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SAIEE | THE OFFICIAL PUBLICATION OF THE SOUTH AFRICAN INSTITUTE OF ELECTRICAL ENGINEERS | OCTOBER 2022

FEATURING
CABLES


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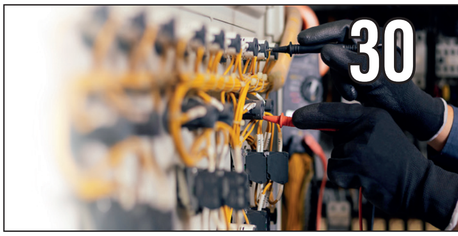

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ISSN: 1991-0452

Dear **watt**now reader,

The Department of Trade, Industry and Competition (DTIC) has gazetted its draft policy proposals to regulate and restrict scrap metal trade in South Africa for public comment.

The draft policy changes are a direct outcome of president Ramaphosa's 2022 State of the Nation Address, where he promised to tackle growing instances of criminality in the scrap metal value chain – particularly with copper theft and other metals stolen from public infrastructure.

Our first feature article, "Copper theft epidemic", discusses how Electrical power utilities' networks have virtually been crippled by the current copper theft epidemic in South Africa. Supply reliability has also been badly affected by numerous unplanned power outages relating to the continuous theft of cables. Read it on page 20.

The paper "The Evolution of Medium Voltage Power Cables and Accessories up to 36kV" covers the evolution of medium voltage (MV) power cables over the last century. It considers some pros and cons of all the different insulation materials used for MV power cables. In South Africa, most Utilities still install three-core Paper Insulated Lead covered (PILC) and consider three-core Cross-Linked Polyethylene (XLPE) insulated cables. No Utilities install three-core Ethylene Propylene Rubber (EPR) insulated cables, although these are extensively used in the mining industries. Read it on page 30.

I want to take this opportunity to thank all the contributors, especially SAIEE Senior Member Patrick O'Halloran for their valuable contribution to this issue. Without their assistance, you, my reader, would'nt have had this 76 page issue. Thank you, Patrick - you rock!

The November issue features Automation, and the deadline is 17 October. Please email any articles or news to minx@saiee.org.za.

Herewith the October issue; enjoy the read!

Minx

Water Security Driven by IR 4.0

Virtual Symposium

25 – 27 Oct 2022 // 10 AM – 13 PM

The University of Johannesburg, the South African Institute of Electrical Engineers, and the Water Research Commission of South Africa invites stakeholders to a strategic conversation on Water Security as Driven by IR4.0.

The 4th industrial revolution attempts to reset our thinking concerning water security. "We stand on the brink of a technological revolution that will fundamentally alter how we live, work, and relate to one another" [WEF]. The traditional approach to water security would depend on the public sector to build more capacity to collect, store, process and distribute rainfall in response to increasing demand. The new thinking for water security is to build new capacity in open and transparent bilateral and competitive markets that is big data-driven. The goal is for all resources to convert water flows to cash flows. Based on the Harvard case study approach, the lessons of the Southern African Power Pool (est., 1995) and the Joburg Fresh Produce Market (est., 1870) are transferred to the water sector as in "big data, markets and cash flows". It is envisaged that a bullish, liquid, transparent and efficient market will attract capital and operational investments that will enhance cross-border bulk freshwater transfers, promote desalination of coastal seawater, and promote the processing and recycling of used and sanitation water. The result will be enhanced financial sustainability and cash flows of national water boards and municipal water and sanitation services. Customers will continuously enjoy quality specified water, sustainably with resilience.

Day 1: Tuesday 25th October 2022
Time: 10:00 to 13:00

Theme 1: Towards the Establishment of the Southern African Water Pool

Chairman: Mr. Francis Masawi

REGISTER

Day 2: Wednesday 26th October 2022
Time: 10:00 to 13:00

Theme 2: Towards the Establishment of the Municipal Fresh Water Market

Chairman: Dr. George Tsibani

REGISTER

Day 3: Thursday 27th October 2022
Time: 10:00 to 13:00

Theme 3: Towards the Establishment of Community-owned Farms for Nutritional Security

Chairman: Prof Michael Rudolph

REGISTER

MEET OUR HOSTS

Francis **Masawi**
Cross Border Water Transfers

George **Tsibani**
Municipal Environment

Michael **Rudolph**
Water, Energy, Food Nexus

INDUSTRY AFFAIRS

SAIEE President's Invitational Lecture 2022

From left: Leanetse Matutoane (SAIEE CEO), Dr Angus Hay (SAIEE Past President), Prince Moyo (SAIEE President), Charles Molapisi (MTN CEO) and Prof Pitshou Bokoro (UJ).

From left: Pascal Motsoasele (SAIEE Senior VP), with members of the CGC, Tshego Cornelius, Maandla Maratumbu & Kgomotso Sethlapelo.

Members from UJ Student Chapter in attendance with Gerda Geyer (SAIEE) and Thokozani Mtshali (UJ) in the background.

A future Engineer!

The University of Johannesburg hosted the 42nd SAIEE President's annual invitational lecture as a hybrid event. This year, we hosted MTN Chief Executive Officer Charles Molapisi.

Mr Molapisi was appointed MTN CEO on the 1st of January, 2022. He oversees the entire SA OPCO, with 16 Executive members reporting to him.

Charles joined MTN in 2009 and has held various senior management positions within the company, including that of CIO for MTN Nigeria and CEO of MTN Zambia. He worked for Telkom SA and Liberty Life before joining MTN. Charles was voted "2018 CEO of the Year" across all twenty-one operating companies, and MTN Zambia was voted "The Best Operating Company for 2018" under his leadership.

During the AfricaCOM 2019 Awards Ceremony, Charles received the CXO of the Year 2019 award.

He holds a master's degree in Business Leadership from the University of South Africa, a post-graduate Diploma in Business Management from the University of KwaZulu-Natal and a Bachelor of Commerce Degree from the University of the Witwatersrand.

Additionally, he has completed courses on strategy and talent with Harvard Business School, Columbia Business School, and the Institute for Management Development in Switzerland.

His talk, "Value creation through analytics – MTN case study", presented that MTN has one of the largest information assets, processing 26 billion daily records into their data lake. In line with the MTN Ambition 2025 strategy, the company is exploring data assets as a data-driven organisation but also to create value through the creation of new revenue streams as well as serve and anticipate customer needs.

As part of the journey, Mr Molapisi shared how the organisation has aligned its business strategy and data strategy to leverage artificial intelligence through machine learning models to predict several business scenarios, including customer behaviour prediction, data monetisation, and fraud prevention. wn

SAIEE 71st Bernard Price Memorial Lecture

The SAIEE, in conjunction with Wits University, hosted the 71st Bernard Price Memorial Lecture via webinar on the 22nd of September. Our speaker, Prof Stuart Russell, presented "Provably Beneficial Artificial Intelligence".

Stuart Russell is a Professor of Computer Science at the University of California at Berkeley, holder of the Smith-Zadeh Chair in Engineering, and Director of the Center for Human-Compatible AI and the Kavli Center for Ethics, Science, and the Public. He is a recipient of the IJCAI Computers and Thought Award and Research Excellence Award and held the Chaire Blaise Pascal in Paris.

In 2021 Professor Russell received the OBE from Her Majesty Queen Elizabeth and gave the Reith Lectures. He is an Honorary Fellow of Wadham College, Oxford, an Andrew Carnegie Fellow, and a Fellow of the American Association for Artificial Intelligence, the Association for Computing Machinery, and the American Association for the Advancement of Science. His research covers a wide range of topics in artificial intelligence, with a current emphasis on the long-term future of artificial intelligence and its relation to humanity.

His book "Artificial Intelligence: A Modern Approach" (with Peter Norvig) is the standard text in AI, used in 1500 universities in 135 countries. He has developed a new global seismic monitoring system for the nuclear-test-ban treaty and is currently working to ban lethal autonomous weapons.

