Effective Management of Critical Ageing Cables

Power quality and continuity of supply at critical sites, such as large manufacturing sites or hospitals, is crucial for safety and productivity. Unexpected failure of a company's critical supply cables can potentially cost hundreds of thousands of dollars in lost revenue and add significant additional maintenance and operations costs. These risks are known but often poorly understood and estimated.

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Reactive maintenance, running equipment to failure and fixing issues as they occur are outdated approaches to asset management for these critical assets. Increasingly, companies are using more insightful methods to identify the risk associated with critical assets and actively manage the end-of-life phase. This approach allows organisations to balance the cost of doing something against the cost of doing nothing and to leverage their existing data systems and analytics to create actionable information and unlock value for their stakeholders and customers.

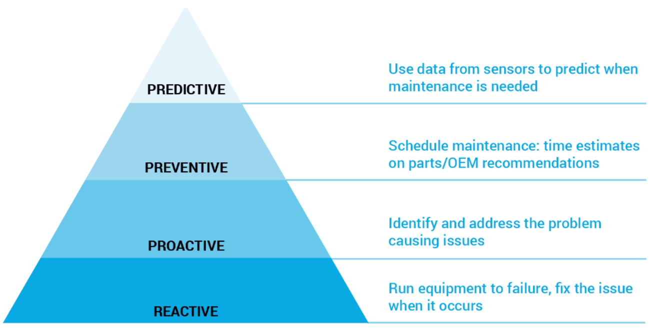

Figure 1 *Hierarchy of maintenance*

Predictive maintenance is about quickly diagnosing incipient failures as they begin to manifest. Near real-time data can enable modelling to predict time to failure and cause of failure, thereby maximising uptime and minimising interventions. The clear advantage of predictive maintenance for high-voltage power systems is that catastrophic failure can be avoided, avoiding costly disruption, emergency maintenance, safety incidents and significant downtime.

Can a more proactive approach to maintenance and assessment of high voltage cable systems be employed - an asset class for which we typically have a scarcity of data?

To effectively manage any asset we first need to understand failure modes and causes. Most cable types used for underground cable distribution networks are paper-insulated cable and XLPE, with a majority of newly installed cables being XLPE.

Paper-insulated cables with a lead sheath and protected on the outside by steel armour tape (PILC) have in general given very good service, as witnessed by the fact that many of the pre-war cables are still performing well; so much so that an expected service life of 70 or more years is not uncommon for these cables. Failures on PILC cables are now usually 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.

XLPE cables were first installed in the late 1960s. The first generation of these cables had a poor service record and many of them had far shorter lives than expected. These early life failures were due to

CABLE TYPE	FAILURE MODE	CAUSE	LIFECYCLE
PILC	Insulation deterioration over long term	Partial discharge	Natural ageing
	Thermal runaway	Local heating • mutual heating from adjacent cables • high thermal resistivity back-fill • overloading • incorrect rating	Installation Operation
	Moisture ingress	Outer sheath damage	Installation Operation
XLPE	Insulation deterioration	• Natural ageing mainly due to cyclic thermal • Mechanical aggression • Manufacture defects	Natural ageing Manufacture
	Water treeing	Moisture ingress • outer sheath damage • lack of water barrier • outer sheath corrosion • faulty joint	Manufacture Installation Operation
	Electric treeing	Defect in insulation Partial discharge Thermal ageing	Manufacture Installation Operation
	Outer metallic sheath arcing	Corrosion due to outer sheath damage	Installation Operation Environment
	Thermal runaway	As for PILC	Installation Operation

Table 1 *Cable type, failure modes and when they occur in the lifecycle*

issues in construction, design, material quality and manufacturing processes. Developments in manufacturing techniques and processes have delivered increasingly reliable XLPE cables, including water-tree retardant polymers. XLPE has become the globally preferred cable for both transmission and distribution underground networks due mainly to cost.

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 associated with joints and accessories, partial discharge activity again being the predominant factor in the failures.

