources of generation. Network operators typically have little control over voltage in these situations and are reliant upon design principles; hence energy storage deployments can be expected.

Examples of applications of energy storage to control power flow, factor and voltage are at:

- Darlington (Rise Carr): The device forms an element of a demonstration project, under the control of a hierarchical system that optimises power flow, factor and voltage;
- Darlington (Maltby Edgar, Wooler St. Mary, Harrowgate Hill): Element of demonstration project. Hierarchical control system;
- Darlington (High Northgate, Wooler Ramsay): Element of demonstration project. Hierarchical control system;
- Norfolk (Hemsby): Demonstration project to evaluate the benefits of short-term energy storage. Under control of network management system;
- Bedfordshire (Leighton Buzzard): A secondary role of the project is to optimise power factor;
- Bristol: A goal of the project is to mitigate high voltages on LV networks;
- Buckinghamshire (Milton Keynes): Elements of a demonstration project, to reduce peak power flows; and
- Berkshire (Chalvey): Demonstration project to absorb power flow and assuage voltage levels arising from LV-connected PV generation.

A2.5.2 Matching Supply and Demand on an Operational Timescale

While the energy market allows supply and demand to be matched on a planned timescale, the inherent requirement for prediction and resultant uncertainty creates the need to balance supply and demand on an operational timescale, a role carried out by transmission system operators. Delivery of balancing adjustments are undertaken by generation and the demand-side; energy-storage can exist on either side. The small influence of electrical energy storage devices on transmission network power flows presently dictates that they participate with the demand-side, whereas the larger size of pumped-hydro energy storage means that they participate on the generation side. In either case the GB Transmission System Operator procures services from commercial operators; as in an unbundled electricity system it cannot own electricity storage assets.

Balancing adjustments made on the generation-side entail a reduction in output or an increase in output, starting from a reduced output. As the efficiency of generation is reduced at part-load, transfer of a greater share of these balancing actions to the demand-side and

energy storage devices offers a way to achieve efficiency and emission savings. In addition the very fast response of energy storage devices compared to prime-mover systems allows control action to be exercised earlier, to reduce subsequent frequency deviation. Frequency deviation is one of the drivers for energy storage; the automatic response of prime mover systems to reduce this to acceptable levels is enshrined in grid codes in GB¹⁹⁶ and all AC transmission systems. Although solid state PCS (e.g. as used by electrochemical systems) offer a quick response time they lack the inertia inherent in prime mover systems. Thermodynamic cycle systems offer greater inertia, which can be advantageous for the SO.

At the time of writing, increasing attention is being paid nationally to securing the additional services required to cater for increased penetrations of renewable energy. Two of the current round of demonstration projects will be providing this type of frequency response. The 6 MW/10 MWh Smarter Network Storage system has recently entered into a contract with National Grid for the provision of FFR. In addition, the 1 MW, 3 MWh battery installed on the Shetland Isles operates in this manner, on a multi-MW island power system that does not have a connection to the mainland. The unique nature of the Shetland Isles power system means that the value of these services is particularly high.

EES is in theory able to contribute to several of the GB balancing services, regardless of location. However, technical or contractual constraints may prevent this (e.g. at the time of writing, it is not currently permitted to offer both frequency response and STOR).

- Mandatory Frequency Response (EES could take over the frequency-responsive role if integrated into >50 MW Power Station registered as a Balancing Mechanism Unit);
- Firm Frequency Response (FFR, Primary, Secondary and High);
- Short-Term Operating Reserve (STOR);
- Demand Management (only if forming part an on-site application and can facilitate provision in whole or part of >25 MW);
- Fast Reserve (if >50 MW);
- Reactive Power Services (> 15 MVAR, location-specific); and
- The forthcoming Demand Side Balancing Reserve (> 1 MW, > 1 h).

In practice, the most-easily accessible services for EES are FFR (~£42k/MW/annum¹⁹⁷) and STOR (~£22k/MW/annum for > 3 MW and >2 hr discharge duration¹⁹⁷). In practice, due to size thresholds, some potential EES services would be more-easily accessed through Energy Aggregators.

A2.5.3 Phase-Balancing

The best utilisation of network assets and the minimum quantity of network losses are realised for unity (true) power-factor and an equal magnitude of current in each phase, this being known as the 'balanced' condition. Voltage drops and power losses are minimised. The overall current-carrying capacity of a three-phase asset is maximised when balanced.

Unbalanced current mainly originates from single-phase loads, which are a greater fraction of demand on residential and light commercial networks. The greater the single-phase current relative to power flow over all three phases, the greater the imbalance factor. Degrees of imbalance can often be tolerated, especially if outside of the times of greatest network congestion. If present during peak times it can contribute to assets being overloaded, especially neutral conductors, if there is little capacity headroom available.

¹⁹⁶ National Grid Electricity Transmission, The Grid Code, Issue 5 Revision 4, Section CC.6.3, 19 August 2013

¹⁹⁷ Values given by NGET at the DECC Energy Storage Workshop, London, 18/3/2013

The connection of micro-generation on Low Voltage networks and the provision of single-phase electric vehicle charging are two sources of imbalance that can persist for many hours at a time and thus have thermal effects on network assets that might need to be managed. Phase imbalance can also vary significantly depending on the time of day (i.e. the phase 'causing' the imbalance can vary). Heating of the neutral conductor in cables is especially significant since it raises the operating temperature of the phase conductors in the cable core.

Unbalance is thus a problem that is to become more significant as GB moves to a lower-carbon economy, through the installation of micro-generation and Electrification of Transport and heat sectors. Properly-specified three-phase power electronic converters with independent phase-current control, equipped with a common DC bus and DC-link storage elements, are capable of drawing power from one or more phases and distributing it to one or more lighter-loaded phases, to achieve balanced phase current.

An example of energy storage devices that are being controlled to balance phase currents is at Chalvey, Berkshire, where three 25 kW, 1 h single-phase devices are being scheduled to provide better current balance, the sources of imbalance being 66 kW PV generation from 10 homes and a significant single-phase industrial load. Each PV system is connected through a single-phase converter.

A2.6 Power System Stability

A synchronous generator connected to the power system will supply a small injection of additional power to the network, following the loss of another generator. This supply-side action occurs naturally and assists the power system in maintaining stable operation, reducing frequency and voltage deviations that would otherwise result.

Asynchronous generators (induction, doubly-fed induction or permanent-magnet) are popular for wind and other forms of renewable and low-carbon generation. In the case of large wind turbines they have the rotating mass sufficient to provide similar inertial power as synchronous generators¹⁹⁸, but they are not presently required to do so. Inertial power transfer can be accomplished through power-converter connected asynchronous generators (most easily from 'fully convertor-connected' permanent-magnet machines) and equally from electrical energy storage devices that trade synthetic inertial response drawn from stored electro-chemical energy, for the true inertial energy storage inherent in the rotating masses of prime movers.

At the time of writing there are no examples of energy storage devices that are providing inertial responses within the GB DNO energy storage deployments outlined in the case studies provided in Appendix 1. Inertial responses, by their nature, are short-term and can be high power. Although the control systems of energy storage devices can provide these responses, due to their short-term nature, a much greater contribution is expected from generators such as wind turbines that have mechanical inertia rather than synthetic and are often operating at fractional power outputs (power can be increased) .

A2.7 Power Quality

¹⁹⁸ Supergen Wind Consortium 6th Educational Seminar, Synthetic Inertia, September 2011

A2.7.1 Mitigation of Harmonic Emissions

Societal demand for electrical appliances is increasing and energy efficiency strategies are leading to a greater share of these being connected through power electronics control systems. Whereas appliances were designed for low capital cost and high performance, the present paradigm is for low life-cycle energy and high performance. Great strides in efficiency are quietly being made¹⁹⁹ and where motive power used to be provided from line-started motors it is increasingly provided through electronically-controlled motors.

The heat pump is one of the key technologies under active development for a low-carbon economy in GB²⁰⁰. These will displace fuelled and pure-electric sources and as efficiencies increase, will also tend towards power-electronic control. All electronic power conversion relies upon digital switching that creates current harmonics ‘emissions’ on power networks, these in turn induce voltage harmonics. Harmonic emissions cause increased heating of network assets and use capacity that could otherwise be given to demand or generation. Mitigation will become increasingly important as the shares of renewable energy and efficient technologies increase.

The power conversion equipment in energy storage devices can, if specified with the appropriate filters and capacitive energy storage on the DC-link, be used to implement so-called ‘active filtering’ for harmonics, whereby the device synthesises the harmonic currents necessary to repair the voltage waveform.

The energy storage devices that are being installed as part of a demonstration project in Milton Keynes, Buckinghamshire, are equipped with harmonic mitigation and will accomplish this for LV networks. “Energy Storage and Management Units” that can provide harmonic mitigation for LV networks²⁰¹ are being deployed within the New Thames Valley Vision project.

A2.7.2 Flicker Reduction

Flicker is the phenomenon of human sensitivity to the change in luminance of a source of illumination. It is carried on power networks by fluctuations in voltage magnitude that occur with periods from sub- to multiple-seconds²⁰². These fluctuations are caused by step-changes in load or changes in network configuration, which on public networks should induce no more than a 3% change in voltage; and fluctuations in the loading conditions of devices that in turn cause fluctuations in the current drawn or supplied by those devices. The effects of flicker range from visible detection of changes in luminance to unconscious perception and nervous response.

Flicker is measured by a method that approximates human sensitivity to the change in luminance of an incandescent light-bulb of 60W rating. Traditional sources of flicker are the instantaneous switching of high-power loads relative to supply capacity e.g. electric showers and the starting of refrigeration compressors on LV networks, starting of large industrial motors and generating sets on Low-Voltage and High-Voltage networks and torque fluctuations in motor-driven applications caused by such factors as un-balanced loads and resonances.

As GB moves towards a low-carbon economy, the number of potential flicker sources will increase due to distributed generation and the electrification of heating and transport. However, the increasing prevalence of power-electronic conversion equipment used to

¹⁹⁹ See http://en.wikipedia.org/wiki/European_Union_energy_label accessed 15/1/14

²⁰⁰ DECC, 2050 Pathways Analysis, July 2010

²⁰¹ Further details of this project will be provided in the 2nd edition of this document.

²⁰² Energy Networks Association, Engineering Recommendation P28, 1989

efficiently control those sources, with its inherent need for small amounts of energy storage, should reduce the relative severity of flicker caused.

In addition, as lighting appliances continue to change from incandescent to fluorescent, and from fluorescent to Light-Emitting Diodes (LEDs), power-electronic conversion is required. While the levels and trend for flicker in a low-carbon economy are not known today, there are projects underway that are collecting flicker data. Similar to use for harmonic mitigation, properly-specified energy storage devices with sub-cycle response to voltage fluctuations, could use their capabilities to reduce the severity of flicker and prevent its otherwise-polluting effect.

The usual methods for mitigating high levels of flicker are to either change the characteristics of the system that produces the flicker to remove its effect, convert the flicker-inducing appliance from single-phase to three-phase, or to reduce the impedance of the supply. This latter, however, increases fault levels. Conversely as fault levels fall, as the share of synchronous generation on the networks decreases and is replaced by convertor-connected generation, levels of flicker will rise. Flicker on HV networks with significant reactance can be compensated by STATCOM equipment without needing significant levels of energy storage. Flicker on LV networks with significant resistance requires energy storage.

There are no examples of flicker mitigation via electrical energy storage in GB at the time of writing.

A2.8 Flexible Networks for Low Carbon Technologies

The low carbon agenda submits electricity networks to a pace of change that is greater than historical; that is accelerating and becoming more complicated as energy efficiency measures are introduced and as incentives for renewable electricity and heat take effect. The traditional planning process for networks, oriented towards new connections and steady growth in the general population of demand, is unsuitable for the prediction of future power flows and investment. New prediction methods are being introduced but are not yet in general application and until time has elapsed, their effectiveness will not be truly known.

While ‘top-down’ methodologies for assessing the necessary electricity network infrastructure for a low-carbon economy can be conceived, a recent study suggests that the difference in value between a top-down²⁰³ approach and a strategy of incremental development²⁰⁴ is minimal (difference of between three and fifteen percent)²⁰⁵. Top-down methods also suffer from the problem that if the predicted generation and technology mixes, location and magnitude of generation or demand change from that predicted, then assets and capacity can be built that would not be utilised efficiently (e.g. may add more capacity than is necessary, or become insufficient before the end of their life, requiring further reinforcement).

Rather than deploying assets of certain capacity that can be poorly utilised, a strategy of building flexibility, based upon the use of control systems to regulate power flows to within existing asset ratings can be employed. Due to the nature of the cyclic loading present on most network assets, only a fraction of the capacity that might be required for a traditional “24/7” reinforcement solution needs to be deployed and typically only for a few hours duration during the days for which asset load peaks. The necessary controllable systems

²⁰³ Defined within the study as “the smart grid case of conventional and smart solutions, where an upfront investment of enabler technologies is deployed in advance of need, followed by investment as and when networks reach their headroom limits.

²⁰⁴ Defined within the study as “the grid case of conventional and smart solutions, where investment only occurs as and when networks reach their headroom limits.”

²⁰⁵ Energy Networks Association, Assessing the Impact of Low Carbon Technologies on Great Britain’s Power Distribution Networks, Version 3.1, July 2012

can be built from demand-side responses, generation-side responses via active network management and the panacea of energy storage.

Utilising a strategy of incremental development enables the capacity necessary for a low-carbon economy to be deployed in chunks and at a rate appropriate to the pace of change that is being experienced; reducing uncertainties in the generation and demand predictions necessary for planning networks.

The three competing controllable technologies each have advantages and disadvantages. The unique advantages of electrical energy storage over those competitors are:

1. The capability to increase or decrease load on thermally-constrained networks at the appropriate times of the day or according to the network state;
2. The capability to provide voltage control on voltage-constrained networks, to increase tolerable power flow;
3. The capability to control power factor to reduce network losses and release network capacity; and
4. The capability to be deployed as a single asset at a location chosen to solve a network constraint and not to be reliant upon wide-area communications systems to manage the constraint effectively.