This informative talk discussed how AI advances in capabilities and moves into the real world. Its potential to benefit humanity seems limitless. Yet we see serious problems, including racial and gender bias, manipulation by social media, and an arms race in lethal autonomous weapons.

View the recording of this webinar here.

Download the 71st BP Booklet here. wn

Prof Stuart Russell
71st BP Memorial Lecturer

The objective of this event was to raise the Max Clark Museum profile and raise funds for the SAIEE Historical Section activities. Around 300 people attended the event during the day.

The site is under the auspices of the South African Radio Astronomical Society (SARAO). This public event included multiple activities around the site's heritage, including the 1910 Telescope, which was ably hosted by the Astronomical Society of South Africa, along with many related activities for members of the public to enjoy.
Visitors were entertained with talks at the Innes Dome, the Papadopoulos and Jacobs Domes. Children enjoyed Astronomy-related activities, and the Herbert Baker Library was open for viewing precious books and other astronomically significant items on display, including telescope-making demonstrations. Solar telescopes were available for viewing throughout the day, and sky viewing at the three domes was available in the evening from 7 pm.

The Max Clarke Museum now holds a good sample of the legacy and history of South African electrical engineering innovation. This has been carefully curated for our current and future generations to learn, enjoy and appreciate the significant contribution to society of some of the engineering giants of the past.

Many of the benefits we enjoy today will be better appreciated when you see the journey of technology and innovation towards the convenience and safety we currently enjoy and take for granted.

Other stakeholders, including the Urania Village community and the Johannesburg Children's Home, founded in 1892, the oldest charitable institution in the city, also participated along with the Antique Wireless Association of South Africa (AWASA). The latter was on hand to demonstrate the international communication capabilities of our very own 'radio shack,' the ZS6IEE museum station at the museum.

The vintage car club was also invited, and some attended to bring style and colour to the campus on the day.

This was the first time we have collaborated across a few organisations, and if we can keep the relationships going, we may be able to make this an annual event. A huge shout-out to:

- South African Antique Wireless Association (SAAWA)
- The Astronomical Society of South Africa (ASSA) Johannesburg Branch,
- The South African Radio Astronomy Observatory (SARAO)
- The Johannesburg Children's Home (JCH)

We engaged the services of a professional health and safety practitioner to get the requisite city operational compliances done, and they had a fully equipped ambulance and paramedics on site all day should any member of the public require it.

SAIEE Historical Section paid homage to South African Heritage Day

A public open day was held on Heritage Day, Saturday, 24 September 2022, at the SAIEE Museum of electrical engineering in Observatory (Johannesburg) – The Max Clark Museum at the site of the Johannesburg Observatory.

We had several sponsors for the day who donated wonderful prizes that visitors could win. These prizes were used to drive interest in the Max Clarke Museum and heritage assets at the site by requiring the entrants to the tag-a-photo on their respective social media profiles to be eligible to win one of the great prizes on offer.

The relationships we have made with SARAO and ASSA will bode well for the sustainability of the whole site if we can build on the collaboration in the future.

Thanks to the Historical Section committee and the wider Heritage Day event organising committee for their support. Check out the next page for fun photos. wn

Thank you to our valued sponsors; they are:

SPONSOR	PRIZE	VALUE
Kieviets Kroon	A Cultivar Package – getaway for two including Dinner, Bed & Breakfast, a Lunch and 2-hour Spa treatments for two at the magnificent Kievits Kroon Gauteng wine estate	R 7000
Saxon	Experience the Saxon – the gift of luxury. A Sunday brunch for two in the fabulous Qunu Restaurant.	R1 500
Emperors Palace	A Dinner, Bed & Breakfast stay over for two.	R3 000
Emperors Palace	A show at the Barnyard theatre with dinner for two.	R1 600
Supersonic	Hamper of Chocolates	R1 000
Smoke Daddy's Restaurant	Meal voucher at Smoke Daddy's Restaurant in Cedar Square in Fourways	R400

MyTechie - making mobile simple.

Visitors taking an early morning break!

From left: Gerda Geyer (SAIEE), André Hoffmann (Chairman SAIEE Historical Section) and Janine Meyer-Hoffmann (MyTechie).

Members of the SAIEE Council.

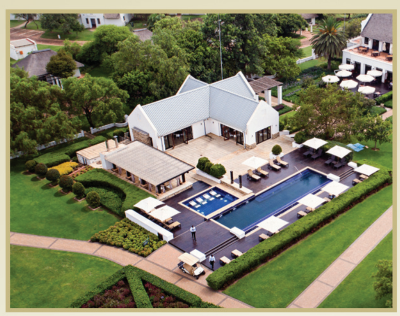
Stan Bridgens (SAIEE Past President) with his grand daughters.

Visitors in the Max Clarke Museum.

Johannesburg Children's Home.

Boerewors station - manned by Minx Avrabos.

Braaimaster - Andreas Avrabos.



Greek start-ups find it extremely difficult to recruit tech talents

After conducting a survey showing that Greek start-ups find it extremely difficult to recruit the talent they need, the entrepreneurial ecosystem Starttech Ventures has launched a global competition. The aim is to attract skilled workers to Greek start-ups. Those with the required skills can win a job at a start-up in Athens.

"The report shows that Greek start-ups are restricted in their growth due to difficulties finding the right people to fill their vacant positions. That is why we are launching a global competition to win a job and free legal and administrative support in obtaining an EU visa," says Dimitris Tsingos, founder of Starttech Ventures.

The survey shows that 70 per cent of the companies expect to employ more than ten people during the coming year, and 30 per cent expect to hire more than five people. Half of the companies rate the difficulty of finding suitable applicants an eight or more on a scale of one to ten. Moreover, 60 per cent have chosen not to fill open positions due to a lack of qualified applicants.

"This means there is a real opportunity for skilled workers to relocate to Greece and work for Greek start-ups," says Dimitris Tsingos.

The report shows that there is a need for many kinds of software engineers. The most difficult-to-find and sought-after engineers are front-end engineers, followed by full-stack engineers. But other types of software engineers are also needed and hard to find.

The results align with previous studies and interviews that Starttech Ventures conducted with four start-up founders who participated in the survey. An essential requirement is that the skilled workers have a few years of experience within the field and can communicate in English.

"You do not need to learn Greek, even though you are welcome to do so, and I know that those hired for these positions will find that working in Athens has many things to offer.

Those who have already taken the step attest to the warm welcome and inclusiveness they have experienced at Greek start-ups," says Dimitris Tsingos.

Enter the competition and register for the seminar here.

Seminar: 5 October 2022 online
19h00 - 21h00 CAT. wn

More local focus as Zest WEG launches new motor assembly line

A motor being moved with the jib crane.

A new assembly line for its low voltage (LV) premium efficiency WEG IE3 electric motors is yet another advance by Zest WEG in sustainability and local economic impact.

Zest WEG CEO Eduardo Werninghaus says the addition of the new facility is an important contribution to local manufacturing capacity in South Africa. It improves flexibility in the company's electric motor supply chain, and ensures prompt delivery times for customers. The line produces WEG W22 IE3 LV motors in various sizes, offering high reliability in all applications.

"As a Level 1 B-BBEE company, our commitment to transformation includes continuous promotion of local manufacture," said Werninghaus. "Our focus on premium efficiency IE3 motors is also significant as it helps drive energy efficiency – a key sustainability goal for mines and other industries."

According to Sindi Mbhalati, Operations Executive at Zest WEG, the assembly line required considerable investment in equipment. This included jib cranes for easier materials handling, an air reticulation system to feed compressed air to the pneumatic tools on the line as well as to the spray booth and packaging equipment, enhancing the efficiency of the production processes and a state-of-the-art test panel.

As with any world class manufacturing and assembly operation, record keeping is an important cornerstone. The panel is therefore synchronised with the advanced WEG manufacturing facilities in Brazil, for complete and accurate record tracking and evaluation. Each motor undergoes routine testing which includes winding resistance tests, accessories tests, insulation resistance tests and no-load tests.