Ideally, cable asset management should begin during the design phase and continue through the cable lifecycle. Cable failure root cause analysis identifies either manufacture, installation or operation phase as the stage where problems manifest.

Scarcity of relevant data and up to date information on the condition of older cable networks brings with it uncertainty of the ongoing integrity and reliability of supply. Nonetheless, using a combination of engineering reviews and targeted condition assessment, uncertainty can be reduced and allow cable systems to be more proactively managed.

When cables are installed on cable trays and ladders in industrial sites (as opposed to direct buried) defects most often attributed to installation can also develop in the operation phase of the lifecycle. However, the fact that they are installed on ladder provides the opportunity to visually examine and identify defects that require maintenance and intervention.

CONDITION ASSESSMENT OF CABLES – MOVING TO PROACTIVE

Periodically taking cables out of service allows data on the condition of the assets to be gathered. As shown in Table 1, partial discharge is a key indicator of condition. The traditional method for the measurement of PD has been to take the cables offline and energise using a power supply, often operating at Very Low Frequency (VLF). Online PD testing of cables is also available depending upon cable earthing arrangements. A typical VLF test set used for PD mapping of HV cables will often have integrated tan delta diagnostic capability so both tests can be carried out simultaneously.

Whilst PD measurement is suitable for detecting electrical trees, tan delta measurement provides an indication of the overall health of the insulation. Although it is a bulk measurement which can limit its usefulness, it can detect ageing of the insulation e.g. through the presence of water treeing or impurities.

A further technique, that to a certain extent overcomes the bulk measurement limitation of tan delta, is LIRA (Line Impedance Resonance Analysis). Whilst the cable is out of service for PD measurement, LIRA testing can be undertaken in just a few minutes. LIRA enables the detection and pinpointing of localised degradation or faults in the insulation material of electrical cables, as well as detection of global degradation.

CONDITION BASED RISK MANAGEMENT (CBRM) – TURNING DATA INTO ACTIONABLE INFORMATION

The first component of CBRM is the derivation of a numeric representation of the condition of each asset in the form of an 'Asset Health Index' (AHI). The health index of an asset is a mathematical combination of its age, operating environment and duty, as well as specific condition and performance information. AHI is a numerical representation of the condition or apparent age of the asset and has a defined mathematical relationship to its expected end of life (EOL) and probability of failure.

After undertaking the above-mentioned series of tests, the resolution of the AHI is measurably improved. This enables us to predict the Future AHI, using the ageing rate derived from the calculation of the current AHI. CBRM relates AHI to the probability of condition-based failure (PoF) through the mathematics of the Weibull failure curve.

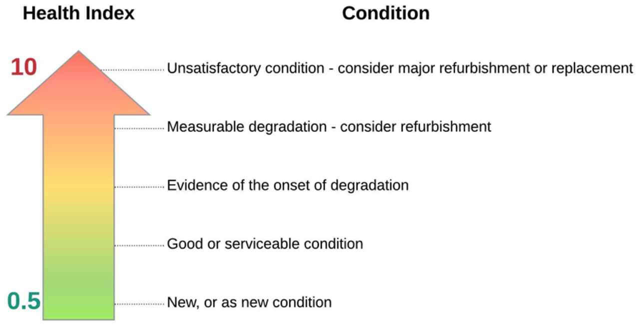

Figure 2 *Concept of Health Indices*

CONSEQUENCES OF FAILURE AND RISK

When an asset fails, there will be an associated impact resulting from that failure referred to as Consequences of Failure (CoF). CBRM monetises the CoF, specified in real terms in the current year. Combining the PoF and the CoF allows quantification of the monetised risk associated with the age and condition of each asset. These yearly risk cashflows allow asset managers to perform cost benefit analysis to justify and prioritise the operating and capital expenditures required to manage the assets under their control. It is important to recognise that these risk cashflows are a real cost to the business over time.

So, in the case of our tested cables, the analysis can inform decisions on the benefit and timing of any proposed works e.g. replace a joint, repair sheath damage, overlay a section or full replacement of the asset and give management confidence the works are necessary and cost effective.