Electrical energy storage is therefore a flexible tool for the management electricity networks, and with flexibility being a key advantage in coping with change, there is significant potential for its deployment to support an electricity system suitable for low-carbon technologies.

A2.9 Mitigating the Impacts of New Demand and Generation Technologies

New demand technologies such as heat pumps and electric vehicles will increase the quantity of energy transferred across networks.

Off-peak retail tariffs will, to some extent, discourage demand when networks are congested. For EVs, a daily distance-driven of 25 miles would require 10 kWh²⁰⁶ (a 3 hour charge-time from a 13A supply), which can easily be accommodated off-peak using simple delay-charging mechanisms. However, mileage greater than this, or more-frequent use could spill-over to peak times. The scenario of a workforce returning home and charging vehicles at the same time as the normal evening demand peak creates a need for mitigation solutions. One solution that does not require householder intervention nor restrict the ability to charge, is the deployment of energy storage at a local level, that enables demand to be met while preventing it aggregating up networks.

Such devices can store energy during the day, to supply it during the evening peak for the charging of EVs, should the magnitude of these become a concern for the network operating company.

If those locations are subject to Photo-Voltaic generation occurring during the daytime, then energy storage mitigates both the problem of EV-charging and of PV-export while engendering a community-approach to energy.

During the summer months when PV-export is a concern, energy storage makes it possible to match supply and demand on a local basis, especially if EVs are present. A low-carbon energy system is likely to have a great numbers of heat pumps²⁰⁰. A typical home with a

²⁰⁶ Autocar, Vauxhall Ampera Review, 27 June 2011, accessible at autocar.co.uk, accessed 22/11/2011

design heat-loss of 7 kW at 0°C would require around 35 kWh of electricity across a winter's day, which, without a form of storage, would need to be delivered throughout the day and during peak times. The same electrical energy storage that facilitates the transfer of energy from PV to EVs during the summer can mitigate heat pump day-time demand in the winter from energy delivered overnight. Thermal storage could offer an alternative (potentially cheaper) solution for heat pumps. However, the space necessary to accommodate a thermal store within a domestic property may be a barrier to uptake.

Other forms of low-carbon heat are Combined Heat and Power (CHP) that can be applied via energy centres and heat networks or as boiler-replacements in the form known in the domestic arena as micro-CHP. Both generate electricity at the same time as heat. While the deployment of CHP devices at the same time as heat pumps could attractively balance the supply and demand impact of each, in many circumstances this could not be achieved due to a lack of gas-supply or heat-demand densities that are too low to be economic.

There is thus a need to provide extra supply capacity for heat pumps, which can be achieved by traditional means, by restricting heat provision or by the addition of energy storage. Traditional reinforcement of lines and cables can take a long time due to negotiation of access and way-leaves that might be required, community engagement and planning consent. Energy storage, when sufficiently developed to become an off-the-shelf product and where there is space available, should be a much faster solution to deploy. Should the need for capacity change, these devices can be moved around networks to enjoy multiple applications.

Appendix 3 Electrochemical Energy Storage Technologies

This Appendix provides further details of the different electrochemical energy storage technologies described in Section 3.2 (i.e. batteries and flow batteries). The maturity of each of the various technologies discussed in this section is rated according to the Technology Readiness Level (TRL) scale²⁰⁷, defined as follows:

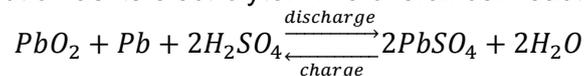
- TRL 1: Basic principles observed and reported;
- TRL 2: Technology concept and/or application formulated;
- TRL 3: Analytical and experimental critical function and/or characteristic proof-of-concept;
- TRL 4: Technology basic validation in a laboratory environment;
- TRL 5: Technology basic validation in a relevant environment;
- TRL 6: Technology model or prototype demonstration in a relevant environment;
- TRL 7: Technology prototype demonstration in an operational environment;
- TRL 8: Actual technology completed and qualified through test and demonstration; and
- TRL 9: Actual technology qualified through successful mission operations.

A3.1 Battery Energy Storage Technologies

A3.1.1 Lead-Acid (Pb-Acid) Batteries

Pb-Acid batteries are the longest established rechargeable battery technology (since 1859). Early applications included the provision of night time power in the era of DC generation, electric vehicles and submarine propulsion²⁰⁸. Following the development of the technology, Pb-Acid batteries are now used in various applications such as automotive SLI (Starting, Lighting and Ignition), traction, submarine propulsion, backup power and Uninterruptible Power Supplies (UPS).

The Pb-Acid battery comprises of a lead-dioxide (PbO₂) cathode, metallic lead (Pb) anode and a sulphuric acid solution as its electrolyte. The overall cell reaction can be written as:



Due to the maturity of their technology, Pb-Acid systems offer significant advantages such as providing cost-competitive, proven and highly reliable solutions to a range of storage requirements. A major disadvantage, however, is their low energy density (30-50 Wh/kg)²⁰⁹ due to high density of lead. This limitation results in a high total mass in large energy storage systems and a large footprint, which could be a limiting factor in urban applications. Other drawbacks associated with the technology are its relatively limited cycle life and poor low temperature performance (although this is true of all electrochemical power sources other than high temperature systems, which operate at a controlled, elevated temperature) and relatively low power density, notwithstanding that the Thin Plate Pure Lead (TPPL) variant can offer significant advances in the latter aspect.

²⁰⁷ <http://www.publications.parliament.uk/pa/cm201011/cmselect/cmsctech/619/61913.htm> Accessed 17/01/14

²⁰⁸ Battery Council International; Lead-Acid Battery Resources; 2005; Accessible from

<http://www.leadacidbatteryinfo.org/resources.htm>; Accessed on 10 October 2013

²⁰⁹ European Commission; DG ENER Working paper "The future role and challenges of Energy Storage"; 2013

A3.1.1.1 Example Installations

A summary of some field deployments of Pb-Acid systems over the past 25 years is shown in Table A3.1 below.

Table A3.1: Example Installations of Pb-Acid Systems

Plant Name and Location	Year of Installation	Rated Energy (MWh)	Rated Power (MW)	Application
Chino, California ²¹⁰	1988	40	10	<ul style="list-style-type: none"> • Peak shaving • Load levelling • Load following • Spinning reserve • Frequency control • Grid stability
Manweb, Wrexham	1990	0.08	0.04	<ul style="list-style-type: none"> • Load levelling
PREPA, Puerto Rica ²¹⁰	1994	14	20	<ul style="list-style-type: none"> • Spinning reserve • Frequency control
Vernon, California ²¹⁰	1995	3.5	5	<ul style="list-style-type: none"> • Security of supply • Power quality
Metlakatla, Alaska ²¹⁰	1996	1.5	1	<ul style="list-style-type: none"> • Stabilisation of island grid
Tappi Wind Park, Japan ^{211,212}	2001	0.8	0.2	<ul style="list-style-type: none"> • Stabilisation of fluctuations in wind power output • Energy shifting – deliver power at times of high demand rather than low demand
Kaheawa Wind Power I, Hawaii ²¹³	2006	0.4	1.5	<ul style="list-style-type: none"> • Ramp control
Albuquerque, New Mexico ^{212,214}	2011	1	0.5	<ul style="list-style-type: none"> • Simultaneous voltage smoothing • Peak shifting
Duke Energy Notrees Energy Storage Project ²¹⁵	2012	24	36	<ul style="list-style-type: none"> • Integration with wind generation • Ancillary services
Kaheawa Wind Power II, Hawaii ²¹³	2012	7.5	10	<ul style="list-style-type: none"> • Ramp control • Frequency response • Voltage support • Responsive reserves
Shetland, UK	2013	3	1	<ul style="list-style-type: none"> • Peak shifting • Stabilisation of fluctuations in wind power output

²¹⁰ GE Energy Company; Utility-scale Battery Energy Storage Systems & Applications; 2010; Accessible from <http://uvig.avenuefactory.com/wp-content/uploads/2012/12/Manz-BESS.pdf>; Accessed on 10 October 2013

²¹¹ Electric Power Research Institute (EPRI) and U.S. Department of Energy; Energy Storage for Grid Connected Wind Generation Applications; 2004

²¹² Sandia National Laboratories; DOE/EPRI 2013 Electricity Storage Handbook in Collaboration with NRECA; 2013

²¹³ Xtreme Power Inc.; Experience; 2013; Accessible from <http://www.xtremepower.com/advantage/experience>; Accessed on 14 October 2013

²¹⁴ U.S. Department of Energy; Public Service Company of New Mexico – PV Plus Battery for Simultaneous Voltage Smoothing and Peak Shifting; 2013; Accessible from http://www.smartgrid.gov/sites/default/files/OE0000230_Fact%20Sheet_PNM%20Jul2013_3.0.pdf; Accessed on 14 October 2013

²¹⁵ Notrees Energy Storage Project. Duke Energy. Information sheet available from:

<http://energy.gov/sites/prod/files/ESS%202012%20Peer%20Review%20-%20Notrees%20Wind%20Storage%20-%20Jeff%20Gates.%20Duke%20Energy.pdf> Accessed 10/11/2014

A3.1.1.2 Variants of Pb-Acid

Vented Pb-Acid (VLA)

VLA batteries, also known as flooded Pb-Acid batteries, are the oldest type of rechargeable battery. The term “flooded” is used because the electrodes are fully immersed in excess liquid electrolyte. The electrolyte level should always be maintained at a level above the top of the electrodes. Hence, water should be added regularly to avoid damage to the cells. Advantages of VLA batteries include high discharge rate capability, low cost, high power density and long deep cycle life. Drawbacks of using this technology are the requirements for regular water addition, to maintain the cells, and ventilation, as they outgas hydrogen and oxygen continuously on float charge. VLA batteries can also only be used in an upright position.

Valve Regulated Pb-Acid (VRLA)

VRLA batteries were developed in the 1970s. They were designed to operate by means of an “internal oxygen cycle”²¹⁶. Oxygen evolved from the cathode, during charging and discharging, can move to the anode where it is reduced to water. This cycle largely reduces water loss and decreases the rate of hydrogen evolution. A pressure-relief valve is fitted as a safety measure to allow any surplus hydrogen to be vented so as to prevent high pressure within the battery, hence the name “valve-regulated”. Due to their construction, VRLA batteries do not require water addition to the cells, can be mounted in any orientation and require low maintenance.

VRLA batteries can be further classified into 2 types: Absorbed Glass Mat (AGM) and Gel. They are named based on the mechanisms used to allow oxygen transfer. AGM batteries have the electrolyte held in a glass mat separator whereas gel batteries have the electrolyte immobilized as a gel.

Advantages of VRLA batteries over VLA batteries include:

- Reduced maintenance as there is no need for regular water addition to the cells;
- Can be mounted in any orientation;
- Higher ratio of power to “floorspace”;
- High-rate power capacity; and
- Fewer requirements for room ventilation.

Disadvantage of VRLA batteries compared to VLA batteries are:

- Lower reliability;
- Higher manufacturing costs;
- Less tolerant to overcharging – leads to premature failure; and
- Shorter useful life.

VRLA batteries are well suited for deep cycle, deep discharge applications such as portable power, powered wheelchairs and motorcycles. Due to their high-rate power capacity, they are also used in standby and emergency backup applications such as UPS and emergency lighting applications.

²¹⁶ D.A.J. Rand, P.T. Moseley, J. Garche, C.D. Parker; Valve-Regulated Lead-Acid Batteries; 2004

Thin Plate Pure Lead (TPPL)

The TPPL battery is a further variant of the AGM battery constructed from flat plates made with 99.99% pure virgin lead. Pure lead plates can be made thinner so that more can fit into the battery, leading to a higher surface area and hence, more power can be provided. Advantages of TPPL batteries include deep cycling capability, high rate of discharge capability, high energy density and their ability to operate in any position.

UltraBattery®

The UltraBattery® is a hybrid energy storage device that integrates a supercapacitor with a Pb-Acid battery in a single unit. Four partners currently have an involvement in the technology; Furukawa Battery Co. Ltd. (Yokohama, Japan), East Penn Manufacturing (USA), Ecoult (Australia) and the Commonwealth Scientific and Industrial Research Organisation (Australia). The UltraBattery® concept itself originates from the Commonwealth Scientific and Industrial Research Organisation (CSIRO) of Australia. Advantages of the technology over conventional Pb-Acid batteries include²¹⁷:

- High efficiency in a continuous Partial State of Charge operation;
- Longer life;
 - 92High cycle life;
- Lower lifetime cost;
- Requires fewer refresh cycles, leading to less downtime; and
- Fast charge and discharge.

The UltraBattery has been successfully deployed in automotive and stationary energy applications. As part of a two-year project run by the Advanced Lead Acid Battery Consortium (ALABC) in the United States a Honda Civic Hybrid Electric Vehicle (HEV) retrofitted with UltraBattery modules completed more than 100,000 miles^{217,218}. The Honda Civic had no significant loss in battery capacity. It had also achieved comparable fuel efficiency as the same model of car powered by Nickel Metal Hydride (NiMH) batteries but at a significantly lower cost.

The UltraBattery technology has been implemented in several MW-scale energy storage projects in Australia and the United States. The range of applications where the UltraBattery is being used in includes grid ancillary services, stabilisation of fluctuations in solar and wind energy outputs, energy shifting, demand management, peak shaving and diesel efficiency optimisation on standalone power systems²¹⁷.

Ongoing Developments

Advanced Pb-Acid technologies are being developed in order to improve specific battery performance parameters. Approaches taken include the use/addition of:

- Different alloying compounds to one or both electrodes;
- High-density positive active material;
- Silica-based electrolytes²¹²; and
- A spherical silica electrolyte retention system to maintain the life performance of Pb-Acid batteries in a sealed state²¹⁹.