Elaborating on this, Mbhalati says that the panel tests winding resistance per phase with an imbalance test to compare the imbalances between the resistance results, while the accessories resistance test confirms that the accessories installed in the motor are in working order. The panel also tests for insulation resistance which provides the team with data on the motor winding health. A No-Load test is conducted to determine the current that the motor draws at no-load and determines the imbalance of the current drawn between the phases.

"Further ensuring operational efficiency, the line was capacitated with state-of-the-art equipment including a heating and greasing facility as well as rotor assembly C-hooks," says Mbhalati. "In addition and most importantly the assembly line has been engineered to allow multiple shifts to be worked should it become necessary to increase capacity and output. This type of futureproofing to accommodate market demands is in line with Zest WEG's commitment to its customers."

The facility has created several new jobs within the business. Most of the new employees are dedicated to the W22 motor assembly line, while some others are shared with the company's various production lines.

WEG W22 IE3 LV motors in various sizes after being painted.

"To ensure the highest quality standards in the assembly process, Zest WEG put our new staff through extensive technical and process training relevant to the new line," she says. "This included in-depth product and component training, as well as the operation of the specialised test panel."

Among the components Zest WEG procures for assembly are rotors, stators and bearings. These are produced mainly at WEG's extensive manufacturing facilities in Brazil, under stringent quality conditions. These are thoroughly tested before shipment to Zest WEG. Smaller components are sourced from local suppliers wherever possible, in line with the company's supply chain development policy.

"Governed by our ISO 9001 quality certification, the new assembly line is closely monitored by our dedicated quality department," says Mbhalati. "All motors are tested and quality inspected prior to dispatch to customers."

She highlights that Zest WEG's quality control personnel are rigorously trained to assess motors during the build process as well as final quality inspection and testing. All aspects are aligned with WEG quality procedures, ensuring world class standards are maintained across all operating parameters.

Werninghaus highlights that mines are always looking for opportunities to promote local supply chains in line with the Mining Charter, and also to reduce their energy consumption and carbon footprint. With some 65% of industrial energy worldwide consumed by motors, WEG's global corporate strategy aims to use resources responsibly and to create fewer emissions.

Werninghaus recently assumed the role of CEO at Zest WEG, bringing 15 years of experience in the WEG group in Brazil and the US. This includes five years as part of establishing WEG's wind turbine capability. His two years in the US included an important role as vice-chair of the National Electrical Manufacturers Association (NEMA), which develops standards for electric motor designs, frame sizes, enclosures and configurations.

As part of the Brazil-based WEG group, a leading global player in electric motors, Zest WEG is one of a wide network of the group's manufacturing facilities. He emphasises that this ensures the highest level of quality and engineering locally.

"We apply WEG's stringent quality control protocols to new LV motor assembly line here in South Africa," he says. "All the motors produced from our local facility undergo the same standard of testing and analysis as any of our factories across the world."

Zest WEG's extensive manufacturing base in South Africa means that it achieves almost 90% local content capability for its transformers and more than 70% local content capability for other products such as E-houses and panels. These products form part of the company's wide range of solutions, including energy generation, electrical infrastructure, automation and generator sets. wn

Astron Energy
- looking after the future of lubricants

At Astron Energy, we don't accept the status quo, particularly when challenges are industry-wide and costly. We sat down with David MacIntyre, Finished Lubricants Technical Manager at Astron Energy to find out which big innovation solutions have been developed for the energy sector.

Q. What is one of the biggest challenges that the energy sector faces given its reliance on equipment like turbines, hydraulic systems and compressors?

A significant challenge the energy sector faces is the build-up of varnish in lubrication systems. Varnish is a sticky residue that leads to system control valve malfunctions, blockages in lubricant galleries and filters, plus increased bearing friction and heat.

Varnish is caused by oil degradation and primarily through oxidation. Oxidation happens naturally in all lubrication systems due to the presence of oxygen. The oxidation process is accelerated by high temperatures. Excessive system heat is one of the most common triggers. Although lubricant manufacturers use antioxidants to inhibit oil oxidation and extend lubricant life, these antioxidants are gradually used up. For quite some time as the oil gradually degrades and impurities begin forming, these impurities remain dissolved in the oil and don't cause any harm. As more and more accumulate, they begin to condense and polymerise together forming insoluble, suspended submicron particles. The problem is that these deposits aren't collecting at the bottom of tanks but are moving throughout the system instead. Ultimately, these particles become electrically attracted to metal surfaces. When they start sticking to those surfaces, they become tacky varnish, that blocks up systems. Varnish is a wide-ranging term encompassing various types of deposits in oil systems.

A great explanation on how varnish is formed - "The products of lubricant degradation are called sludge and varnish. These products start in the dissolved form and accumulate until the lubricant reaches its capacity, referred to as the saturation point, forcing any excess to convert into insoluble degradation products. In certain instances, deposits form on machine surfaces at the exact location where the oil has degraded. In other cases, the oil degrades in one location, but the insoluble degradation products are carried elsewhere by the moving fluid forming deposits on surfaces. Over time, some deposits can thermally cure to a tough enamel-like coating." (from article in MachineryLubrication by Jim Fitch, Noria Corporation.)

Q. What is the significance of varnish in the energy sector?

The role of turbine oil under ideal circumstances is to lubricate and cool bearings while protecting the system against rust, corrosion and harmful deposits. Since turbine equipment is normally used in key applications, the reliability of rotating machinery and its lubricant is critical. Over time, varnish seriously impedes these functions causing a range of reliability concerns as mentioned above including, increase component wear, valves seizing and sticking, inefficient heat exchangers and overheating of journal bearings, as well as reduce lubricant, filter and seal life.

This makes the process inefficient and reduces the lifespan of components and the lubricant. When you consider that a single turbine oil tank could hold 60,000 litres of oil, having to potentially dump this oil prematurely comes at an extremely high cost.

Q. How can businesses determine if they have varnish in their systems?

Varnish can be very difficult to detect. Most operator have an oil analysis programme to check for contaminants in the oil, but standard oil analysis test may not indicate varnish even if it is present. However, incorporating oil analysis tests such as the RULER test - which monitors the depletion of antioxidants and Membrane Patch Colorimetry (MPC) - which measures the creation of varnish-forming oil degradation products, will measure the precursors of varnish.

The combination of a quality oil and a fit for purpose oil analysis program will payback in the form of increased oil life and greater plant reliability.

Q. How has varnish traditionally been treated?

A common traditional method of varnish removal is chemical cleaning. Chemical cleaning requires the system is "shut down" and chemicals are used to flush the system. The chemicals soften the varnish which is then flushed and captured through fine filters. This process can be time consuming. The system then needs to be flushed again to remove all traces of chemical and contaminants that may contaminate the new charge of lubricating oil.
The requirement that the system be shut down is problematic and alternative solutions that can alleviate this are desirable.

Q. Astron Energy is committed to finding innovative solutions for client challenges. What is the solution for varnish?

Chevron has developed a product called VARTECH™ that has completely revolutionised how businesses can combat the challenges presented by varnish. VARTECH™ comes in two products, VARTECH™ ISC (Industrial System Cleaner)- a concentrate deposit cleaning product and GST Advantage RO with VARTECH™ – premium turbine oil with VARTECH™ technology that inhibits varnish formation.

For customers who are nearing a routine maintenance cycle which includes an oil change, the VARTECH™ ISC concentrate can be added directly to the oil in use during operation to clean a system of varnish and sludge deposits before a scheduled oil change. It helps prepare the system for optimum performance of a new, fresh oil charge preferably our Caltex GST Advantage RO with VARTECH™. This significantly reduces downtime.

Thereafter, GST Advantage RO with VARTECH™ will prevent varnish build up from taking place as a matter of course while the equipment is operational. This keeps the entire system running optimally and ensures the full lifecycle of oil. The cost saving benefits are extremely high.

Q. Are future applications for VARTECH™ planned?

Absolutely. Chevron are in the process of testing and developing VARTECH™ for other applications, that also suffer from varnish. Widespread adoption of VARTECH™ will significantly reduce both planned and unplanned equipment shutdowns.

