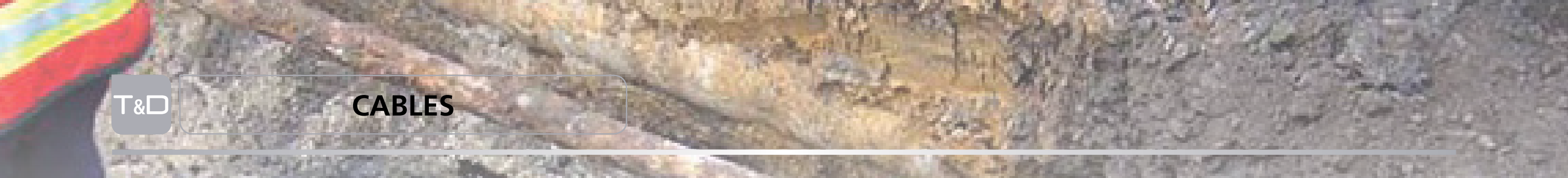

REDUCING FAILURE RATES AND BETTER MANAGEMENT OF UNDERGROUND CABLE NETWORKS

When maintained in good condition, underground cable distribution systems provide exceptionally high security of supply compared with overhead line systems, due to a low incidence of failure from external causes such as severe weather or external accident. However, underground cables are subject to deterioration from a range of root-causes, and without dedicated asset management, the systems will inevitably under-perform.

By Ying Wang and Neil Davies, EA Technology

As most cable failure root causes can be traced back to manufacture, installation and operation phases, ideally cable asset management should start at an early stage and continue through the cable lifecycle. Management effort is required from the procurement phase through installation, maintenance and to replacement at the end of cable service life. However, existing cable systems in utilities and other private networks were invariably installed without consistent lifecycle focus. Scarcity of relevant data and up to date information on the condition of the network, brings with it uncertainty with the ongoing integrity and reliability of the cable system. Nonetheless, using a combination of engineering reviews and targeted condition assessment the uncertainty can be reduced enabling cable systems to be more effectively managed.

FAILURE MODES AND ROOT CAUSES

To effectively manage any asset we first need to understand failure modes and root causes. Most cable types used for underground cable distribution networks are paper-insulated cable, oil filled paper-insulated cable and XLPE, with a trend of increasing use of XLPE cable.

Paper-insulated cables with a lead sheath, and protected on the outside by steel armour tape have in general given very good service, as witnessed by the fact that many of the pre-war cables are still giving satisfactory service; so much so that an expected service life of 70 years is not uncommon for PILC cable. Failures on PILC cables are mainly age related as these cables have reached the end of their service lives. The main failure mode is deterioration of the paper insulation over the long term due to partial discharge.

Oil filled paper-insulated cables are known as partial discharge free in the paper insulation and this feature gives the cable insulation almost infinite life. However, many utilities have experienced oil leak issues and treat oil leaks as the main failure mode. It is easy to know if an oil filled cable is leaking oil, but it is expensive to locate and repair the leak. The oil leak is usually due to metallic sheath corrosion caused by moisture ingression.

XLPE cables were first installed in the late 1960s and the first generation of XLPE cable had a poor service record and many of them had far shorter service life than expected due to issues in construction, design, material quality and manufacturing processes. Today with developments in manufacturing techniques and processes, XLPE cable has become the globally preferred cable for both transmission and distribution underground networks. Failure modes for XLPE cables include insulation deterioration due to natural ageing, water treeing, electric treeing and outer metallic sheath arcing. It is often the case that failures on XLPE cable systems are more often associated with joints and accessories, partial discharge activity being the predominant factor in the failures.

The table below shows the link between cable type, failure mode and root cause in different phases in the cable lifecycle.

	FAILURE MODE	ROOT CAUSE	LIFECYCLE
PILC Cable	Insulation deterioration over long term	Partial discharge	Natural ageing
	Thermal runaway	Local heating - mutual heating from neighbouring cables - cable surrounding material with high thermal resistivity - overloading - Incorrect design rating	Installation Operation
	Moisture ingress	Outer sheath damage	Installation
Oil Filled Cable	Oil leak	Oil pipe corrosion due to outer sheath damage	Manufacture defect Installation
	Thermal runaway	As for PILC cable type	Installation Operation
XLPE Cable	Insulation deterioration	- Natural ageing mainly due to cyclic thermal - Mechanical aggression - Manufacture defects	Natural ageing Manufacture
	Water treeing	Moisture ingression - outer sheath damage - without water barrier - outer metallic sheath corrosion - fault joint	Manufacture Installation
	Electric treeing	Defect in insulation Partial discharge Thermal Ageing	Manufacture Installation Operation
	Outer metallic sheath arcing	Corrosion due to outer sheath damage	Installation cable environment
	Thermal runaway	As for PILC cable type	Installation Operational

Table 1 *Cable Types, Failures, Root Causes and Phases in Cable Lifecycle*

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Example 1 - Local heating caused by cable installation configuration

For almost all cable condition related failures, the root causes can be traced back to the manufacture, installation or operation phases in the cable lifecycle.

With installation condition getting more difficult and complex as "green field" becomes less available, cable installation has become the predominant factor in building a reliable underground cable network.