²¹⁷ Furukawa Battery Co., Ltd, East Penn Manufacturing, Ecoult, Commonwealth Scientific and Industrial Research Organisation (CSIRO); Ultrabattery; Accessible from <http://www.ultrabattery.com/>

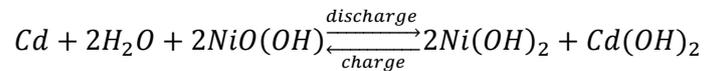
²¹⁸ The Advanced Lead-Acid Battery Consortium; ALABC UltraBattery Hybrid Surpasses 100,000 Miles of Fleet Duty; Accessible from http://www.alabc.org/press-releases/PR_ALABC_UB_Civic_100K_060513.pdf

²¹⁹ GS Yuasa Corporation; GS Yuasa Storage Battery System Adopted by Sekisui House for Eco-Home; 2011; Accessible from <https://www.gs-yuasa.com/us/topics/pdf/20110808e.pdf>

A3.1.2 Nickel Cadmium (NiCd) Batteries

Invented in 1899, NiCd batteries rank alongside Pb-Acid batteries in terms of their maturity. They have been used in various applications including portable devices, standby power, electric vehicles (EVs), power tools, utility scale storage as well as aircraft power systems.

The NiCd battery comprises of a nickel oxide hydroxide (NiO(OH)) cathode, metallic cadmium (Cd) anode and potassium hydroxide electrolyte solution. The overall cell reaction can be written as:



NiCd batteries offer advantages over Pb-Acid batteries in terms of their higher energy density (40-60 Wh/kg), robustness, chronological and cycle life expectancies and low maintenance requirements. Other advantages include high rate discharge capacity, high reliability and high power at low State-of-Charge (S-o-C) characteristics. A significant problem, however, is the susceptibility of the NiCd battery to “memory effect” where it tends to lose its charge faster as it ages. This is due to the battery being repeatedly recharged before it is fully discharged, which then results in the battery losing its maximum energy capacity. In addition, cadmium toxicity also poses a hazard to the environment and human health. The Batteries Directive 2006/66/EC imposed a restriction on the use of cadmium in portable batteries, industrial batteries and accumulator batteries in electric vehicles with certain exemptions (e.g. batteries intended for use in emergency and alarm systems, including emergency lighting, medical devices or cordless power tools)²²⁰. Special handling is required for the disposal of batteries containing cadmium (e.g. recycle, landfill, underground storage or incineration).

The cost of NiCd batteries is estimated to be in the range of \$400-2400/kW and \$800-1500/MWh²²¹. The use of NiCd technology in power utility applications is limited, however the most prominent use of the technology is by the Golden Valley Electric Association (GVEA) in Fairbanks, Alaska in 2003, which is also the world’s largest BESS. GVEA serves 90,000 residents spread over 2,200 square miles where most residents live in remote areas and winter temperatures can fall as low as -50°C. Therefore, the BESS plays a crucial role in providing backup power in the event of grid outage. The main functions of the system are to provide spinning reserve, VAR support as well as power system stabilisation. The system consists of four battery strings, each of 3,440 cells, with a string voltage of 5,200 V. It has the ability to provide 27 MW of power for 15 minutes or 40 MW for 7 minutes²²².

A3.1.3 High Temperature Sodium Based Systems

The majority of the battery energy storage systems of interest to network operators are essentially ambient temperature systems, which operate and function at the prevalent ambient temperatures normally experienced in the UK. In practice however, some degree of cooling or thermal management may be required, both to dissipate the thermal energy generated via inefficiencies in the charge/discharge cycle and, also, to maintain and stabilise temperatures, in extended battery strings.

²²⁰ European Commission; Directive 2006/66/EC of the European Parliament and of the Council; 2006

²²¹ P. Taylor, R. Bolton, D. Stone, X. Zhang, C. Martin, P. Upham, Y. Li, R. Porter; Pathways for energy storage in the UK; Figure 3.1; 2012

²²² ABB Inc.; World’s Largest Battery Energy Storage System Fairbanks, Alaska, USA; 2011; Accessible from [http://www05.abb.com/global/scot/scot232.nsf/veritydisplay/3c4e15816e4a7bf1c12578d100500565/\\$file/case_note_bess_gvea_fairbanks-web.pdf](http://www05.abb.com/global/scot/scot232.nsf/veritydisplay/3c4e15816e4a7bf1c12578d100500565/$file/case_note_bess_gvea_fairbanks-web.pdf); Accessed on 14 October 2013

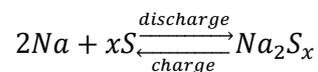
In contrast to such ambient temperature batteries, a further class of “high temperature” batteries exists, which operate at elevated temperatures, typically between 300°C and 400°C. Such elevated temperatures are an essential pre-requisite for the electrochemistries concerned, which also require the packaging of individual battery modules in well insulated containments.

In contrast with many of the other battery technologies considered, there are only a small number of high temperature batteries available on the market. These tend to be associated with either a single vendor or, via various licence and/commercial agreements, by specific vendors for specific market sectors (e.g. stationary, automotive, marine etc.).

The three high temperature battery technologies of interest here are all based on the use of sodium as an active reagent and can all trace their origins to the late 1960s/early 1970s. The further sub-sections now describe some of the characteristics of such battery systems.

A3.1.3.1 Sodium Sulphur (NaS) Batteries

The make-up of the Sodium Sulphur battery comprises individual cells which utilise a solid β -alumina electrolyte, separating a negative Sodium electrode and a positive sulphur electrode. The overall cell reaction is:-



Various proprietary features are used in the design, manufacture and construction of the individual cells and the associated battery modules, which form the basis for complete battery energy storage systems. Notwithstanding that a number of developmental teams actively pursued the development of the NaS system, for both automotive and stationary applications, from the 1970s through to the early 1990s, there is presently only a single vendor present in the market for stationary battery energy storage system applications.

The NaS battery is characterised by its enhanced energy density, reduced footprint and extended cycle and chronological lifetimes, relative to Pb-Acid systems, with these typically being of the order of²²³:

- Energy density: circa 3 to 5 times that of Pb-Acid;
- Footprint: circa 1/3rd of Pb-Acid;
- Cycle life: circa 2,500 cycles plus; and
- Chronological life: 15 years.

The installed capacity base of the technology now equates to in excess of 300MW/1,800MWh, in some 170 installations²²⁴, with such systems being installed in Japan, North America, the Middle East and, to a lesser extent, within Europe.

The technology has an overall good operational track record, although a battery fire which occurred on a system in Japan, September 2011²²⁵, led to a re-evaluation of a number of design features and the implementation of a series of specific modifications, to enhance the overall safety of the system, under extreme failure conditions. The uncertainties associated with this battery fire in Japan led to a planned installation at Lerwick, in Shetland, being curtailed; this is described in the individual Case Study (see Appendix Section A1.9).

²²³ The NAS Battery System for Utility Scale Energy Storage. NGK Sales Literature (undated)

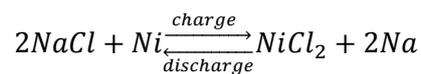
²²⁴ NAS Battery Energy Storage System, NGK, October 2013. Accessible via http://www.eei.org/meetings/Meeting_Documents/Abe.pdf. Accessed 13th February 2014.

²²⁵ NAS Battery Fire Incident and Response; accessible via <http://www.ngk.co.jp/english/announce/>. Accessed 13th February 2014.

A3.1.3.2 Sodium Nickel Chloride (NaNiCl₂)

The Sodium Nickel Chloride battery represents another type of high temperature battery, which has been extensively developed over a similar time frame, to the Sodium Sulphur system discussed above. In contrast to the NaS system however, the principal developmental focus for the technology over the past couple of decades has been for automotive applications and, to a lesser extent, for marine and various other specific applications. Notwithstanding this, the technology is now being offered for the stationary/power utilities applications domain.

The cells in a NaNiCl₂ battery comprise sodium and nickel chloride electrodes, separated by a β-alumina electrolyte, which is able to conduct sodium ions but not electrons. The overall cell reaction for the NaNiCl₂ system is:



Features of the ZEBRA battery are its ability to withstand limited overcharge and discharge, its enhanced cell voltage and favourable safety characteristics. It offers energy densities of within the range 100-120 Wh/kg and power densities within the range 150-200 W/kg.²²⁶

A3.1.3.3 Sodium Metal Halide (NaMH))

A further development from the original Sodium Nickel Chloride system emerged onto the market, circa 6 years ago, in the form of the derivative Sodium Metal Halide system. This utilises patented sodium halide electro-chemistry and has been developed for two principal applications, namely railway locomotives and the stationary/power utilities sector.

The principal advantages of the technology are claimed as²²⁷:

- Long service life;
- Temperature independence (i.e. can operate over a wide range of ambient temperatures);
- Minimal maintenance;
- Low environmental impact (e.g. highly recyclable);
- High reliability;
- Small footprint;
- Scalable, via modular design;
- Ease of integration with existing system wide control software; and
- Safety.

The development of the Sodium Metal Halide system is complemented and supported by a significant investment in manufacturing facilities. Although the system represents a relatively new battery technology, it is being implemented in the WPD FALCON project (Flexible Approaches for Low Carbon Optimised Networks). The 50 kVA/100 kWh systems here will be used for several applications including peak shaving, voltage support, harmonic filtering

²²⁶ V. Antonucci; IPHE Workshop – Battery Energy Storage technologies for power system; 2012; accessible from http://www.iphe.net/docs/Events/Seville_11-12/Workshop/Presentations/Session%201/1.3_IPHE%20workshop_Antonucci.pdf; Accessed on 5 November 2013

²²⁷ GE Energy Storage Brochure. Available from: <http://geenergystorage.com/power-generation/brochures> Accessed 24/11/2014

and distributed intelligence. Further details are given in the case study, contained within Appendix 1, Section A1.11.

A3.1.3.4 Installation Base

The major part of the installation base for high temperature batteries, in the stationary/power utilities applications sector, is attributable to the Sodium Sulphur battery technology, reflecting the pro-active commercialisation of the system for such stationary applications, together with the build-up of manufacturing capacity, over the past ten plus years. In contrast, both the Sodium Nickel Chloride and Sodium Metal Halide systems have only been actively promoted and offered for stationary/power utility applications, within the past 5 years.

Table A3.2, below, provides an indication of a range of example installation and applications, including those already in operation and those planned, in the near future.^{228,229,230,231,232,233,234,235,236,237,238,239}

Table A3.2: High Temperature Sodium Battery Installations

Plant Name and Location	Technology	Year of Installation	Rated Energy (MWh)	Rated Power (MW)	Application
Charleston, West Virginia	NaS	2006	7.2	1.2	• Peak shaving
Wakkanai, Japan	NaS	2006	11.8	1.5	• Voltage and frequency control • Stabilisation of fluctuations in solar power output
Rokkasho-Futamata Wind Farm, Japan	NaS	2008	238	34	• Load levelling • Spinning reserve
Churubusco, Indiana	NaS	2008	14	2	• Stabilisation of fluctuations in wind power output
Bluffton, Ohio	NaS	2008	14.4	2	• Load levelling • Security of supply

²²⁸ Sandia National Laboratories; DOE International Energy Storage Database; 2012

²²⁹ R. Hara, T. Funabashi; Demonstration Project of 5MW PV Generator System at Wakkanai; 2008

²³⁰ The Clean Energy Action Project; Rokkasho-Futamata Wind Farm; 2012; Accessible from http://www.cleanenergyactionproject.com/CleanEnergyActionProject/Energy_Storage_Case_Studies_files/Rokkasho-Futamata%20Wind%20Farm.pdf; Accessed on 16 October 2013

²³¹ A. Nourai; NAS Battery Performance at Charleston, WV; 2006; Accessible from http://www.sandia.gov/ess/docs/pr_conferences/2006/nourai.pdf; Accessed on 16 October 2013

²³² T. Hatta; Recent Applications of NAS Battery System in the United States and in Japan; 2011

²³³ BC Hydro; BC Hydro's energy storage project in Field a Canadian first; 2013; Accessible from http://www.bchydro.com/news/press_centre/news_releases/2013/bc-hydro-completes-energy-storage-project-in-field.html; Accessed on 16 October 2013

²³⁴ BC Hydro; Field battery Energy Storage Project; 2013; Accessible from <https://www.bchydro.com/energy-in-bc/projects/field-battery.html>; Accessed on 16 October 2013

²³⁵ Duke Energy Corporation; Duke Energy's Gaston County research project winds top industry award; 2013; Accessible from <http://www.duke-energy.com/news/releases/2013020701.asp>; Accessed 13th February 2014

²³⁶ FIAMM SpA; FIAMM Energy Storage Solutions; Accessible from www.fiamm.com/downloads/folder_ess_webfolder_eng_def.pdf; Accessed 5th November 2013

²³⁷ <http://geenergystorage.com/todays-news/106-discovery-science-center> Accessed 17th January 2014

²³⁸ <http://geenergystorage.com/todays-news/97-first-european-sale-of-dms-integrated-energy-storage-systems-2>; Accessed 13th February 2014.