INTRODUCING VARTECH™ TECHNOLOGY

GST Advantage RO is the name of our high-performance industrial gas and steam turbine oil. It is formulated with VARTECH™ Technology and its advanced chemistry helps:

- Improve oxidation stability
- Reduce oil degradation
- Extend oil life by limiting harmful precursors that can lead to varnish formation

VARTECH™ Technology inhibits varnish formation to maintain peak performance, reliability and productivity.

PRODUCT FEATURES:

GST Advantage RO turbine oil has exceptional thermal and oxidative stability. It is suitable for use in gas and steam turbines where extreme temperatures are experienced and require circulation systems with exceptionally high temperature stability.

GST Advantage RO turbine oil combines highly refined group II base stocks and unique additive packages that minimises the formation of deposits in reservoirs, high temperature bearings and other hot areas of the turbine.

APPLICATIONS:

VARTECH™ Technology can be applied to non-geared gas, steam and hydroelectric turbines, including:

- Rotating machinery in gas and steam combined-cycle cogeneration units
- Air compressors, turbo-blowers and centrifugal pumps requiring a rust and oxidation inhibited oil
- Marine reduction gears where R&O oils are specified
- Industrial applications requiring R&O type circulating oils with extended service capability.

A COMPARISON OF VARTECH VERSUS CHEMICAL CLEANERS

VARTECH™	COMPETITIVE CLEANERS
Turbines remain online and productive	Shutdown sometimes required
Varnish micro-particles are gradually removed to avoid overwhelming filters	Large pieces of varnish can break loose and settle in other areas of the system
Compatible with internal equipment components, including seals	Harsh chemicals can damage seals and cause leaks
Demonstrated compatibility with most turbine and compressor oils	Has the potential to lower lubricant flash point causing higher fire and explosion risk
Minimally impacts performance of new oil	May accelerate oil degradation, shorten oil life and cause system corrosion
Compatibility with the in-service oil can allow longer residence time (if needed) for better removal of stubborn, baked-on varnish	Short cleaning cycle doesn't effectively clean
Can temporarily remain in the system causing no operational constraints	Repeated filter plugging and shorter filter life
Efficient cleaning process saves time and money	Shorter equipment life and higher maintenance costs

Copper theft epidemic

– THE TIME TO CHANGE ELECTRICAL CONDUCTORS IS NOW!

Electrical power utilities' networks have virtually been crippled by the current copper theft epidemic in South Africa. The reliability of supply has also been badly affected by numerous unplanned power outages relating from continuous theft of cables.

In addition to these unplanned outages, during loadshedding periods copper thieves are gaining access to electrical power utility substations and network assets and steal copper earthing, cables and transformers.

By Patrick J O'Halloran (SMSAIEE), ARB Global

Electrical power utilities are spending unnecessary CAPEX and OPEX budgets on replacing stolen infrastructure instead of strengthening and maintaining existing electrical networks.

Customers are forced to spend extra money on standby generation for all these outages and these costs unfortunately get passed on to the consumers.

The risk of theft and vandalism is an important consideration in South Africa and needs to be considered when designing the earthing system to ensure the safety of the public and operational staff.

It's safe to say that the current copper theft situation in South Africa is becoming a daily "war" and there appears to be no end in sight.

UNSAFE ELECTRICAL CONDITIONS CREATED DUE TO COPPER THEFT

It should always be remembered that electricity is dangerous and has the potential to kill people. The cost of a life can't be linked to a Rand value and therefore any known unsafe conditions need to be urgently rectified at any cost to prevent any fatal incidents from occurring.

Earthing has two objectives:

a) to provide a means to carry and dissipate electric currents into the ground under normal and fault conditions without exceeding any operating and equipment limits or adversely affecting continuity of supply, and
b) to assure such a degree of human safety, that a person in the vicinity of earthed facilities is not exposed to unsafe step and touch potentials.

An earthing system is a system intended to provide at all times, by means of one or more earth electrodes, a low impedance path for the immediate discharge of electrical energy, without danger, into the ground.

Earthing in any electrical power network is critical to ensure safety to operating staff and public. Once any part of the earthing system is stolen and not replaced the electrical power network becomes extremely unsafe. Copper thieves only need to remove one small

PRETORIA NEWS

FRIDAY APRIL 21 2017

WAR ON CITY CABLE THEFT

PRINTED BY CAXTON PRINTERS, 16 WRIGHT STREET, INDUSTRIA

Examples of how serious copper theft is in South Africa

piece of copper and the entire electrical network becomes unsafe.

An example of the above is when copper thieves steal the neutral tail from the star point of the power transformers. This causes serious over voltages on the live phases and on the important neutral phase which should be clamped to zero volts at all times. This in return renders the system unearthed and during an earth fault condition like a cable fault, the high earth fault currents can't return to the star point of the transformer and then the associated earth fault protection doesn't trip and dangerous fault currents stay on the power network causing damage and unsafe step and touch potentials to exist.

When a three-phase electrical power network operates in an unearthed condition many customers experience voltage fluctuations which damage equipment and shocks from house taps as these alternatively earthed appliance have now have a raised voltage potential. Unfortunately, many fatal incidents have occurred because this problem was not rectified intime.

Where alternative earthing conductors to copper are installed for either the

earth electrode or bonding leads the galvanic corrosion between the different metals needs to be carefully considered. Galvanic corrosion is an electrochemical process whereby one metal corrodes in preference to another metal that it is in contact with through an electrolyte. Galvanic corrosion occurs when two dissimilar metals are immersed in a conductive solution and are electrically connected. Galvanic corrosion is also known as bimetallic corrosion.
Lastly, due to the continuous and repeated theft of copper conductors in the electrical networks, many times the repair work is done differently and inadequately which in the future creates long term dangerous problems caused by corrosion of materials.

Examples of theft and vandalism in South Africa.

Interventions applied to try and prevent the theft and vandalism from occurring
These are only some of the many interventions applied currently:

- Use of aluminium instead of copper conductors
- Restraint devices for cables
- Pouring concrete over cables once laid
- Alarm system to detect digging near cables
- Marking the conductors inside cables to try and prove ownership
- Policing of know scrap dealers

Copper is the traditionally preferred conductors for cables and earthing applications. Aluminium and aluminium ally are preferred for overhead lines conductors. Aluminium has become a good substitute for power cables and many utilities has changes already to using only aluminium conductors where possible. Aluminium has a physical size limitation due to cold flow properties and strength (brittleness). Aluminium unfortunately corrodes easily, forms an oxidation layer immediately and lastly has a good scrap value so is now being stolen as well.

Stolen copper conductors.

Copper is currently used for power and control cables smaller than 25mm^2. Alternative low scrap value materials like copper clad steel and stainless steel have successfully been used for earthing systems and copper thieves have rather stolen copper from other installations.

In South Africa there is legislation prohibiting the trade of stolen scrap metals. The trading of stolen copper for cash is not permitted but because positively identifying the stolen copper is a real challenge, this is an endless challenge to police. There is big focus now to stop cash for scrap transactions. Scrap dealers will need to have licences and should only do EFT payments when trading scrap copper. Stolen copper is now being exchange for drugs and not cash and this is a huge problem in our communities.

The percentage of stolen cables and conductors for the use for illegal connections is increasing. This makes theft prevention even more challenging as these cables and conductors are not stolen to be scraped but used. The only way to overcome this challenge is to be able to prove ownership of the recovered cables and conductors, but to date this has virtually been impossible to do.

What next should be considered to try and prevent the above from happening Utility Electrical Engineers are challenged to identify new technical solutions to deter copper theft. Copper theft is a worldwide problem and suitable alternative electrical conductors for cables and earthing conductors do exist.