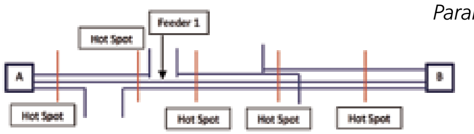
A good installation design with well managed installation will prevent many potential failures. The reverse argument is probably also true that a poor installation design with poor management and workmanship in installation will accelerate cable condition deterioration.

The examples above and below are related to cable installation and operation issues.

In example 1 above, multiple feeder cables are laid over each other without appropriate separation. The cables are poorly arranged in the trench with unsuitable material installed as the cable backfill. Result: overheating and accelerated ageing.

Example 2 - Mutual heating in multiple cables in parallel

Parallel feeder cables



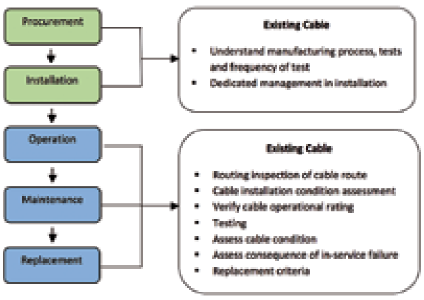
CABLE HOTSPOTS

A feeder cable connecting two substations is always joined by other feeder cables at various locations along its route. Due to space limitation and the number of cables involved, the location where the multiple parallel cables share the trench can be a hotspot.
The influence of factors such as loadings from neighbouring cables, cable crossovers, cable type, burial depth, ground moisture and the properties of backfill all need to be considered when assessing cable systems and their ability to perform the function for which they are required without excessive deterioration.

For example in the hot spots of Example 2, a PILC cable will suffer more de-rating if it has XLPE neighbouring cables, as the maximum operating temperature is usually limited to 70^{0}C at the conductor for PILC, compared with a maximum operating temperature of 90^{0}C for XLPE cable. This may not have been considered in original design calculations when PILC cable was the default cable type.

CABLE ASSET MANAGEMENT

The goal for utility cable asset management is to achieve highly reliable performance while keeping the cables in service as long as possible. This can only be achieved with dedicated asset management through the cable lifecycle, including procurement, installation, operation, maintenance, and replacement.



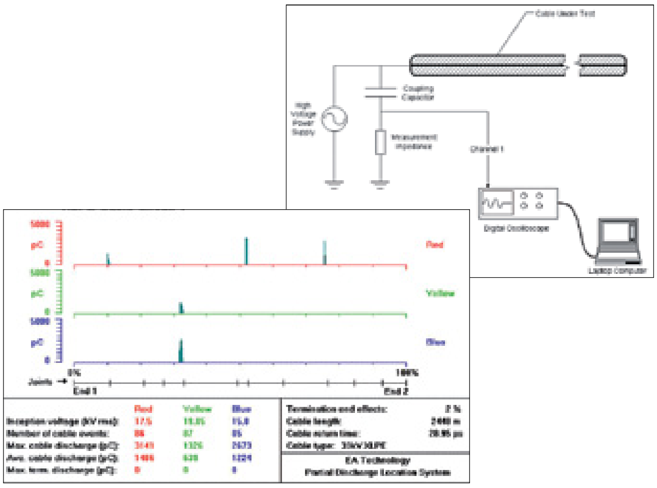
Cable lifecycle Management

CABLE CONDITION ASSESSMENT

There is often a lack of information on the current condition of installed cables. Off-line cable testing can be carried out e.g. through using a Very Low Frequency (VLF) AC test set. The technique is often applied after cable installation or repair to understand the condition of the complete cable circuit and whether additional defects are present.

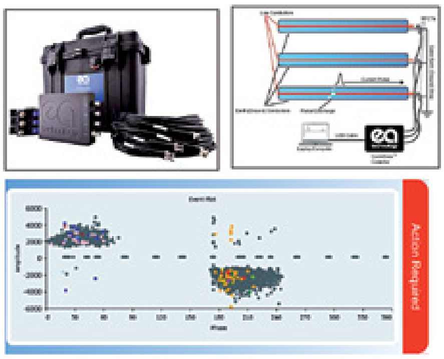
Offline VLF Cable PD Mapping

Improved decisions can then be made on the most cost effective long term solution e.g. whether to replace the complete cable, overlay a section of cable or simply repair the faulted area. The offline technique can therefore provide valuable asset management information. However with the time, complexity and cost of performing this testing it can be advantageous to utilise on-line testing for the wider network.



Partial Discharge Testing of Live Cables

Instruments such as the CableData Collector™ can measure partial discharge activity in live distribution voltage cables, without the need to de-energise them. This is a major advantage compared with offline testing, as test results can be collected for each circuit in less than 10 minutes and therefore many cables can be tested in a single day. On-line techniques can be utilised to gain a better overall picture on the health and condition of the whole cable network, help target more intrusive off-line inspection work and provide up to date information to feed into the asset management decisions.



CONCLUSIONS

Applying good asset management principles on both future and existing cables enables underground networks to be more effectively managed.

Cable failure rates can be reduced by dedicated lifecycle asset management, from cable procurement, through installation, operation, maintenance and to replacement at the end of cable service life. In particular, they can be reduced by eliminating root causes from the installation phase for new cables, and detecting hidden failures on aged cables by VLF and partial discharge testing in the maintenance stage.

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