²³⁹ <http://www.genewsroom.com/Press-Releases/Africas-Largest-Self-Sufficient-Solar-Microgrid-Project-Created-through-Technologies-from-MAECI-GE-and-Princeton-Power-Systems-275933> Accessed 26/08/2014

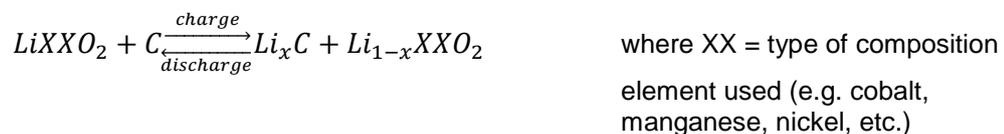
Plant Name and Location	Technology	Year of Installation	Rated Energy (MWh)	Rated Power (MW)	Application
Luverne, Minnesota	NaS	2008	7.2	1	<ul style="list-style-type: none"> • Peak shaving • Frequency regulation • Wind smoothing • Wind levelling
Reunion Island Pegase Project, France	NaS	2009	7.2	1	<ul style="list-style-type: none"> • Energy shifting • Security of supply
Noshiro, Japan	NaS	2012	480	80	<ul style="list-style-type: none"> • Load levelling • Peak shifting • Security of supply
Japan-US Collaborative Smart Grid Project, New Mexico	NaS	2012	6	1	<ul style="list-style-type: none"> • Stabilisation of fluctuations in solar power output • Ramp control • Load following • Demand response
PG&E Vaca Battery Energy Storage, California	NaS	2012	14	2	<ul style="list-style-type: none"> • Load following • Stabilisation of fluctuations in renewable energy • Frequency control • Spinning reserve • Energy shifting
BC Hydro Energy Storage, Canada	NaS	2013	7	1	<ul style="list-style-type: none"> • Supplement power supply during peak periods • Security of supply
Duke Energy, Rankin substation, NC, USA	NaNiCl ₂	2010	0.3	0.4	<ul style="list-style-type: none"> • Renewables integration
Green Energy Island, Almisano, Italy	NaNiCl ₂	2011	0.23	0.18	<ul style="list-style-type: none"> • Renewables integration
Discovery Science Centre, Santa Ana, CA, USA	NaMH	2014 (planned)	0.5	-	<ul style="list-style-type: none"> • Load shifting • Back-up power provision
GE Brilliant Wind Turbines, Mills County, TX, USA	NaMH	2014 (planned)	-	-	<ul style="list-style-type: none"> • Integrated wind turbine control system
WPD FALCON Project, UK	NaMH	2013 on	0.1 (multiple systems)	0.05 (multiple systems)	<ul style="list-style-type: none"> • Peak shaving • Voltage support • Harmonic filtering
Microgrid project, Annobon Province, West Central Africa	NaMH	2014 (planned)	Capacity Unknown	Integration with 5MW solar plant	<ul style="list-style-type: none"> • Security of supply • Renewables integration

A3.1.4 Lithium-ion (Li-Ion) Batteries

The Li-Ion technology has emerged as the fastest developing battery technology over the past 25 years. It was initially developed for the 3Cs (camera, cell phones and computers) sector due to its high energy density (75-250 Wh/kg)²⁰⁹. This fast development of the technology is being driven by a number of factors including:

- Extensive research and development programmes worldwide, decreasing costs, improving performance and safety; and
- Complementary automotive (EV) programme developments contributing to advances in cost, performance and safety.

The Li-Ion battery comprises a lithium metal oxide cathode and graphite-based anode. There are several variants of the Li-Ion technology and the name of the variant is usually given according to the composition of cathode used in the battery. All Li-Ion cells use a non-aqueous, liquid electrolyte (with the exception of lithium polymer cells using a polymer or gel electrolyte). The operating principle of the technology, however, is the same for all variants, involving the reversible movement of lithium ions. During charging, lithium ions move out (de-intercalate) from the cathode and move into (intercalate) the graphite-based anode. The reverse process occurs during the discharge process. The overall cell reaction involved is shown below:



Li-Ion technology has a high energy density which is typically twice of the energy density of the NiCd battery. The lifetime is also relatively high (typically more than 4,000 cycles²⁴⁰), and it requires little maintenance, has relatively low self-discharge and does not need prolonged charging when it is new. One of the main disadvantages of the technology is the propensity of individual cells to enter an unstable “thermal runaway” failure mode, under failure/abuse conditions. This has the potential to lead to a series of cell failures cascading through the battery pack. This means that strict attention should be paid to the safety case. Other disadvantages include its (to date) high manufacturing costs (about 40% more than NiCd batteries), possible restrictions on transportation where shipments of large quantities may be subject to regulatory control and the need to maintain lithium cells within well-defined operating limits to prevent permanent cell damage or failure. Fire hazard is another issue for Li-Ion batteries due to the lithium ions and flammable electrolytes²⁴¹. There have been several cases of fire due to overheating of Li-Ion batteries including fire incidents in residential houses²⁴² and aircraft²⁴³. Further details are provided in Section 9.2.5.

Apart from the 3Cs sector, Li-Ion batteries are also being increasingly used in the automotive sector for both electric and Plug Hybrid Electric Vehicles (PHEV). The technology has a further advantage, in that numerous vendors of both cells and battery systems are able to offer products into the market.

²⁴⁰ P. Taylor, R. Bolton, D. Stone, X. Zhang, C. Martin, P. Upham, Y. Li, R. Porter; Pathways for energy storage in the UK; Table3.1; 2012

²⁴¹ R. Butler; Managing the lithium (ion) battery fire risk; 2013; Accessible from http://www.hemmingfire.com/news/fullstory.php/aid/1790/Managing_the_lithium_ion_battery_fire_risk.html; Accessed on 29 October 2013

²⁴² J. Gilbert; Charging battery cause of weekend house fire; 2013; Accessible from <http://www.yumasun.com/articles/fire-90343-battery-house.html>; Accessed on 29 October 2013

²⁴³ S. Pope; UPS 747 Crash Highlights Lithium Battery Danger; 2013; Accessible from <http://www.flyingmag.com/news/ups-747-crash-highlights-lithium-battery-danger>; Accessed on 29 October 2010

A summary of some Li-Ion utility installations are listed below^{244,245,246,247,248,249,250}

Table A3.3: Example Installations of Li-Ion Applications

Plant Name and Location	Year of Installation	Rated Energy (MWh)	Rated Power (MW)	Application
Jeju Smart Place, South Korea	2010	0.03	0.04	<ul style="list-style-type: none"> • Electric bill management • Time shifting
Laurel Mountain, West Virginia	2011	8	32	<ul style="list-style-type: none"> • Frequency regulation • Stabilisation of fluctuations in wind power output
Guodian Supply-Side Energy Storage Project, China	2011	10	5	<ul style="list-style-type: none"> • Renewables (wind power) capacity firming
DynaPeaQ®, UK	2011	0.2	0.6	<ul style="list-style-type: none"> • Dynamic voltage control • Peak shifting • Grid stability • Stabilisation of fluctuations in wind power output
Angamos, Chile	2011	5	20	<ul style="list-style-type: none"> • Security of supply • Spinning reserve
National Wind and Solar Energy Storage and Transmission Demonstration Project (I), China	2011	36	6	<ul style="list-style-type: none"> • Time shifting • Stabilisation of fluctuations in wind and solar power output
Jeju Smart Renewable, South Korea	2012	0.2	0.8	<ul style="list-style-type: none"> • Renewables (wind power) capacity firming • Generation shifting
Auwahi Wind Farm, Hawaii	2012	4.4	11	<ul style="list-style-type: none"> • Renewable energy (solar and wind power) integration
Tait, Ohio	2013	-	40	<ul style="list-style-type: none"> • Operating reserve • Frequency regulation
Orkney Storage Park Project, UK	2013	0.5	2	<ul style="list-style-type: none"> • Transmission congestion relief
Customer-Led Network Revolution, UK	2013	5.7	2.85	<ul style="list-style-type: none"> • Peak shifting
Sendai Substation Li-Ion Battery Pilot Project	2015 (planned)	20	40	<ul style="list-style-type: none"> • Frequency response • Voltage support • Supply capacity firming

²⁴⁴ AES Energy Storage; AES Energy Storage Project; 2013; Accessible from <http://www.aesenergystorage.com/projects.html>; Accessed on 22 October 2013

²⁴⁵ ABB; Case study - DynaPeaQ® energy storage in Norfolk, England; 2013; Accessible from <http://www.abb.com/industries/ap/db0003db004333/8c1f3603e2c36bebc1257892003252aa.aspx>; Accessed on 22 October 2013

²⁴⁶ A123 Energy Solutions; Grid Storage Proven in the Field; 2013; Accessible from <http://www.a123energy.com/smart-grid-storage.htm>; Accessed on 29 October 2013

²⁴⁷ What's on Tianjin; World's largest battery energy storage station settles in Zhangbei, Hebei; 2012; Accessible from <http://www.whatsontianjin.com/news-2239-world-s-largest-battery-energy-storage-station-settles-in-zhangbei-hebei.html>; Accessed on 29 October 2013

²⁴⁸ Smart Grid Division; Five Areas of Jeju Smart Grid Test-bed – Smart Place; 2010; Accessible from <http://smartgrid.jeju.go.kr/eng/contents/index.php?mid=0301>; Accessed on 29 October 2013

²⁴⁹ Smart Grid Division; Five Areas of Jeju Smart Grid Test-bed – Smart Renewable; 2010; Accessible from <http://smartgrid.jeju.go.kr/eng/contents/index.php?mid=0303>; Accessed on 29 October 2013

²⁵⁰ <http://www.energystorageexchange.org/projects/931> Accessed 10/11/2014

A recent breakthrough for the technology has been achieved by scientists at the Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg (ZSW) (Centre for Solar Energy and Hydrogen Research Baden-Württemberg) where Li-Ion batteries have demonstrated a very high cycle life (more than 10,000 full cycles) with retention of more than 85% of original capacity and have a power density of 1,100 W/kg²⁵¹. Japanese companies, NEC Corporation, Tanaka Chemical Corporation and Sekisui Chemical Co. Ltd. have also developed an advanced Li-Ion battery that uses an Iron-substituted manganese oxide cathode and has an energy density of 271 Wh/kg²⁵².

Lithium batteries have also begun to enter the solar PV market²⁵³. Panasonic targeted German residential PV installation in 2012, with a 1.35 kWh Li-Ion battery unit with a lifetime of 5,000 cycles²⁵³. Earlier in 2013, the German utility, RWE, started to offer its residential customers a Li-Ion energy storage system called RWE HomePower which was developed in collaboration with German battery manufacturer, VARTA²⁵³. American energy service provider, Solar City, is also selling a Li-Ion home energy storage system, whose technology is developed by electric vehicle company Tesla²⁵³.

A3.1.4.1 Variants of Li-Ion

Lithium Cobalt Oxide (LCO)

LCO batteries are the most mature variant of the Li-Ion battery. It is most commonly used in the 3Cs sector due to its high energy density. The LCO battery consists of a lithium cobalt oxide (LiCoO_2) cathode and graphite carbon anode.

A main disadvantage of the LCO battery is its thermal stability. Due to its cathode instability, the LCO battery is more susceptible to thermal runaway when overcharged or used in high temperature operation. This may be manageable in small portable applications as heat can be more easily dissipated, but may pose a safety concern when used in larger applications (e.g. aircraft). Other drawbacks of the technology include short life span and the increase in internal resistance that occurs with cycling and aging.

Lithium Nickel Cobalt Aluminium Oxide (NCA)

The NCA battery consists of a lithium nickel cobalt aluminium oxide ($\text{Li}(\text{Ni}_{0.85}\text{Co}_{0.1}\text{Al}_{0.05})\text{O}_2$) cathode and graphite anode. It is mainly used in automotive applications (e.g. EVs and power trains) and is also gaining importance in energy storage applications. Advantages of NCA batteries include enhanced energy density and life span. The downsides of the technology are its high cost and safety issues.

Lithium Nickel Manganese Cobalt Oxide (NMC)

The NMC battery consists of a lithium nickel manganese cobalt oxide ($\text{Li}(\text{Ni}_{0.33}\text{Mn}_{0.33}\text{Co}_{0.33})\text{O}_2$) cathode and graphite anode. The cathode combination of one-third nickel, one-third manganese and one-third cobalt lowers the raw material costs due to reduced cobalt content. NMC batteries are usually used in EVs, power tools and energy storage applications²⁵⁴. Advantages of NMC batteries are their enhanced charge and

²⁵¹ Green Car Congress; ZSW develops process for Li-ion batteries with extended cycle life; 10,000 charge cycles; 2013; Accessible from <http://www.greencarcongress.com/2013/06/zsw-20130604.html>; Accessed on 21 October 2012

²⁵² NEC Corporation, Tanaka Chemical Corporation, SEKISUI CHEMICAL CO., LTD.; NEC Develops Advanced Lithium Ion Battery with High-Energy Density; 2013; Accessible from http://www.sekisuichemical.com/about/whatsnew/2013/1237558_17313.html; Accessed on 21 October 2013

²⁵³ AZoM.com; The Future of the Lithium-Ion Opportunity in Solar Energy Storage; 2013; Accessible from <http://www.azom.com/article.aspx?ArticleID=9891>; Accessed on 22 October 2013

²⁵⁴ M. Abshar; Application of lithium-ion batteries in Energy Storage Equipment.

discharge (power) ratings and low temperature performances. However, their costs remain as the main drawback.

Lithium Iron Phosphate (LFP)

The LFP battery consists of a lithium iron phosphate (LiFePO_4) cathode and graphite anode. LFP batteries have better thermal stability of cathode (safety advantage on overcharge), high current rating and long life span. However, they have lower cell voltage and reduced energy density compared to other lithium-based batteries. LFP batteries are mostly used in power tools, EVs and energy storage applications.

Lithium Polymer (Li-Po)

The Li-Po battery differentiates itself from the other Li-Ion batteries in the type of electrolyte used. The Li-Po battery uses a solid polymer or gel electrolyte rather than a liquid electrolyte. One major advantage of Li-Po batteries is their flexibility to be packaged in different shapes (cylindrical, prismatic or as a pouch). They also have high reliability for impact and vibration due to the lamination structure of the electrode and electrolyte²⁵⁵. However, Li-Po batteries have lower energy density, high internal resistance and poor conductivity. Heating the cell to 60°C and higher increases the conductivity but reduces the life span of the cell. Gel electrolyte was also introduced to improve the battery conductivity. Li-Po batteries are used in mobile phones, military and automotive applications.

Lithium Titanate (LTO)

The LTO battery is a type of Li-Ion battery that is based on advanced nano-technology. It uses lithium-titanate nanocrystals on the surface of its anode instead of carbon. The crystalline surface increases the surface area of the anode, allowing electrons to enter and leave the anode quickly. This enables the battery to be charged faster and at higher rates. Other advantages of the LTO battery include a wider operating temperature range (-30 to 55°C), high recharge efficiency exceeding 98%, long cycle life (> 3000 to 7000 cycles), high safety and high stability²⁵⁴. However, the battery has a lower cell voltage and lower energy density compared to conventional Li-Ion batteries. LTO batteries are mainly used in the automotive sector (e.g. EVs) but are also being increasingly used in energy storage systems and military applications.