The current thinking locally and internationally is to use alternative electrical conductors that have acceptable electrical properties:

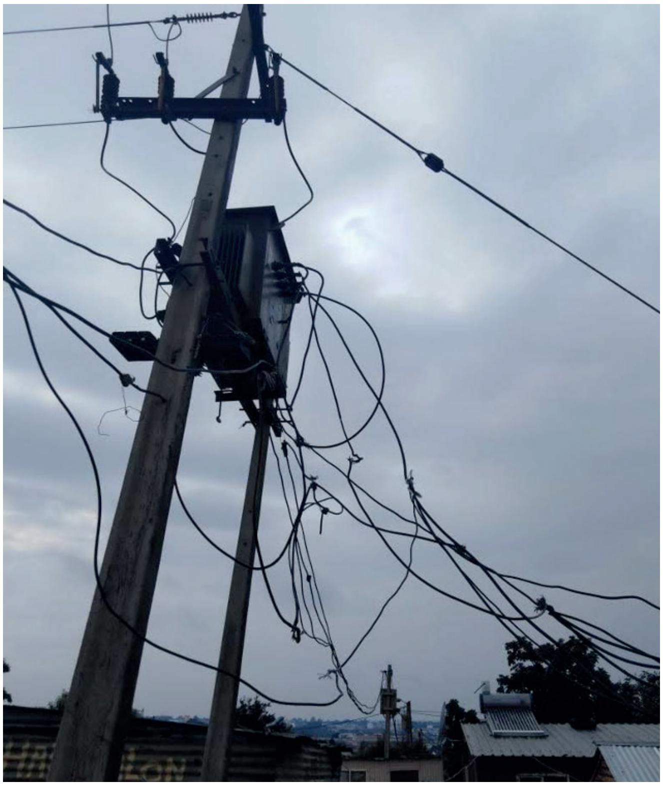
- but have low scrap value,
- will contaminate the copper or aluminium refining batches if recycled together, and
- can be identified as stolen utility conductors unlike copper and aluminum which is used extensively

The American ASTM B01 committee for cable and conductor standards have four different categories for electrical conductors:

- B01.04 Conductors of Copper and Copper Alloys
- B01.05 Conductors of Ferrous Metals
- B01.06 Bi-Metallic Conductors
- B01.07 Conductors of Light Metals

Looking at the above American ASTM cable and conductor categories with regards to alternative electrical conductor, South Africa via the SABS should closely align and adopt more of these proven technologies that already have ASTM standards, in addition to the IEC standards which only allow limited electrical conductor options.

It's good to have compulsory SANS cable standards but these cable standards should cater for alternative electrical conductors that would deter electrical cable and conductor theft across all industries and not only Electrical Power



Examples of illegal connections in South Africa

Utilities that have published NRS industry standards.

The adoption of the IEEE 80 standard for A.C. Substation earthing systems as SANS 725 have given Utility Electrical Engineers different electrical conductors to use instead of only copper conductors.

SANS 725/IEEE 80 is the international accepted earthing guide for safety in A.C. substation grounding and covers the:

a) Safety limits of potential differences that can exist in a substation under fault conditions between points that can be contacted by the human body.
b) Substation grounding practices with special reference to safety, and develop safety criteria for design.
c) Provide a procedure for the design of practical grounding systems, based on these criteria.
d) Develop analytical methods as an aid in the understanding and solution of typical voltage gradient problems.
e) Provide benchmarks cases to compare the results of IEEE Std 80™ equations to commercially available software programs.

SANS 725 can be used to calculate the electrode resistance, earth potential rise (EPR) and step and touch voltage etc. If the proposed earthing grid conductor material is other than copper, SANS 725 will assist the user in calculating the required conductor size, the resistivity of the material selected and maximum allowable temperature based on the connection types affects the sizing of the conductor that will safely carry the fault current for a specified duration.

The NRS utility standards like NRS 102 and NRS 110 have pioneered the early technology changes with regards to alternative earthing and low voltage cables conductor technologies.

Material	Conductivity (%)	T_m ^{a} (□C)	K_f
Copper, annealed soft-drawn	100.0	1083	7.00
Copper, commercial hard-drawn	97.0	1084	7.06
Copper, commercial hard-drawn	97.0	250	11.78
Copper-clad steel wire	40.0	1084	10.45
Copper-clad steel wire	30.0	1084	12.06
Copper-clad steel rod	20.0	1084	14.64
Aluminum EC Grade	61.0	657	12.12
Aluminum 5005 Alloy	53.5	652	12.41
Aluminum 6201 Alloy	52.5	654	12.47
Aluminum-clad steel wire	20.3	657	17.20
Steel 1020	10.8	1510	15.95
Stainless clad steel rod	9.8	1400	14.72
Zinc-coated steel rod	8.6	419	28.96
Stainless steel 304	2.4	1400	30.05

Table 1 : Earthing materials covered in SANS 725/IEEE 80

NRS 102: This specification recommends theft deterrent materials, including conductors and connections that may be used in all industrial and utility electrical applications for the purpose of earthing.

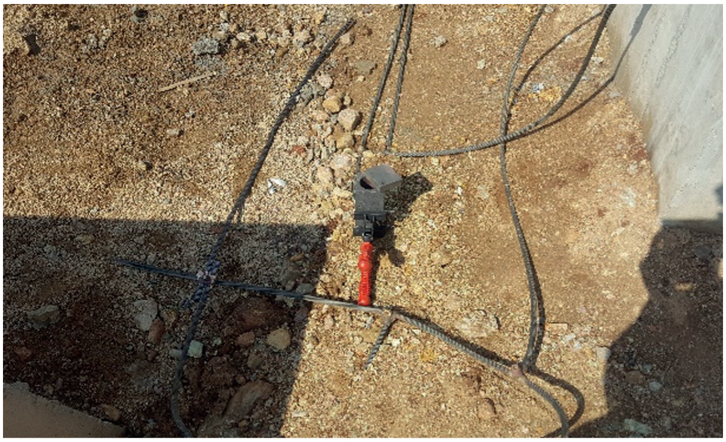
CONNECTION TYPE	MAXIMUM ALLOWABLE TEMPERATURE °C
Bolted	250
Crimped	450
Brazed	600
Exothermic	1084

Table 2: Connection types and maximium temperatures covered in NRS 102

NRS 110: This specification is a guideline and specifies requirements for utility low voltage power and control cables with copper clad aluminium alloy (CCAA) conductors for use in theft deterrent low voltage cable constructions up to 600/1000 V AC.

NRS 110 covers solid and stranded circular or shaped conductors specified for use in insulated electric power and control cables. These cables are intended for use only up to the point of supply as defined in SANS 10142-1.

This guideline is intended to establish the requirements for research and development of alternate theft deterrent cable types below, which are not covered in the current national standards. All aluminium alloy conductors without copper cladding will be considered for future inclusion. This specification is not intended to be used for conductors intended for bare earthing applications on cable systems (refer to NRS 102 for earthing applications).



Examples of copper clad steel (CCS) being installed for substation earth grids in accordance with NRS 102.

Specific cable types covered in this specification include the following:

- Single core and multicore control cables with solid class 1 conductors of maximum size 4 mm2, compliant with either SANS 1507-2, 1507-3, SANS 1507-4 or SANS 1507-5, (conductors compliant with the requirements of this specification);
- Single core and multicore power cables with stranded class 2 circular conductors in sizes 2.5 mm2 to 240 mm2, compliant with either SANS 1507-2, SANS 1507-3, SANS 1507-4 or SANS 1507-5 (conductors compliant with the requirements of this specification);
- Multicore power cables with 2 or more stranded class 2 shaped conductors in sizes 16 mm2 to 240 mm2, compliant with either SANS 1507-3, SANS 1507-4 or SANS 1507-5 (conductors compliant with the requirements of this specification).
- Concentric service cables in accordance with SANS 1507-6 with span lengths;
- Flexible single-core class 5 cables in accordance with SANS 1507-3 or 1507-4 for minisub applications; and
- Aerial bundled conductors in accordance with SANS 1418.

