Unlocking Insights: Benchmarking and Lifecycle Risk Analysis of HV Cables

With the recent uptake in high voltage electrical network construction seen across Australia, benchmarking and long-term analysis of HV cables is more critical than ever. Asset owners are looking to forecast and trend their HV cables into the future in order to develop efficient long-term maintenance and intervention plans.

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Due to this, it is more crucial than ever to gain effective condition monitoring data from day one. Starting with diagnostic commissioning tests.

FAILURE MODE ANALYSIS: A CRITICAL STEP IN HV CABLE TESTING

The first step when determining any HV testing programme is to understand the potential failure modes. For HV Cables there are multiple failure modes that can occur at different stages of the asset life cycle. Table 1 below shows a breakdown of common failure modes for both PILC and XLPE cable.

CABLE TYPE	FAILURE MODE	CAUSE	LIFE CYCLE STAGE
PILC	Insulation Deterioration	• Partial Discharge • Workmanship	Installation Operation
	Thermal Runaway	• Local heating • Mutual heating from adjacent cables • High thermal resistivity back-fill • Overloading • Incorrect rating	Planning Installation Operation
	Moisture Ingress	• Outer Sheath Damage	Installation Operation
XLPE	Insulation Deterioration	• Natural Aging mainly due to cyclic thermal • Mechanical Aggression • Manufacturing defects	Installation Operation Manufacturing
	Water Treeing	• Moisture Ingress • Outer Sheath Damage • Lack of water Barrier • Outer Sheath Corrosion • Faulty Joints	Manufacturing Installation Operation
	Electrical Treeing	• Insulation defect • Partial Discharge • Thermal Aging	Manufacturing Installation Operation
	Outer Metallic Sheath Arcing	• Corrosion due to sheath damage	Operation
	Thermal Runaway	• Local heating • Mutual heating from adjacent cables • High thermal resistivity back-fill • Overloading • Incorrect rating	Planning Operation

Table 1 *Cable type and Common Failure Modes*

As shown the three main stages of the HV cable lifecycle where defects can be introduced are;

1. Manufacturing
2. Commissioning
3. Operation

A study in 2024 for the IEEE electrical safety workshops showed the breakdown of HV cable failures and the root causes. Higinbotham found that the root cause of 57% of the HV failures that were investigated had workmanship defects as their root cause, with manufacturing defects making up 16% (9% in cables, 7% in cable accessories). The full breakdown is shown below;

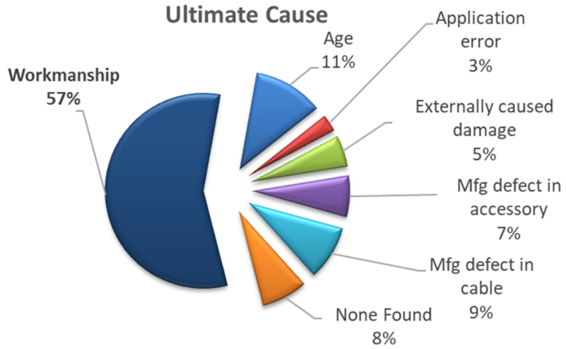

Figure 1 *Ultimate cause of HV Cable Failures*

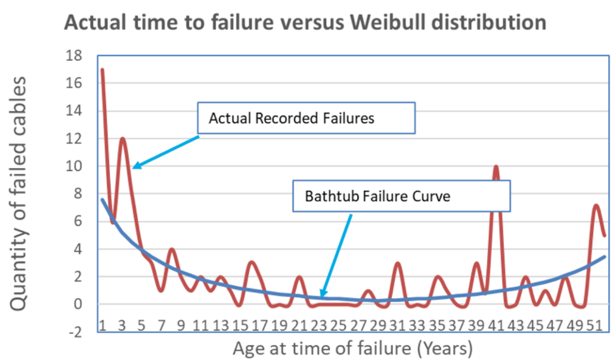

Figure 2 *Age of failures over cable life cycle*

Due to this, it is important to consider that the majority of defects on HV cables are likely to be introduced before or during the commissioning stages. Therefore, it is necessary to design commissioning testing plans that will identify these as early into their operational life as possible.

It is also important to understand that not all defects caused during the manufacturing or commissioning stages will lead to immediate failure, with many defects causing a slow deterioration of the asset, leading to failure over many years.

COMMISSIONING BENCHMARK TESTING: GAIN FULL INSIGHTS INTO YOUR CABLE HEALTH

Commissioning testing traditionally involves performing withstand style acceptance tests that have pass/fail results. Generally, these tests are defined, allowing for easy standardisation across the industry. The IEEE 400.2 – 2023 defines acceptance tests for HV cables as "A field test made after cable system installation, including terminations and joints, but before the cable system is placed in normal service". The industry standard for withstand acceptance testing to perform a VLF test under IEEE 400.2.-2013 guidelines, traditionally up to 3.0U_0.

While withstand testing works well as an initial pass/fail test to determine initial safety and network reliability, it does not offer any diagnostic or trendable data. Withstand testing is primarily used to detect issues in the infant mortality section of the asset lifecycle bathtub curve and has the potential to miss defects that cause slow degradation of the cable system. These types of defects require more diagnostic information to identify.

Due to this, EA Technology has adopted the approach of performing full benchmark testing during any commissioning of HV cables. These involve a test suite including:

1. VLF Withstand - IEEE 400.2-2013
2. VLF Tan Delta - IEEE 400.2-2013
3. VLF Partial Discharge - IEC 60270-3 / IEEE Std 400.3

There is also the opportunity to perform additional offline testing such as Line Impedance Resonance Analysis (LIRA), while the HV cables are offline. EA Technology also recommend and perform online partial discharge testing immediately after energisation. The benefit of immediate online testing is to provide test coverage for the components that were not tested during offline testing, such as terminations and connections.

By performing this suite of tests, it gives the highest potential confidence that all defects along a HV cable run will be identified. This will allow for immediate rectification of any critical issues. It also gives low-level defects that do not need immediate rectification sufficient data to allow for long term trending.

The key benefit of running PD, Tan Delta and LIRA during the commissioning test is the additional diagnostic data which provides asset engineers a baseline to compare regular routine testing. This gives confidence in the long-term trending of data and network health.

FORECAST NETWORK RISK: PROACTIVE RISK MANAGEMENT FOR HV CABLES

Once a benchmark of new assets has been performed, long term planning and risk management can come into play. With the applicable data such as cable type and manufacturer, repeat condition monitoring testing (online and offline), network parameters and other historic data, it is possible to forecast long term health and degradation of the HV cables along their life cycle. Doing this type of analysis allows asset owners to make informed decisions on the expected life of their assets. This can be used to create maintenance and intervention plans based on the current health of the HV cables.

OPTIMISE THE LIFESPAN OF YOUR CABLE ASSETS THROUGH BENCHMARKING

Asset managers are looking to optimise the lifespan of their networks. To do this, acquiring high quality condition data from day one is crucial. For HV cables in particular, EA Technology recommends implementing diagnostic PD, Tan Delta testing and LIRA into any commissioning testing program. This will provide an in-depth benchmark for all future regular condition monitoring tests and allow asset health and risk models to effectively predict asset life. These models can then be used to deploy an effective maintenance schedule. T&D

References:

- *Bill Higinbotham, IEEE Electrical Safety, Technology, Maintenance & Safety (ESTMP) Workshop, Calgary, March 2024*

Contact EA Technology for more information
www.eatechnology.com.au
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www.hvds.co.nz if in New Zealand