Other Developments

A number of other lithium chemistries are under development as follows:

- **Lithium Air:** The lithium air battery has the potential to provide energy density two to ten times higher than current Li-Ion batteries^{256,257}. The lithium air battery uses lithium as its anode, the oxygen content of the air as its cathode and a porous carbon electrode. In 2013, Toyota Motor Corporation and Bayerische Motoren Werke AG announced plans for lithium air batteries²⁵⁸. IBM also announced its plans to build a battery prototype in 2014 that would mark a large improvement by packing in more storage capacity²⁵⁸. A recent research by the Massachusetts Institute of Technology (MIT) in the US have shown that the use of genetically modified viruses greatly

²⁵⁵ T. Osawa, M. Kono; Lithium-Ion Batteries – Chapter 21: Polymer Electrolyte and Polymer Battery; 2009

²⁵⁶ R. Marsh; Lithium-air- batteries go viral for greater durability and performance; 2013; Accessible from <http://www.gizmag.com/m13-virus-electrode-lithium-air-battery/29791/>; Accessed on 11 December 2013

²⁵⁷ Lithium Air Industries, Inc.; Lithium Air Industries – Advanced Energy Storage Technology; Accessible from <http://www.lithiumair.us/index.html>; Accessed on 11 December 2013

²⁵⁸ C. Martin; Lithium Air Battery Gives IBM Hope of Power Without Fires; 2013; Accessible from <http://www.bloomberg.com/news/2013-02-21/lithium-air-battery-gives-ibm-hope-of-power-without-fires.html>; Accessed on 13 December 2013

increases the surface area of a nanowire array that work as electrodes in a lithium air battery's cathode, which in turn improves the charge-storage capacity of the lithium air battery²⁵⁹. Research is also being carried out by PolyPlus Battery, AIST from Japan, University of Strathclyde, St. Andrews University and Newcastle University.

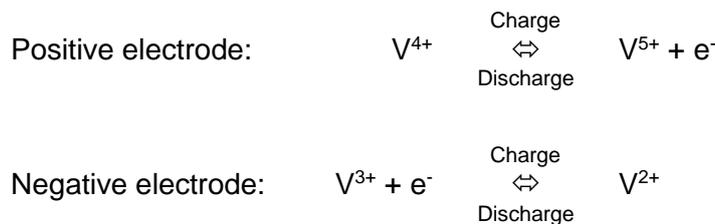
- Lithium Sulphur/Sulphide:** This technology has significantly higher energy density compared to other Li-Ion technologies; energy densities of more than 350 Wh/kg have been achieved and values exceeding 600 Wh/kg seem achievable in the foreseeable future²⁶⁰. The technology is under development for EVs, energy storage and defence applications. OXIS Energy and Steatite from the UK have signed an agreement in 2013 to develop lithium sulphur rechargeable battery systems with advanced communications for use in the Oceanographic, defence and energy industry²⁶¹. Other companies involved in the development of the technology include Sion Power and PolyPlus Battery in the United States.

A3.2 Flow Battery Technologies

The sub-sections below provide further details of a number of flow battery technologies. A summary of flow battery deployments/demonstration projects is provided in Section A3.2.8.

A3.2.1 Vanadium Redox (V:V)

The vanadium redox battery employs the V2/V3 and V4/V5 redox couples in sulphuric acid as the negative and positive electrolytes respectively. The reactions that occur in the battery during charging and discharging can be expressed simply by the following equations:



Vanadium redox batteries are potentially suitable for a wide range of energy storage applications including enhanced power quality, uninterruptible power supplies, peak shaving, increased security of supply and integration with renewable energy systems. The technology itself is based on an original set of patents emanating from the University of New South Wales, that are now largely expired and/or not applicable in Europe, India, China or South Africa.

The principal developers and suppliers of the technology to date have been VRB Power Systems, Sumitomo Electric Industries (SEI) and Prudent Energy, with the latter organisation

²⁵⁹ Physics World; Viruses breathe new life into batteries; Accessible from <http://physicsworld.com/cws/article/news/2013/nov/26/viruses-breathe-new-life-into-batteries>; Accessed on 12 December 2013

²⁶⁰ Sion Power; Product – High Energy Development; Accessible from <http://www.sionpower.com/product.html>; Accessed on 16 December 2013

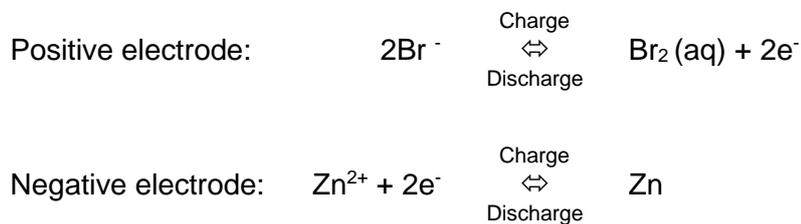
²⁶¹ Oxis Energy; Oxis Energy and Steatite sign an agreement to develop lithium sulphur battery systems; 2013; Accessible from <http://www.oxisenergy.com/blog/oxis-energy-and-steatite-sign-an-agreement-to-develop-of-lithium-sulfur-bat/>; Accessed on 16 December 2013

acquiring the assets of VRB Power Systems in January 2009²⁶², following on from the former filing for insolvency in November 2008²⁶³.

Other companies that are pursuing vanadium redox energy storage development programmes include Gildemeister (previously Cellstrom), Imergy, Magnam Technologies (see also Section A3.2.6) and Renewable Energy Dynamics Technology (REDT). A demonstration of the REDT system is currently in progress, funded by DECC. Some of the salient points to emerge from the project to date are captured in the project case study (see Section A1.17, Appendix 1).

A3.2.2 Zinc Bromine

The zinc bromine flow battery consists of a zinc negative electrode and a bromine positive electrode separated by a microporous separator. Solutions of zinc and a complex bromine compound are circulated through the two compartments of the cell from two separate reservoirs. During charge, zinc is electroplated on the cathode and bromine is evolved at the anode; this is stored as a chemically complexed organic phase at the bottom of the positive electrolyte tank. A third pump is used for recirculation of the organic phase during the discharge cycle. On discharge, the zinc is oxidised to zinc ions and bromine is reduced to bromide ions. The reactions that occur at the two electrodes during charge and discharge can be expressed simply by the following equations:



The zinc bromine flow battery was first developed by Exxon in the early 1970s. A number of multi-kWh units have been demonstrated and with developers active in the field including ZBB Energy Corporation (ZBB), Primus Power and Premium Power Corporation (PPC). The then Scottish & Southern Energy company (now SSE plc) took a \$1M equity stake in the latter, June 2008²⁶⁴ which was also linked to their taking a PPC Powerblock 150 (PB150) 100kW/150kWh unit, for trials application at Nairn, outside of Inverness. Some of the learning to emerge from this project to date is captured in the project case study (see Section A1.11, Appendix 1).

A3.2.3 Iron Chromium

The iron chromium electrochemistry was one of the first couples investigated for potential flow battery applications, dating back to National Aeronautics and Space Administration's (NASA's) work, in the 1970s. The positive reactant comprises an aqueous solution of ferric-ferrous redox couple, whilst the negative reactant is a solution of chromous-chromic couple, both acidified with hydrochloric acid.

²⁶² Prudent Energy announces its assets acquisition of VRB Power Systems Inc. 29th January 2009. <http://www.pdenergy.com/news-012909-acquisition.php> (accessed 30th July 2014).

²⁶³ VRB Power Applies to Appoint Interim Receiver and Makes Filing under Insolvency Legislation. CNW, 20th November 2008. <http://www.newswire.ca/en/story/333579/vrb-power-applies-to-appoint-interim-receiver-and-makes-filing-under-insolvency-legislation> (accessed 30th July 2014).

²⁶⁴ Scottish & Southern Energy plc. New investment in Premium Power Corporation. RNS News Release 0685X, 19th June 2008; Available from <http://www.proactiveinvestors.co.uk/companies/rns/080619sse> (accessed 24th July 2014).

The EnerVault company, established in 2008²⁶⁵, is pursuing the commercial development of the technology and commissioned its first utility scale (250kW/1MWh) system, at Turlock, CA, May 2014²⁶⁶.

A3.2.4 Bromide Polysulphide (Regenesys™)

The Regenesys™ system was developed by RWE Innogy and its predecessor companies (Innogy and National Power), in the late 1990s/early 2000s. The system utilised the reversible electrochemical reaction between two salt solution electrolytes, namely sodium bromide and sodium polysulphide:



During the charging cycle, the electrochemical reaction proceeds from left to right; during the discharge cycle the reaction proceeds from right to left.

Regenesys™ was marketed as a grid-connected utility scale storage system, for power ratings in excess of 5MW and progressed as far as two initial demonstration plant, although in the event, neither facility was fully completed, nor commissioned.

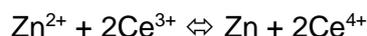
Notwithstanding the significant scale-up of and commitment to Regenesys™ related activities, RWE Innogy announced in December 2003 that it would no longer be funding the technology's development and subsequent commercialisation²⁶⁷.

An insight into the some of the learning to emerge from the Regenesys™ development programme is provided in a DTI Report, published on the subject²⁶⁸.

In September 2004 RWE-Innogy subsequently announced the sale of an exclusive five year licence on the Regenesys™ Intellectual Property and related physical assets to VRB Power Systems, for the sum of \$1.3M²⁶⁹. As noted in Section A3.2.1 VRB Power Systems subsequently filed for insolvency, in November 2008, with its assets then being acquired by Prudent Energy. It is not believed that VRB Power Systems pursued any further development of the bromide/polysulphide system per se, although various facets of the Regenesys™ IP portfolio could potentially have found value in the VRB Power Systems and/or Prudent Energy V:V flow battery developmental programmes.

A3.2.5 Zinc Cerium

The zinc cerium flow battery uses the positive ceric / cerous ion couple in combination with the zinc⁰ / zinc²⁺ ion and methanesulphonic acid as the common electrolyte. A key differentiator of the Zinc Cerium system is its use of organic acids in a flow battery, with this allowing higher ionic concentrations to be achieved (relative to mineral acids), with the resultant potential of higher energy and power densities. Its operation is represented by the equation:



²⁶⁵ EnerVault. <http://enervault.com/> (accessed 24th July 2014).

²⁶⁶ EnerVault Unveils First Of Its Kind Iron-Chromium Megawatt-Scale Flow Battery. <http://www.forbes.com/sites/peterdetwiler/2014/05/30/enervault-unveils-first-of-its-kind-iron-chromium-megawatt-scale-flow-battery/> (accessed 24th July 2014).

²⁶⁷ Disempowered. The Engineer, 20th February 2004. <http://www.theengineer.co.uk/in-depth/disempowered/268309.article> (accessed 31st July 2014).

²⁶⁸ Regenesys Utility Scale Energy Storage. Project Summary. DTI. Contract No. K/EI/00246/00/00. URN No. 04/1048.DTI, 2004.

²⁶⁹ VRB Power Acquires Regenesys Electricity Storage Technology, Power Engineering International, 27th September 2004.

Development of the Zinc Cerium system was pursued around 2005 - 2006, by the Scottish company, Plurion Limited, established in October 2005 as a joint venture between Plurion Systems (USA) and ITI Energy (an adjunct to Scottish Enterprise). At the time, ITI-Energy announced that it was to invest £9.3 million in the company²⁷⁰. A subsequent announcement, in March 2008, indicated that Applied Intellectual Capital (AIC) had purchased ITI-Energy's interests and rights to Plurion. Coincidental with this, Plurion announced that it would be opening a new manufacturing facility in Fife²⁷¹.

Plurion is understood to have entered liquidation, in November 2009, and with the Intellectual Property (IP) rights returning to Scottish Enterprise. Scottish Enterprise is since reported to have written off the debt associated with Plurion, in an endeavour to attract a further investment in the company²⁷².

A3.2.6 Vanadium Bromine

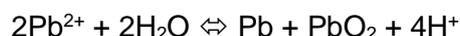
Sometimes referred to as the “next generation” Vanadium Redox flow battery, the Vanadium Bromine system utilises the VBr_2/VBr_3 redox couple at the negative electrode and the $Cl^-/BrCl_2^-$ redox couple, at the positive electrode²⁷³. The principal aim of the Vanadium Bromine development is to improve upon the modest 25 to 35 Wh kg⁻¹ energy density of the all vanadium system, via its ability to increase the concentration of active ions. This, potentially, allows energy densities of up to 50Wh kg⁻¹ to be achieved.

The development of this “next generation” Vanadium Redox battery was initiated in 2003 by Magnam Technologies²⁷⁴, a start-up company that was established by two of the original inventors of the Vanadium Redox flow battery. This subsequently led to the establishment of V-Fuel Pty Ltd., which further pursued the development of the technology, until it ceased trading in July 2010²⁷⁵.

A3.2.7 Soluble Lead

The soluble lead system is an example of a single electrolyte flow battery that is able to operate without a membrane separator.

In the soluble lead flow system, the cell has two inert electrodes and a single electrolyte consisting of a high concentration of lead methanesulfonate in methanesulfonic acid, which is circulated through the inter-electrode gap. The operation of the system is represented by the following equation:



The system is different from the traditional Pb-Acid acid battery in that the electrode reactions do not involve insoluble Pb(II), i.e. lead sulfate within a paste. The system is therefore expected to have quite different performance characteristics from the Pb-Acid

²⁷⁰ Scotland Bids for World Power. The Sunday Times, 20th November 2005.

<http://www.thesundaytimes.co.uk/sto/business/article156513.ece> (accessed 31st July 2014).

²⁷¹ Boost for Methil Job Hopes. Fife Today, 4th March 2008. <http://www.fifetoday.co.uk/news/local-headlines/boost-for-methil-job-hopes-1-150013> (accessed 31st July 2014).

²⁷² Debt Write Off Sparks New Hope for Battery Project. The Herald Scotland, 26th November 2011.

<http://www.heraldsotland.com/business/company-news/debt-write-off-sparks-new-hope-for-battery-project.15234056> (accessed 31st July 2014).