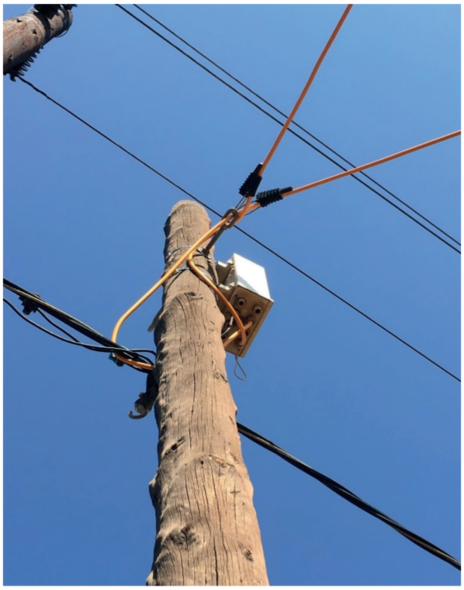
Cable manufactures in South Africa are well setup to make electrical cables and conductors conventional with copper and aluminium conductors, but they need to now develop new utility power cables that use proven bimetallic and aluminium alloy conductors that will go a long way in fighting the current battle against copper theft in South Africa.

Example of low voltage utility cables with copper clad aluminium ally (CCAA) conductors in accordance with NRS 110

CONCLUSION

A solution to stop the current copper theft epidemic is not going to happen overnight. It is a journey that has started some time back. The need for new electrical power cable that are less attractive to copper thieves because they don't have scrap value and provide uniqueness so that ownership can be proven are now possible.

The time to change electrical conductors in South Africa is now! wn



Examples of low voltage utility cables with unique colour sheaths to allow quick identification of alternative conductor cable designs.

Don't Upsize.
Upgrade Your Grounding Conductors and Save Money!

Wow, a $25,000 factor of safety! Did you know that 3 out of 4 considerations for selecting a grounding conductor are NOT electrical?!

By Jeffrey T. Jordan, P.Eng., MBA

IEEE Standard 80, Section 11.1, provides basic requirements for grounding selection. Of course, the first requirement:

(a) is the ability to carry the maximum fault current of the substation. But, the rest are related to maintaining strength over the expected service life, including
(b) the ability to resist mechanical deterioration,
(c) to be mechanically reliable, and
(d) be able to handle physical abuse.

So why do engineers upsize? Because the grounding conductor only works if it is still there.

The reliability of a grounding conductor is measured in terms of its ability to resist the effects of weather and human intervention. Reliability is the name we give to a conductor's total probability of success over its service life. Reliability is written in math as R(t). We measure R(t) by estimating the inverse, which is the probability of failure, or Q(t). The probability of failure of a grounding conductor considers theft, corrosion, loosening, and breaking over an expected 30-year lifecycle.

A little-known secret is that every good (conservative) engineer adds a factor of safety where they are unsure, especially when the probability is concerned. It's like insurance to ensure the design won't fail in this real-life game of chance.

For substation grounding, this is usually applied to the break load strength of copper. And it is common practice to size up.

FOR EXAMPLE,

The design software says a 2/0 copper conductor is needed to meet the electrical requirements. A conservative design engineer will likely select a 4/0 just to be safe.

But that 2x factor of safety—jumping from a 2/0 copper (133 kcmil) to a 4/0 copper (213 kcmil) grounding conductor—can get really expensive. A copper 2/0 conductor is around $2.00/ft today, but a 4/0 is around $3.25/ft. Upsizing this way adds more than a dollar to the price. And a common distribution substation might use 20,000 ft in the ground grid. In this example, that's a $25,000 adder per substation.

REAL MONEY!

The following figure shows the nominal break load strengths for 2/0 and 4/0 copper in grey. The difference between the orange bars on the graph represents the cost of upsizing. In contrast, the comparative costs of a typical substation ground grid application for 2/0 and 4/0 copper are shown in orange.

BETTER THAN COPPER

In 2021, Copperweld reinvented copper-clad steel, CCS, introducing the ArcAngel line of CCS grounding conductors and supporting connectors from major electric utility suppliers.

After all our testing and development, Copperweld discovered that copper clad steel (CCS) is properly optimised for short circuit performance to replace copper, with added flexibility for linemen in the field and tin plating for corrosion