BEYOND PROACTIVE

While preventive maintenance brings many benefits over reactive maintenance and moves a step further on from a proactive approach, it is essentially inefficient, with the risk of personnel becoming 'busy fools' through arduous maintenance schedules. Stating the obvious, maintaining a safe, uninterrupted power supply is the critical priority. When the focus is purely on preventive maintenance, the reliance on carrying out regular checks and maintenance can lose sight of that goal. Activity is focused on scheduled, calendar-based inspections that may be neither necessary nor timely. The application of the CBRM process and development of the ageing curves and risk profiles allows sensible decisions to be made on the frequency of inspection and intrusive testing.

Installation of permanent sensors and online monitoring of partial discharge for critical cables moves us further up the maintenance hierarchy towards predictive, at least for the most critical condition factor for cables – the measurement of partial discharge. Continuous online monitoring has the effect of lowering risk by reducing the probability of disruptive or catastrophic failure and providing time to intervene in a considered and proactive manner.

SUMMARY

Managing ageing critical cable assets is something that doesn't need to be based on chance and age. Application of good condition assessment techniques based on root causes of failure, coupled with proven business processes for effective management of electrical assets allow good decisions to be made. Asset Managers should adapt their approach to critical cable assets, as they approach their end of life. Using modelling tools and established methodologies that produce actionable information from data, enables the efficient allocation of labour and capital resources whilst managing the risk of a failure or outage. These systems can inform decisions around when a cable will need to be subjected to offline testing or fitted with permanent monitoring. This approach allows a steady transition towards predictive maintenance, as the asset ages and its condition deteriorates. Monetised risk is a quantification of the real cost to the business of doing nothing, or suboptimal management of assets. T&D

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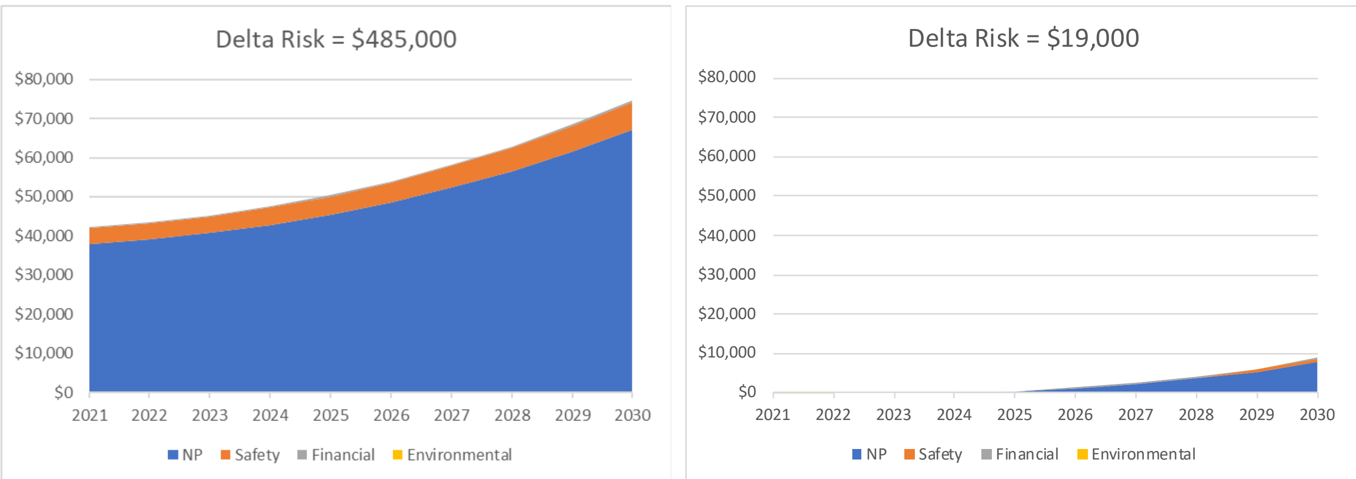

Figure 3 *Increasing risk without intervention and with targeted intervention*