²⁷³ Redox Flow Cells for Energy Conversion. Ponce de Leon, C., Frias-Ferrer, A., Gonzalez-Garcia, J., Szanto, D.A., and Walsh, F.C. Journal of Power Sources 160 (2006), 716-732.

²⁷⁴ New Start-up Company to Commercialise Generation 2 Vanadium Fuel Cell; The Novel Vanadium Bromide Redox Cell. <http://www.arizonaenergy.org/Analysis/FuelCell/Vanadium%20Battery/THE%20NOVEL%20VANADIUM%20BROMIDE%20REDOX%20CELL.htm> (accessed 31st July 2014).

²⁷⁵ V-Fuel web-site: <http://www.vfuel.com.au/> (accessed 31st July 2014).

battery and to find entirely different applications. Its development has been pursued at laboratory scale by C-Tech Innovation and the University of Southampton²⁷⁶.

A3.2.8 Flow Battery Deployments

Table A3.4 below summarises flow battery demonstration projects based on the various electrochemistries described above.

Table A3.4: Flow Battery Installations

Plant Name and Location	Technology	Year	Rated Energy (MWh)	Rated Power (MW)	Details
REDT Demonstration – Isle of Gigha, Scotland	V:V	To be installed on Gigha during 2015.	1.25	0.105	Project funded by DECC. In Progress. ^{277, 278} . Described in project case study A1.17.
Minami Hayakita Substation Vanadium Redox Flow Battery ²⁷⁹	V:V	2013 onwards	60	15	This system is due to be commissioned in 2015 and is designed to assist with the integration of PV generation.
Premium Power Corporation - Nairn	ZnBr	Originally installed in 2009.	0.150	0.1	A unit was installed at Nairn substation in 2009, but was subsequently shut down, de-commissioned and removed after an initial period of testing. A fully functional system from PPC may be installed at the site at some point in the future ²⁸⁰ . Described in project case study A1.11.
Primus Power Modesto Irrigation District, California, USA ²⁸¹	ZnBr	Announced in 2013	112	28	Primus Power is developing and deploying a 28 MW/112 MWh EnergyFarm energy storage system in the Modesto Irrigation District in California's Central Valley. The system is intended to provide flexible capacity for the region and compensate for the variable nature of wind and solar energy.

²⁷⁶ A Novel Flow Battery. A Lead Acid Battery based on an electrolyte with soluble lead (II). Part VIII. The cycling of a 10cm x 10cm flow cell. Collins., J. et al. Journal of Power Sources 195 (2010), 1731-1738.

²⁷⁷ £5M boost for Energy Storage Innovation. Department of Energy and Climate Change Press Release, 4th November 2013. <https://www.gov.uk/government/news/5-million-boost-for-energy-storage-innovation> (accessed 23rd July 2014).

²⁷⁸ The Isle of Gigha Flow Battery Project. Baker, J.N., Wilson, S.D. and Samuel, J. Presentation to All-Energy 2014, held Aberdeen, 21st-22nd May 2014. Available from <http://www.all-energy.co.uk/novadocuments/54267?v=635376493250870000> (accessed 30th July 2014).

²⁷⁹ <http://www.energystorageexchange.org/projects/930> Accessed 10/11/2014

²⁸⁰ SSEPD Transmission Innovation Funding Incentive (IFI) Report 2012 - 2013. Available from <http://www.ssepd.co.uk/Innovation/IFIAndRPZ/> (accessed 23rd July 2014).

²⁸¹ <http://www.energystorageexchange.org/projects/9> Accessed 10/11/2014

Plant Name and Location	Technology	Year	Rated Energy (MWh)	Rated Power (MW)	Details
EnerVault system - Turlock, CA	Iron Chromium	Commissioned May 2014	1	0.25	Optimising the use of energy in a system including 150kW of solar generation and a 260 kW. The demonstration is funded in part by over \$4.7 million from the US Department of Energy and \$476,000 from the California Energy Commission, and aims to demonstrate the feasibility of iron-chromium redox flow batteries as reliable utility-scale storage resources. ²⁸²
Regenesys™ – two planned systems at Little Barford, Cambridgeshire and Columbus, Mississippi	Bromide Polysulphide	Circa 2001-2002 (never completed, nor commissioned)	120 (each)	12 (each)	Two initial demonstration plants were planned, although in the event, neither facility was fully commissioned prior to the discontinuation of the Regenesys™ development programme.

²⁸² <http://www.forbes.com/sites/peterdetwiler/2014/05/30/enervault-unveils-first-of-its-kind-iron-chromium-megawatt-scale-flow-battery/> Accessed 10/11/2014

Appendix 4 Codes, Standards and Licensing Considerations

A4.1 The Batteries and Accumulators and Waste Batteries and Accumulators Directive

For the purpose of the Regulations, a “battery” or “accumulator” is defined in the following terms:

- A “battery” or “accumulator” means any source of electrical energy generated by direct conversion of chemical energy and consisting of one or more primary battery cells (non-rechargeable) or consisting of one or more secondary battery cells (rechargeable); and
- A “battery pack” means any set of batteries or accumulators that are connected together or encapsulated within an outer casing so as to form a complete unit that the end-user is not intended to split up or open.

The key requirements of the Directive are as follows:

- Labelling requirements – all new batteries to be marked with a crossed out wheeled bin symbol and the appropriate chemical symbol where applicable;
- Registration of all ‘producers’ e.g. manufacturers or importers of batteries into the UK with the Department for Business, Innovation and Skills²⁸³;
- A ban on the disposal of untreated automotive and industrial batteries in landfill or by incineration;
- A requirement for ‘producers’ or third parties acting on their behalf to arrange for the collection and recycling of waste industrial and automotive batteries; and
- Restrictions on the use of cadmium and mercury in the design and manufacture of new batteries.

These regulations apply to all types of batteries and accumulators. Various categories of battery are defined by the regulations. Utility scale EES systems as discussed within this GPG fall under the definition of an “Industrial” battery.

A4.2 Transport of Batteries and Energy Storage Systems

Section 6.2.4 sets out the definition of “dangerous goods” and how this may relate to the transport of components/sub-systems of EES systems. As noted within the main body of this Guide, Class 9 (Miscellaneous dangerous substances and articles) includes lithium and Li-Ion cells and batteries, which are represented by the following UN Numbers:

- UN3090: Lithium Metal Batteries;
- UN3091: Lithium Metal Batteries Contained in Equipment or Lithium Metal Batteries Packed with Equipment;
- UN3480: Lithium Ion Batteries; and
- UN3481: Lithium Ion Batteries Contained in Equipment or Lithium Ion Batteries Packed with Equipment.

The implications of CDG are now reviewed in relation to the transport of Lithium Ion batteries (UN No. 3480 in the list above).

²⁸³ <http://npwd.environment-agency.gov.uk/Public/BatteriesHome.aspx> Accessed 25/02/2014

Li-Ion batteries may be transported by road as:

- An “excepted” category, as defined by the CDG Regulations; or, alternatively as
- Fully regulated Class 9 dangerous goods

For treatment as an “excepted” category, the following provisions apply:

- Successful testing in accordance with the requirements of UN38.3;
- Cells/batteries must not be defective in nature;
- Protection against short circuits must be provided;
- Individual cell and battery capacities limited to 20Wh and 100Wh, respectively, and subject to maximum shipment weight/quantity limits, according to the transport mode; and
- Specified packaging, labelling and documentation requirements.

For transport of Li-Ion batteries as Class 9 Dangerous Goods, as would be required above the 100 Wh threshold, then further and specific requirements apply in accordance with the ADR Regulations, in relation to:

- Marking;
- Packaging;
- Labelling; and
- Documentation.

In addition to the above, businesses that handle, process or transport dangerous goods on a regular basis must appoint a Dangerous Goods Safety Adviser (DGSA). However, the appointment of a DGSA is not required for those businesses whose main or secondary activities are not the carriage or related loading or unloading of dangerous goods, but limited to occasional instances of such activities²⁸⁴. As such, electricity network operators and other owner/operators of EES storage systems are likely to fall under this latter exemption.

A specific derogation (Road Derogation 15²⁸⁵) exists for the collection and carriage of used Li-Ion cells/batteries “from the consumer collecting point and the intermediate processing facility”; as such, this is not applicable in the context of the present industrial battery systems.

A4.3 Mechanical Design and Safety

Legislation, codes and standards in relation to mechanical design and safety includes:

- Health and Safety at Work Act 1974
- SI - 2008 - No. 1597: The Supply of Machinery (Safety) Regulations
- SI - 1999 - No. 3242: The Management of Health and Safety at Work Regulations
- SI - 2006 - No. 438: The Management of Health and Safety at Work (Amendment) Regulations
- SI - 1998 - No. 2306: The Provision and Use of Work Equipment Regulations

²⁸⁴ DfT Guidance; Moving Dangerous Goods. Available from <https://www.gov.uk/moving-dangerous-goods> (accessed 16th September 2014).

²⁸⁵ Carriage of Dangerous Goods: Approved Derogations and Transitional Provisions. DfT. Available from: <https://www.gov.uk/government/publications/the-carriage-of-dangerous-goods-approved-derogations-and-transitional-provisions> (accessed 1st August 2014).

- SI - 2007 - No. 320: The Construction (Design and Management) Regulations
- BS EN ISO 12100-2:2003 Safety of Machinery. Basic Concepts, General Principles for Design. Technical Principles.
- BS EN 1050: Safety of Machinery – Principles for Risk Assessment

A4.4 Electrical Design and Safety

Legislation, codes and standards in relation to electrical design and safety includes:

- The Electricity Act 1989
- The Health and Safety at Work Act 1974
- SI-1992 - No. 2051: The Management of Health and Safety at Work Regulations
- SI-1998 - No. 2306: The Provision and Use of Work Equipment Regulations
- SI-1994 - No. 3260: The Electrical Equipment (Safety) Regulations 1994
- SI-1989 - No. 728: The Low Voltage Electrical Equipment (Safety) Regulations 1989
- SI-1989 - No. 635: The Electricity at Work Regulations
- SI-2006 - No. 3418: The Electromagnetic Compatibility Regulations 2006
- SI-2002 - No. 2665: The Electricity Safety, Quality and Continuity Regulations 2002 (Amended 2006)
- BS EN 60146: Semiconductor Converters (General Requirements)
- IEC/TS 61000-3-4: Electromagnetic compatibility (EMC) - Part 3-4: Limits - Limitation of emission of harmonic currents in low-voltage power supply systems for equipment with rated current greater than 16 A
- IEC 61000-3-5: Electromagnetic compatibility (EMC) - Part 3-5: Limits - Limitation of voltage fluctuations and flicker in low-voltage power supply systems for equipment with rated current greater than 75 A
- IEC 61000-5-1: Electromagnetic compatibility (EMC) - Part 5: Installation and Mitigation Guidelines - Section 1: General Considerations - Basic EMC publication
- IEC 61000-5-2: Electromagnetic compatibility (EMC) - Part 5: Installation and Mitigation Guidelines - Section 2: Earthing and Cabling
- BS EN 55014: Radio Interference - Industrial Power Equipment
- BS EN 50081: Electromagnetic Compatibility (Generic Emission Standard)
- BS 7671: Requirements for Electrical Installations
- BS EN 62305-1: Protection Against Lightning. General Principles
- BS EN 62305-2: Protection Against Lightning. Risk Management
- BS EN 62305-3: Protection Against Lightning. Physical Damage to Structures and Life Hazard
- BS EN 62305-4: Protection Against Lightning. Electrical and Electronic Systems Within Structures
- The Distribution Code of the Licensed Distribution Network Operators of Great Britain
- Engineering Recommendations G59/-: Recommendations for the Connection of Generating Plant to the Distribution Systems of Licensed Distribution Network Operators
- Engineering Recommendations P28: Planning Limits for Voltage Fluctuations Caused by Industrial, Commercial and Domestic Equipment in the United Kingdom
- Engineering Recommendations G5/4-1: Planning Levels for Harmonic Voltage Distortion and the Connection of Non-Linear Equipment to Transmission Systems and Distribution Networks in the United Kingdom

The IET Wiring Regulations classify low voltage as not exceeding 1000V AC or 1500V DC between conductors, or 600V AC or 900V DC between conductors and earth. Voltages above this are classified as high voltage.

A4.5 Chemical Design and Safety

A4.5.1 COSHH and CLP

The Control of Substances Hazardous to Health (COSHH) Regulations, 2002, impose a duty on employers to control substances that are hazardous to health. In practice, compliance with the COSHH Regulations is enacted via the performance of a COSHH Assessment, which identifies and describes the relevant substance(s), their intended application and the hazards presented by the substance(s) concerned. The risks presented by the proposed application are then assessed and an appropriate control strategy developed, to mitigate these risks²⁸⁶.

The COSHH Regulations are applicable to any substance which classed as very toxic, toxic, harmful, corrosive or irritant and which is listed in Annex IV, Part 3, Table 3.2 of the Classification, Labelling and Packaging (CLP) of Substances Regulations 2009 (see Section A4.5.2). Specifically, the COSHH Regulations apply to any preparation (mixture) that is dangerous for supply, under the CLP Regulations, any substance which has a Workplace Exposure Limit (WEL), certain categories of dust and any other substance that creates a risk to health because of its properties and the way it is used or is present in the workplace.

For the operators of energy storage systems these regulations have implications if any handling of free chemicals is required (e.g. H₂SO₄ electrolyte). This would need to be written into the operational procedures for the system, with the requisite COSHH assessment. However, for the majority of battery systems (as implemented to date) no handling of the free electrolyte is required so the regulations do not impact directly on DNO/TO/SO end users. However, future implementations of flow battery energy storage systems may involve the handling of free electrolyte in which case these regulations would have to be applied, as appropriate.

A4.5.2 CHIP

The Chemicals (Hazard Information and Packaging for Supply) (CHIP) Regulations 2009 (also known as CHIP4) address the marketing of dangerous substances and preparations. CHIP imposes a requirement on the suppliers of applicable substances and preparations to decide whether they are 'dangerous' and in what way, and then to provide information to their customers in the form of warning labels. Such substances and preparations must also be properly packaged.