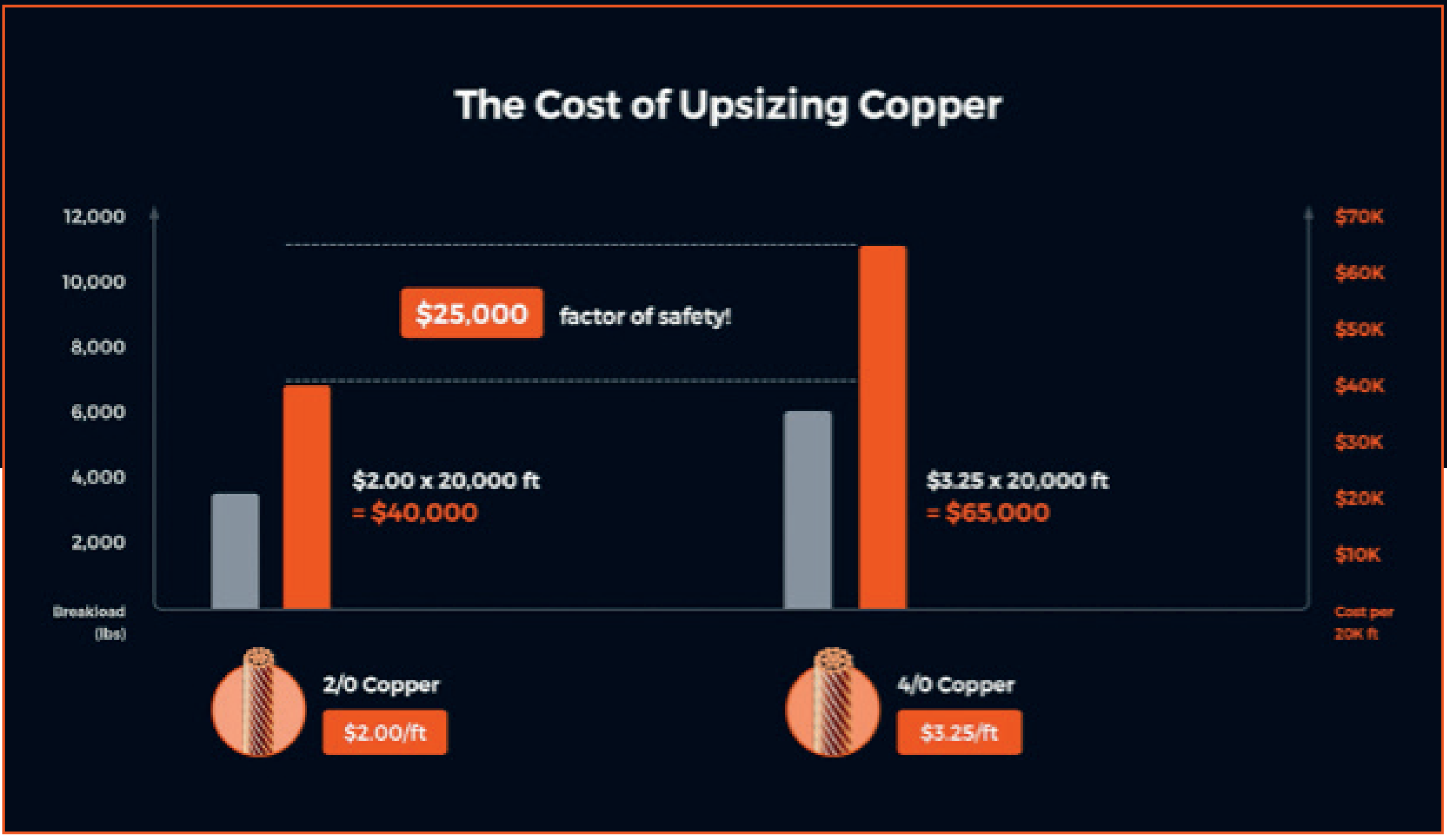


Figure 1: The cost of upsizing copper

Figure 2: Technical comparison between equivalent conductor sizes

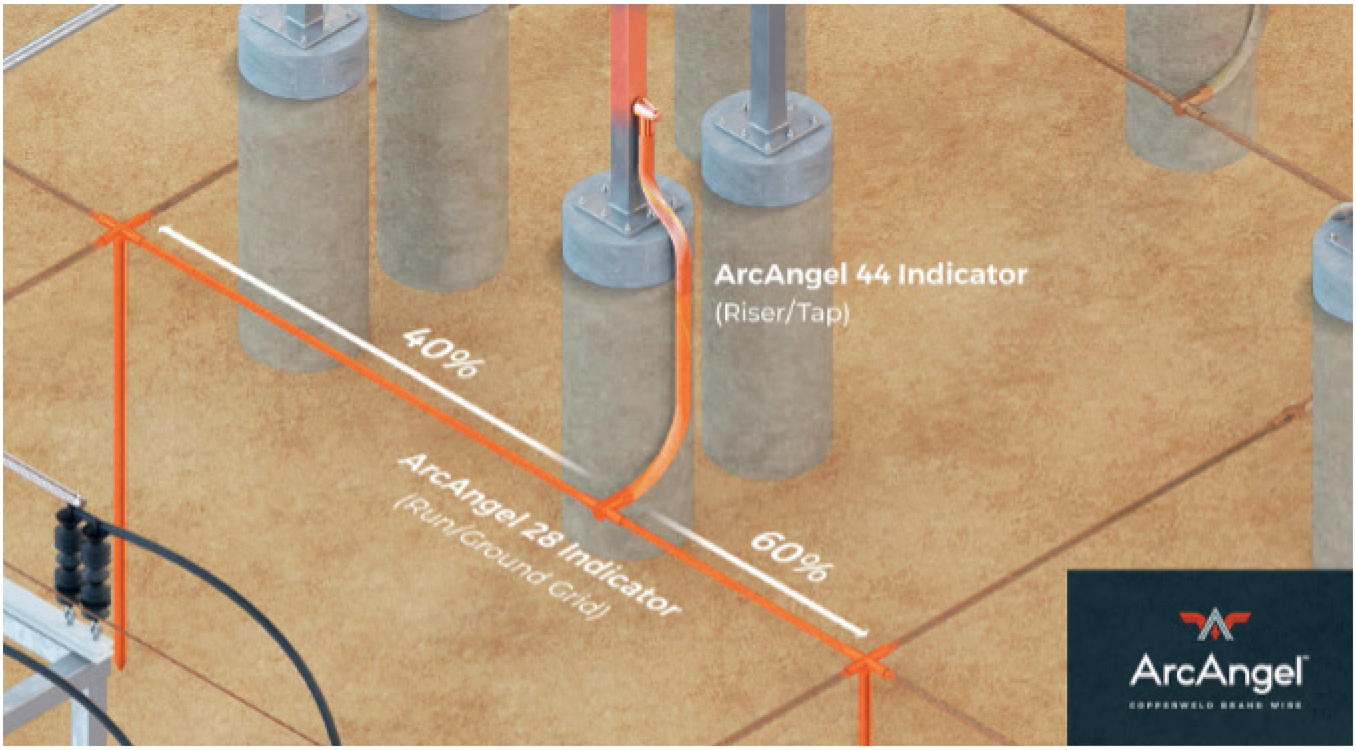


Figure 3: Shows the typical fault current distribution in a Substation earthing grid

resistance in buried ground grids. It turns out it's also strong, REALLY strong!

FOR EXAMPLE,

4/0 soft-drawn copper has a max electrical load of 42 kA and a max break load of 6,000 lbs.

But, ArcAngel 44 has a max electrical load of 47 kA and a max break load of 12,000 lbs for about the same price with condition monitoring for free!

Copperweld's new ArcAngel is proven to be a better solution electrically, mechanically, and financially $$$. A patented green stripe is also stranded into each tin-plated CCS 'Indicator' cable for condition-based monitoring. The stripe melts away when the conductor carries 80% of its maximum short circuit fault rating, alerting the lineman that it needs to be replaced. In this condition, however, the conductor still remains in service, ready to carry one more fully rated fault current.

An ArcAngel option replaces each standard size of the copper in the market. Discount versions of ArcAngel Indicator are also available with all the benefits of ArcAngel but without tin plating and a green stripe. See Figure 2.

Note: Converting American wire gauge (AWG) to Metric conductor sizes:

Number 2/0 = 70mm^2

Number 4/0 = 120mm^2

Number 350 MCM = 185mm^2

Number 500 MCM = 240mm^2

BETTER THAN UPSIZING

The biggest challenge with optimising a substation ground grid is the interface with the soil, not the size of the conductor. In other words, there is no benefit to selecting a 4/0 copper buried ground grid if the leads tying into it are also 4/0 unless the designer worries about mechanical strength.

Grounding is all about providing the path of least resistance to the Earth. The short circuit fault current will follow this path. Once underground, the current then splits at each tee into the ground grid, and splits again, and splits again. Copperweld has proved that the worst case is a 60/40 split at each tee, based on practical grounding design rules and high-power lab verification tests.

Rather than upsizing, a much better design practice is to upgrade by selecting ArcAngel 44 Indicator equipment taps and then connecting them to the ArcAngel 28 Indicator ground grid. (Exothermic and swage connectors are commercially available.) Without upsizing, the ArcAngel 28 is already 20% stronger than a 4/0 copper anyway. Reliability over the expected service life is built-in.

Substation designs can now be optimised for the best value, redesigned with ArcAngel. The result is a design that saves $25,000 per substation and increases the reliability and resiliency of substations because of increased strength and condition-based monitoring for free—savings multiplied on every installation! There is no need to upsize to gain extra strength and reliability. wn

SAIEE

Webinars
Combating the scourge of cable theft

9 16 23 Nov 2022 | **17 – 18.30**

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Register now!
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About the series

The South African Institute of Electrical Engineers (SAIEE) is curating a webinar series on cable theft in South Africa. This 3-part webinar series will be held online on the 9th, 16th and 23rd of November 2022 for 90 min each, commencing at 17h00.

The historical overview on the 9th of November, is open to all and free to attend. The second and third webinars are **free to attend for SAIEE Members** but have a minimal cost for non-members at R200/webinar. If you are interested in booking both sessions, the booking fee is R350 for both days.

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Technical Advisor SARPA
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23 November 2022 | 17h00
Conclusion: Strategies on the way forward
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The Evolution of Medium Voltage Power Cables and Accessories up to 36kV

This paper covers the evolution of medium voltage (MV) power cables over the last century. It considers some pros and cons of all the different insulation materials used for MV power cables. In South Africa, most Utilities still install three-core Paper Insulated Lead covered (PILC) and consider three-core Cross-Linked Polyethylene (XLPE) insulated cables. No Utilities install three-core Ethylene Propylene Rubber (EPR) insulated cables, although these are extensively used in the mining industries.

By Patrick J O'Halloran (SMSAIEE), ARB Global

This is not the case internationally, where utilities predominantly only install either single or three-core MV XLPE or EPR cables and have programs for replacing their existing PILC cable networks.
All new High Voltage (HV) cable projects in South Africa are all single-core XLPE insulated. The old existing fluid-filled HV power insulated cables are being replaced because of the intensive maintenance requirements of these oil pressurised systems.