The CHIP Regulations will be completely replaced by the CLP Regulations (European Regulation (EC) No 1272/2008 on Classification, Labeling and Packaging of Substances and Mixtures (CLP Regulation)), with effect from 1st June 2015. In the interim, the CHIP regulations have been amended to ensure that UK national law is aligned with the transitional arrangements in the CLP Regulation and to include the necessary enforcement provisions where chemical suppliers choose to apply the CLP provisions as an alternative to CHIP ahead of the mandatory compliance dates.

A4.5.3 REACH

²⁸⁶ Further guidance is available from the HSE via: <http://www.hse.gov.uk/coshh/> Accessed 28/10/13.

The Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) Regulations 2008 is the system for controlling chemicals in Europe. It can affect importers of chemicals into the European Union.

Since 1 December 2008, chemical substances imported into Europe in amounts of one tonne per year or more have to be registered with the European Chemical Agency (ECHA). Individual chemicals require registration. Where a chemical is imported as part of a deliberate mixture (e.g. in paint or glues) it is the individual ingredients that are registered. In some cases, substances in “Articles” also require registration.

An “Article” is defined in REACH as “*an object which during production is given a special shape, surface or design which determines its function to a greater degree than does its chemical composition*”. The definition of an “Article” would therefore apply to most electrochemical cells. Importers are not required to submit a registration for each “Article” under REACH. A registration could however be required in specific circumstances for individual components of the article, specifically if the “Article” contains any “Substances of Very High Concern” (SVHC). It would therefore be beneficial for suppliers to provide a statement confirming the absence/presence of any SVHC. Should any SVHC be present, there are a number of duties which importers must comply with²⁸⁷.

It is likely that users of energy storage systems will procure these systems from a manufacturer. The manufacturer (or system integrator) would be responsible for importing the unit into the EU and therefore would be responsible for ensuring the appropriate registration/notification procedures are followed.

A4.5.4 Restriction of Hazardous Substances Directive (RoHS)

The Restriction of Hazardous Substances Directive (2002/95/EC) (RoHS) took effect from 1st July 2006 and restricts (with exceptions) the use of six hazardous materials in the manufacture of various types of electronic and electrical equipment. The Directive restricts the use of lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls and polybrominated diphenyl ether. ‘RoHS 2’ (an update to the original Directive, 2011/65/EU) took effect on 2nd January 2013, addressing the same substances as the original directive whilst improving regulatory conditions and regulatory clarity²⁸⁸.

Compliance is the responsibility of the company that puts the product on the market (in a similar manner to CE Marking, discussed in Section 6.4) and applies to products in the EU, whether they are made within the EU or imported. A product sold with a valid CE mark must satisfy the RoHS 2 requirements.

A4.5.5 DSEAR and ATEX

The emphasis of the DSEAR (Dangerous Substances and Explosive Atmosphere) Regulations 2002 is on the presence of “*dangerous substances in the workplace*”, with the regulations requiring employers to assess the risks of fires and explosions and to eliminate or reduce such risks as far as is reasonably practicable.

Dangerous substances are defined under DSEAR as any substances used or present at work that could, if not properly controlled, cause harm to people as a result of a fire or explosion. Flammable and explosive gases, such as hydrogen, therefore fall under the DSEAR Regulations.

²⁸⁷ Further details are available from the HSE: <http://www.hse.gov.uk/reach/index.htm> Accessed 21/11/2013

²⁸⁸ Guidance Available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/236285/bis-13-1142-restriction-of-hazardous-substances-regulations-guidance-2.pdf Accessed 05/03/2014

Compliance with the DSEAR Regulations involves:-

- an assessment of the fire and explosion risks;
- implementation of prevention or control measures;
- implementation of mitigation measures;
- preparation of emergency plans & procedures; and
- provision of information & training.

If required, in the context of any particular energy storage system(s), appropriate mitigation measures could include the provision of adequate ventilation and/or the installation of flameproof/explosion proof electrics, in the energy storage room(s)/compartment.

Guidelines on provisions against explosion hazards for Pb-Acid and NiCd batteries are provided in Section 8 of BS EN 50272-2:2001, as described in Section 6.2.2. This also draws attention and provides guidance on the hazardous zone, likely to be present in the immediate vicinity of the battery itself. The HSE Publication HSE INDG139(rev1)⁶⁸ also addresses this issue, with it noting that a Zone 1 Hazardous Area (an area in which an explosive gas atmosphere is likely to occur in normal operation) should be considered to exist for up to one metre, in all directions around (Pb-Acid) batteries under charge. As such, it recommends that all equipment present in the Hazardous Zone should be suitable and constructed and designed to an appropriate standard.

DSEAR furthermore sets out the link between zones, and the equipment that may be installed in that zone. Equipment categories are defined by the European ATEX (derived from the French title of the EC Directive, “Appareils destinés à être utilisés en **AT**mosphères **EX**plosibles”) equipment directive, set out in UK law as the Equipment and Protective Systems for Use in Potentially Explosive Atmospheres Regulations 1996 (SI 192, 1996). British Standard BS EN 60079-10: 2003 “Electrical Apparatus for Explosive Gas Atmospheres” covers the selection of electrical equipment for use in such atmospheres. The latter Regulations define an “explosive atmosphere” and “potentially explosive” atmosphere in the following terms:

- Clause 3.2 (f) “explosive atmosphere” means the mixture with air, under atmospheric conditions, of flammable substances in the form of gases, vapours, mists or dusts in which, after ignition has occurred, combustion spreads to the entire unburned mixture; and
- Clause 3.2 (g) “potentially explosive atmosphere” means an atmosphere which could become explosive due to local and operational conditions.

Under the normal operating conditions of the electrochemical energy storage systems neither an explosive or a potentially explosive atmosphere is generated. In the case of fault conditions (e.g. over charging of Pb-Acid systems, or thermal runaway failure of Li-Ion systems) an explosive atmosphere could be generated. The explosion risk from a particular system, and any requirement for compliance with DSEAR or ATEX should be assessed on a case-by-case basis.

A4.6 Pressure Systems Regulations

A4.6.1 Pressure Equipment Regulations

The design, manufacture and conformity of pressure systems is covered by the Pressure Equipment Regulations (SI 1999/2001, as amended by SI 2002/1267), which apply to

pressure equipment and assemblies of pressure equipment with a maximum allowable pressure of greater than 0.5 bar. The Pressure Equipment Regulations (PER) represent the UK implementation of the Pressure Equipment Directive (97/23/EC).

The general requirements of the PER make it an offence for a “responsible person” to place on the market, put into service or otherwise supply pressure equipment and assemblies above specified pressure/volume thresholds unless:

- They are safe;
- They meet essential safety requirements covering design, manufacture and testing;
- They satisfy appropriate conformity assessment procedures and are accompanied by a Declaration of Conformity; and
- They carry the CE mark.

Pressure equipment and assemblies which fall below specified pressure/volume thresholds must:

- Be safe;
- Be designed and manufactured according to “Sound Engineering Practice” (SEP);
- Be accompanied by adequate instructions for use; and
- Bear specified markings (but not the CE marking).

The requirements of the PER vary depending on a number of factors. These are set out below as a series of questions which will determine the requirements, under the PER, for any particular piece of equipment.

a) *Is maximum allowable pressure greater 0.5 bar?*

If yes, the PER are applicable;

b) *Is the assembly listed in the “Equipment excluded from the scope of the Regulations” list?*

If no, the PER are applicable;

c) *Is the working fluid classified as explosive, extremely flammable, highly flammable, flammable, very toxic, toxic or oxidising²⁸⁹?*

If the PER are deemed to be applicable, then the design authority (“Responsible Person”) is required to assess the pressure equipment, relative to the requirements of the PER, to determine which equipment category is applicable and the conformity requirements associated with this. Useful guidance is given in this respect by the (former) DTI guidance note on the subject²⁹⁰.

Such an assessment is performed via reference to a series of Classifications Charts, which define a series of demarcation lines between the different equipment categories. Essential inputs to the determination of the category of equipment comprise:

- The classification of the working fluid; i.e. whether Group 1 or Group 2;
- PS: The Maximum Allowable Pressure (bar), defined as the “Maximum pressure for which the equipment is designed, as specified by the manufacturer;”
- DN: Nominal Size of Piping (mm), defined as “A numerical designation of size which is common to all components in a piping system other than components indicated by

²⁸⁹ As classified according to the EC Directive on the Classification of Dangerous Substances 67/548/EEC.

²⁹⁰ Pressure Equipment. Guidance Note on the UK Regulations. April 2005. DTI Product Standards. URN 05/1074.

outside diameters or by thread size. It is a convenient round number for reference purposes”. The guidance further clarifies that “In the absence of DN in the standards, it shall be assumed that DN corresponds to the internal diameter in millimetres for circular products or the diameter in millimetres of the equivalent flow section for non-circular products;” and

- V: Volume of Vessels (litres), defined as “For a vessel, the volume in litres.”

The outcome from this assessment will determine the relevant and applicable equipment category, as follows:

- SEP: CE Marking is not required under the PER; equipment must be manufactured in accordance with “Sound Engineering Practice (SEP)”; or
- Category I to III: CE Marking is required. Higher categories involve increasingly demanding requirements. Category I requires internal production control, whereas Categories II and above required involvement of “notified bodies”.

In practice, a piece of pressure equipment may comprise an assembly of various vessels, piping and associated components. In this case, it is required to be considered as an “Assembly”, defined as several pieces of pressure equipment assembled by a manufacturer to constitute an integrated and functional whole.

The assessment of the integration of the components of the assembly is determined by the highest category applicable to the items concerned, other than that applicable to any safety accessories.

A4.6.2 Simple Pressure Vessels (Safety) Regulations

The Simple Pressure Vessels (Safety) Regulations 1991 (SPV) is applicable to simple pressure vessels intended to contain air or nitrogen at a gauge pressure of between 0.5 bar and 30 bar. The SPV represent the UK implementation of the Simple Pressure Vessels Directive (Directive 87/404/EEC) (SPVD). Simple pressure vessels satisfying the requirements of the SPV are required to carry CE marking.

Schedule 1 of SPV details the essential safety requirements that qualifying vessels must satisfy. It also provides details of how the vessels should be categorised, the technical requirements to be satisfied and the conformity assessment procedures to be followed.

A4.6.3 Pressure Systems Safety Regulations

The use of pressure systems at work is covered by the Pressure Systems Safety Regulations 2000 (PSSR), which aim to prevent serious injury from the hazard of stored energy as a result of the failure of a pressure system or one of its component parts.

Salient points to note from a user perspective are:

- Prior to using any qualifying pressure equipment (new or otherwise), a Written Scheme of Examination (WSE) must be in place, and an examination undertaken;
- A user of hired or leased equipment should make sure that the WSE is in place and that the certificate of examination is also current; and

- PSSR Schedule 2 allows a supplier of an installed system to assume responsibility in writing for the WSE, the operation, the maintenance and the record keeping.

A competent person is required to carry out such duties, including the performance of examinations in accordance with the WSE, paying attention to both the suitability of the WSE, the condition of the equipment and any requirement for actions or repairs. The competent person is also required to draw up or certify Written Schemes of Examination.

A4.6.4 Further Reading

The HSE's Approved Code of Practice²⁹¹ "Safety of Pressure Systems" provides further information on the safety of pressure systems, as relevant and applicable to a full range of dutyholders, including users, owners, competent persons, designers, manufacturers, importers, suppliers and installers of pressure systems.

A4.7 Civil Engineering Considerations

Relevant legislation, codes and standards here includes:

- Health and Safety at Work Act 1974;
- SI – 2008 – No. 1597: The Supply of Machinery (Safety) Regulations;
- SI – 2009 – No. 3242: The Management of Health and Safety at Work Regulations;
- SI – 2006 – No. 438: The Management of Health and Safety at Work (Amendment) Regulations;
- SI – 1998 – No. 2306: The Provision and Use of Work Equipment Regulations; and
- SI – 2007 – No. 320: The Construction (Design and Management) Regulations.

²⁹¹ Safety of Pressure Systems. HSE Approved Code of Practice, 2000. Available from <http://www.hse.gov.uk/pubns/books/l122.htm> (accessed 25th July 2014).

A4.8 CE Marking

A4.8.1 Summary of Potentially Applicable Directives

Low Voltage Directive
Products: Most electrical equipment that is designed for use with a voltage rating of between 50 and 1,000 volts (AC) and between 75 and 1,500 volts (DC)
Requirements: Relate to the provision that electrical equipment must be constructed in accordance with good engineering practice so that it does not endanger the safety of people, domestic animals or property.
Simple Pressure Vessels
Products: Welded vessels made of certain types of steel or aluminium and intended to contain air or nitrogen under pressure, not exceeding 30 bar, e.g. reservoirs for compressor units; automotive and rail braking systems.
Requirements: Relate to raw materials and welding materials used; accessories contributing to the strength of the vessel; vessel design, including wall thickness; manufacturing processes and the manufacturers' instructions to users.
Pressure Equipment
Products: Pressure equipment and assemblies subject to an internal pressure greater than 0.5 bar. The Regulations concern manufacturers of items such as shell and water tube boilers, heat exchangers, vessels, pressurised storage containers, industrial pipework and accessories.
Requirements: Relate to the design, manufacture and conformity assessment of pressure equipment and assemblies.
Electromagnetic Compatibility
Products: Applies to almost all electrical and electronic appliances, equipment and apparatus.
Requirements: Relate to the non-generation of electromagnetic disturbance and immunity from such disturbance.
Machinery
Products: 'Functioning machines', that is assemblies of mechanically linked parts, at least one of which moves.
Requirements: Relate to materials and products used in construction; lighting; design for handling purposes; stability; hazards relating to mobility and lifting; fire; noise; vibration; emission of dust, gases, etc.; maintenance; indicators and instruction handbooks.

A4.8.2 Routes to CE Marking

The usual manner of satisfying the essential requirements is for the product to be manufactured in accordance with the specified European Standard(s) (or the equivalent British Standards). However, in order to allow for innovation and/or unusual circumstances, the manufacturer has the choice of using other methods, provided the essential requirements are met.

It is the responsibility of the manufacturer/authorised representative/person placing the product on the market to show that the product meets the essential requirements. This may be achieved via one of three methods:

- A declaration by the manufacturer (backed up by their own, or independent, test results);
- The certificate of an independent body; or
- The test results of an independent body.

Where the specified European Standard(s) is/are not used, then the manufacturer usually has to obtain a report from an independent body.

There are three essential elements within the CE Marking process, as follows:

- **The Technical File:** The manufacturer or authorised representative must keep a technical file, which must be kept for 10 years after production has ceased. It must be available for inspection by the enforcement authority (Local Authority or Health & Safety Executive in the UK), though the file is not open for inspection by anyone else, for commercial reasons. It includes items such as a description of the equipment (drawings, circuit diagrams, and safety critical calculations), details of the standards and specification adhered to, the procedures used to ensure conformity with the applicable Directives and test data.
- **The Declaration of Conformity:** The Declaration of Conformity must contain all relevant information to identify the Directives to which it is issued (Low Voltage, EMC etc.), the name of the manufacturer, the product and reference to the appropriate Standards. In the case of an imported product, then the importer/person responsible for placing on the market, at the very least, the importer must be able to provide the relevant surveillance authorities with a copy of the declaration of conformity and make the technical documentation available. Hence, they should require formal assurance in writing from the manufacturer that the documents will be made available, at such time as they may be requested by the surveillance authority/ies. Likewise, in order to fulfil their obligations, an importer must ensure that a contact with the manufacturer can be established.
- **Application of CE Marking:** Once the Technical File and Declaration of Conformity are in place marking may then be applied to the product. CE marking, in itself, does not guarantee that a product is safe and the relevant authorities may require a CE marked product to be removed from the market, if they consider it unsafe.

The owner or operator of the product should receive a copy of the Declaration of Conformity from the supplier and the CE Marking symbol (shown below) should be applied to the product.



Figure A4.1: CE Mark Symbol

Appendix 5 Costs and Benefits of EES Systems and CBA

A5.1 System Cost Estimates

The costs below provide an estimate range for the total capital installed cost of various technologies. However, it should be noted that these costs relate to a survey of vendors completed in 2010, and considerable cost reductions have been achieved, particularly in relation to 'newer' technologies.

Table A5.1: Costs of EES Technologies

(abstracted from Table 4-14 "Technology Options: Energy Storage Solutions and System Costs"²⁹²)

Technology Option	Total Cost (\$/kW)	Cost (\$/kWh)
Advanced Pb-Acid	2000 - 4600	625 – 1150
Sodium Sulphur	3200 - 4000	445 – 555
Zn/Br Flow	1670 - 2015	340 – 1350
Vanadium Redox	3000 - 3310	750 – 830
Li-Ion	1800 - 4100	900 - 1700

A5.2 Introduction to the GB Energy Market

BETTA (British Electricity Trading and Transmission Arrangements) govern how electricity is bought and sold across mainland UK. The most important features are:

- Electricity (kWh) is traded in half-hourly (hh) blocks;
- BETTA participants (all those buying and selling electricity on the wholesale market) must be in-balance for each hh, i.e.:
 - Energy Suppliers must buy sufficient electricity to meet the needs of their consumers; and
 - Electricity Generators must match the output they have contracted to sell.

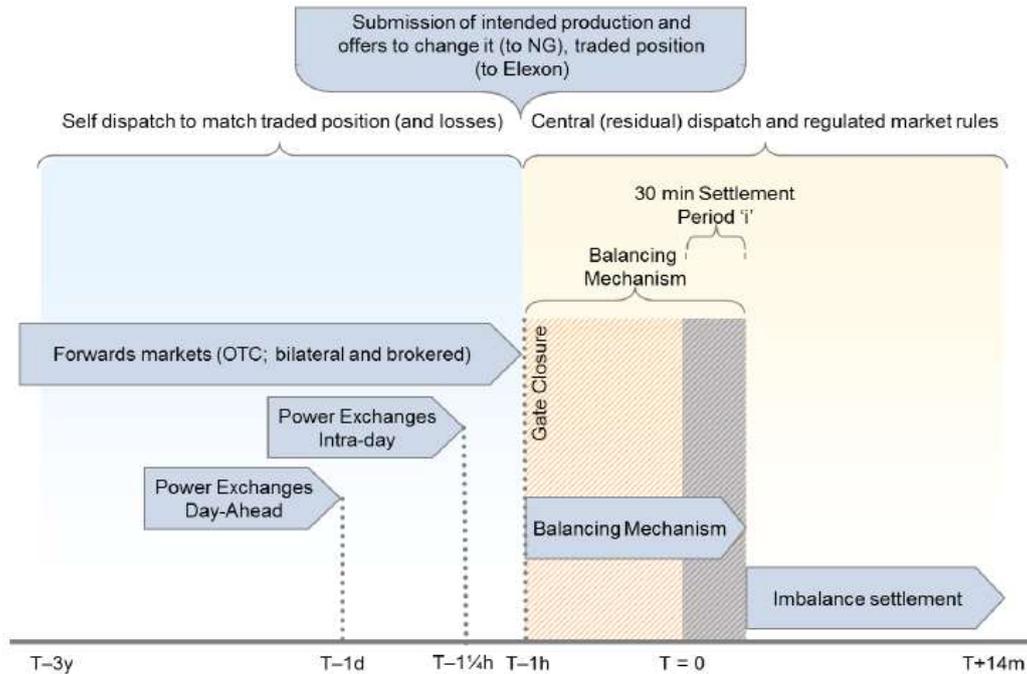
There are multiple elements to the energy trading market which operate at different points relative to the hh in question, as follows:

- Forwards and futures markets which allow contracts to buy and sell electricity to be struck up to several years ahead;
- Short-term 'spot' power exchange(s), enabling participants to fine tune their position (i.e. amount bought or sold) up to 'Gate Closure' (one hour before the half hour in question). The majority of electricity (98%) is traded via these first two methods;
- A Balancing Mechanism which opens at Gate Closure in which National Grid (acting as System Operator) accepts offers (increasing generation/reducing demand) and bids (reducing generation/increasing demand) for electricity to balance the transmission system; and
- A settlement process by which participants whose contracted positions do not match their metered volumes of electricity are charged for this imbalance.

These markets are illustrated in Figure A5.1 below.

²⁹² EPRI. Electricity Energy Storage Technologies Options. A White Paper Primer on Applications, Costs and Benefits. December 2010. Available from:

[https://www.parliament.nsw.gov.au/prod/parliament/committee.nsf/0/7482f370da08bf4eca257a38000982f6/\\$FILE/CSIRO%20attachment%201c%20-%20US%20storage%20economics.PDF](https://www.parliament.nsw.gov.au/prod/parliament/committee.nsf/0/7482f370da08bf4eca257a38000982f6/$FILE/CSIRO%20attachment%201c%20-%20US%20storage%20economics.PDF) Accessed 30/10/2014



Sources: Ofgem and Pöyry Management Consulting.

Figure A5.1: GB Electricity Trading Arrangements under BETTA²⁹³

There are various routes into the energy market if the owner of an EES system wishes to exploit these revenue streams, as follows:

- **Traditional Power Purchase Agreements (PPAs):** a generator (or in this case, EES system owner) enters into an agreement, typically with a licensed electricity supplier to purchase the energy generated. The PPA will define the level of payments that will be made over the term of the agreement. The price agreed can be fixed, vary in line with another benchmark (subject to a guaranteed minimum/floor price), or indexed to another price index.
- **Trading Services:** under this model the trading activities relating to buying and selling the input/output of the EES device would be outsourced to an external entity on behalf of the EES system owner.
- **Trading on own account:** this is the model adopted by owners of large amounts of generation/demand (e.g. generators, suppliers), who can benefit from economies of scale and in-house trading expertise. A generator operating under this model would incur additional costs due to balancing, trading and risk management costs, but is also able to retain a higher value.

It should be noted that not all of these options are available to all parties within the electricity value chain – GB DNOs are currently blocked from trading directly with the market by the regulatory regime. Further details of the potential treatment of EES within the Balancing and Settlement Code (BSC) are given in the Smarter Network Storage report, “Interim Report on the Regulatory and Legal Framework”¹⁶⁶.

²⁹³ Figure 17 in SNS Report (see Footnote 166)

A5.3 NPV Methodology Template

Discount Rate (%):	See definition in Section 13.1
Inflation Rate (%):	Assumed inflation rate over the course of the project (e.g. 2.5%)
Project Life (years):	The time over which the EES asset will be operational – depends on the technology and operating regime (n)
Capital Recovery Factor (%)	See definition in Section 13.1

Year of Operation:	0	1	2	3	...n
Discount Factor	1	Each year: $(1+\text{Discount Rate})^{\text{Year of Operation}}$			
Inflation Factor	1	Each year: $(1+\text{Inflation Rate})^{\text{Year of Operation}}$			
Present Worth Factor	1	Each year: Inflation Factor / Discount Factor			

Capital and Operating Costs

Annualised Capital Costs (£)		Each year: Capital Recovery Factor x Total Capital Costs of Installation
Energy Costs (£)		Each year: Cost of importing/exporting energy into the storage, and any losses
O&M Costs (£)	One off commissioning O&M Costs	Each year: Ongoing maintenance and inspection costs
Aux Load Costs (£)		Each year: Auxiliaries cost (e.g. heating, ventilation and air conditioning, pumps, IT etc.)

Operating Benefits of Application:

Application 1:		Each year: Assumed annual income from each application/revenue stream
Application 2:		
Application 3 (etc.):		

Discounting:

Discounted Capital Costs:	Each year: Annualised Capital Cost / Present Worth Factor
Discounted Operational Costs:	Each year: Sum of all costs (excluding capital costs) x Present Worth Factor
Discounted Benefits:	Each year: Sum of all operating benefits x Present Worth Factor

NPV Calculation:

Costs – NPV:	Sum of discounted capital and operational costs over lifetime
Benefits – NPV:	Sum of discounted benefits over lifetime
Total NPV:	Benefits NPV – Costs NPV

A5.4 Revenue Gap Method Template

Discount Rate (%):	See definition in Section 13.1
Inflation Rate (%):	Assumed inflation rate over the course of the project (e.g. 2.5%)
Project Life (years):	The time over which the EES asset will be operational – depends on the technology and operating regime (n)
Capital Recovery Factor (%)	See definition in Section 13.1

Year of Operation:	0	1	2	3	...n
Discount Factor	1	Each year:	$(1+\text{Discount Rate})^{\text{Year of Operation}}$		
Inflation Factor	1	Each year:	$(1+\text{Inflation Rate})^{\text{Year of Operation}}$		
Present Worth Factor	1	Each year:	Inflation Factor / Discount Factor		

Capital and Operating Costs

Annualised Capital Costs (£)		Each year:	Capital Recovery Factor x Total Capital Costs of Installation
Energy Costs (£)		Each year:	Cost of importing/exporting energy into the storage, and any losses
O&M Costs (£)		Each year:	Ongoing maintenance and inspection costs
Aux Load Costs (£)		Each year:	Auxiliaries cost (e.g. Heating, ventilation and air conditioning, pumps, IT etc.)

Operating Benefits of Application:

Application 1:		Each year:	Assumed annual income from each application/revenue stream
Application 2:			
Application 3 (etc.):			

Annual Calculations

	Annual Revenue Target	Application 1 Revenue	Application 2 Revenue	Application 3 Revenue (etc.)	Revenue Gap
Annuited Revenue Target (£/kW)	Sum of Costs in a Single Year (£) / System Rating (kW)				
Benefits (£/kW)		Application 1 Benefits in One Year / System Rating (kW)	Application 2 Benefits in One Year / System Rating (kW)	Application 3 Benefits in One Year / System Rating (kW)	
Revenue Gap (£/kW)					Annuited Revenue Target – Sum of Benefits

A5.5 LCOE Methodology Template

Discount Rate: (%)	See definition in Section 13.1
Capacity Factor (%)	(%) – the total number of operational hours across all applications divided by number hours per year
Project Life (years)	The time over which the EES asset will be operational – depends on the technology and operating regime (n)
Inflation (%):	Assumed inflation rate over the course of the project (e.g. 2.5%)
Capital Recovery Factor (%):	See definition in Section 13.1

Year of Operation:	0	1	2	3n
Discount Factor:	1	Each year: $(1+\text{Discount Rate})^{\text{Year of Operation}}$			
Real Interest Rate Factor:		Each year: $\frac{1}{(1+(\text{Discount Rate} - \text{Inflation}))^{\text{Year of Operation}}}$			

Capital and Operating Costs

<i>Fixed Costs:</i>	Annualised Cost of Capital (£/kW)	Each year:	Capital Recovery Factor x Total Capital Costs
	O&M Costs (£)	Each year:	Ongoing O&M Costs e.g. cost of maintenance contract with manufacturer, cost of inspections etc. (assumption per year)
	Auxiliary Load Costs (£)	Each year:	Auxiliaries Cost (e.g. air conditioning, pumps, IT etc.) (assumption of cost per year)
<i>Variable Costs:</i>	Energy Costs (£)	Each year:	Cost of importing/exporting energy per year, including any losses. This involves assumptions about the round-trip efficiency of the EES system, its operating regime (e.g. number of cycles per year, depth of discharge etc.) and cost of energy used to charge per kWh.

Energy Output

Energy Exported (kWh)	Capacity (kWh) x Number of cycles per year
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Discounted Figures

Discounted Capital Costs (£):	Each Year:	Annualised Capital Cost/ Discount Factor
Discounted Annual Costs (£):	Each Year:	Sum of All Costs (except cost of capital) x Real Interest Rate Factor
Discount Energy Exported (kWh):	Each Year:	Energy Exported (kWh) x Real Interest Rate Factor

LCOE:

$LCOE (\text{£ per kWh}) = \frac{\text{Total Discounted Capital Costs over life}(\text{£}) + \text{Total Discount Annual Costs over life} (\text{£})}{\text{Total Discounted Energy Exported over life} (\text{kWh})}$	
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