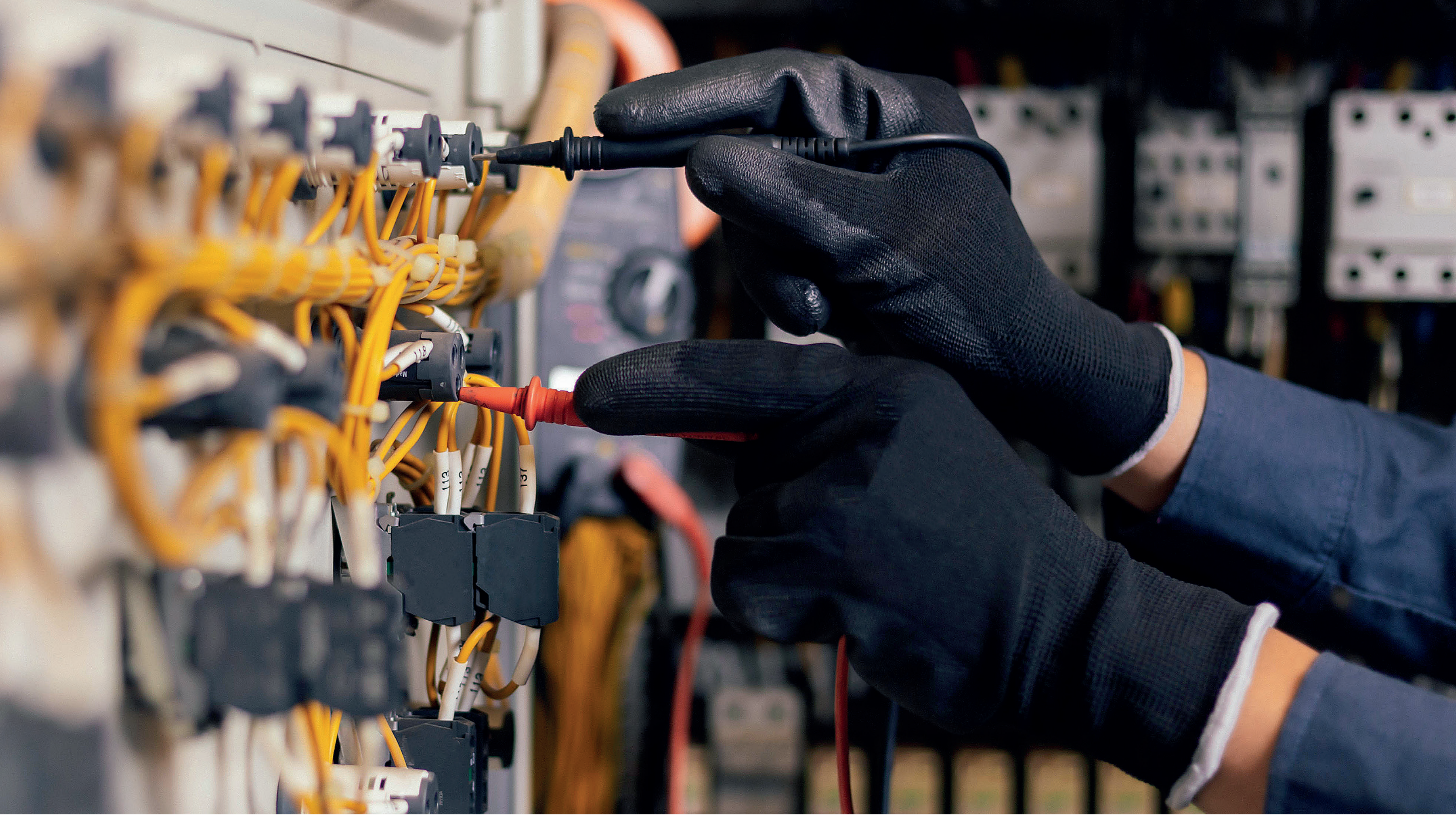
Product evolution has affected all aspects of our lives. Who still uses a typewriter or a pager? These days we have email and smartphones. Technology is changing our lives faster than we could ever have thought possible.

BACKGROUND

Since electricity was first transmitted over MV power cables more than a century ago, their insulation materials and designs have evolved. MV power cable networks make up the biggest asset, which most utilities have to operate and maintain. These MV power cable networks are buried and out of site unless they become unreliable and faults are experienced. In many cases, these networks are run to failure, with very little maintenance or expected life diagnostic testing being conducted.

Utilities must ensure supply reliability; hence, MV cable designs have also evolved. MV power cable insulation ages due to the electrical stress and operating conditions they are exposed to. Cable experts will also remind end users how critical it is not to overload their MV power cables since increased temperatures are the quickest ageing mechanisms for reducing the remaining life of MV power cables. When MV power cable faults occur, they contribute to large area interruptions of supply, and the fault may take considerable time to be located.

This can be very costly to repair. Depending on the MV network design, some faulty cable sections could be quickly isolated and power restored to the healthy parts of the MV network.



MV power cable design changes have also been driven by changes in switchgear design, higher voltages, and the loads required to be transmitted to provide the increased power demands that utilities are required to supply.

The remaining life of an existing MV power cable network is difficult to predict. However, by performing regular condition assessment tests on the existing cables, the degrading results will give utilities a good indication of when the cable insulation system is reaching the end of its life, and repeated failures can be expected.

Online and offline diagnostic testing can be applied to try and predict the remaining life of our existing installed MV power cable networks.

The impact of theft on MV power cables is starting to affect the performance of MV networks. The repeated faults are causing stress on upstream power transformers and associated MV equipment, reducing their remaining life.

Another big concern is the lack of jointer skills needed for repairing all the cable faults utilities experience. Experienced jointers are being lost by Utilities, either as a result of retirement or to other industries. As a result, Utilities are now forced to make use of contractors to be able to perform the critical joints and terminations. The standard to which jointers should be trained and who is competent to provide the required training remains a thorny issue.

INTRODUCTION

Thomas Edison developed the first power distribution system in the early 1880s in New York City. This used a cable constructed from copper rods, wrapped in jute and placed in rigid pipes filled with a bituminous compound.

Picture 1: First power cable was developed by Thomas Edison in the early 1880s.

Although Charles Goodyear had patented vulcanised rubber in 1844, it was not applied to cable insulation until the 1880s, when it was used for lighting circuits. The rubber-insulated power cable was first used for 11000-volt circuits in 1897 when it was installed in the Niagara Falls power project.

Mass-impregnated paper-insulated, lead-covered, medium voltage cables only became commercially practical by 1895. During World War II, several varieties of synthetic rubber and polyethene insulation were used in MV power cables.

By the late 1960s, XLPE insulation was introduced for MV power cable insulation, and this technology significantly changed MV power cable systems. However, like any new technology, this had many teething problems. Manufacturers spent a great deal of time and money resolving the problems experienced in the industry with the first-generation XLPE insulated cables.

The MV power cables currently available in South Africa are all manufactured and tested to stringent standards published by the South African Bureau of Standards (SABS).

These standards are reviewed periodically, and the following SABS South African National Standards (SANS) are compulsory for MV Power Cables in South Africa according to VC 8077;

- SANS 97: Electric cables - Impregnated paper-insulated metal-sheathed cables for rated voltages 3,3/3,3 kV to 19/33 kV (excluding pressure-assisted cables)
- SANS 1339: Electric cables - Cross-linked polyethene (XLPE) insulated cables for rated voltages 3,8/6,6 kV to 19/33 kV
- VC 8077 - Compulsory specification for the safety of medium voltage electric cables

In addition to the above standards, the Electricity Suppliers Liaison Committee (ESLC) has published the NRS 013 specification for Medium-voltage cables. This specification recommends rationalised options for PILC and XLPE MV power cables used by Utilities.

MV POWER CABLE CONSTRUCTION

The construction of the above compulsory MV power cables needs to be clearly understood to grasp the major technical differences between the two technologies. Both technologies are available in single or three-core and as unarmoured or armoured. Depending on the end users' preference or power needs, the conductors are either stranded Copper or Aluminium. The Copper conductor has been preferred over Aluminium for many good reasons, but not cost. The extruded outer sheaths vary depending on the final applications. Polyvinyl chloride (PVC) is typically a flame retardant but can also be low-halogen for mining applications.

Cables intended for underground use, or direct burial in the ground, will have heavy plastic or metal, most often lead sheaths, or may require special direct-buried construction. A water-resistant polyethene outer sheath covers new XLPE cables. When cables must run where they could be exposed to mechanical impact damage, they may be protected with a flexible steel tape or wire armour.

PILC MV power cables are insulated with mass-impregnated paper insulation, and XLPE MV power cables are insulated with cross-linked polyethene insulation. These two insulation materials are very different in many ways.

PILC MV power cables have been around for more than 100 years and make up the main installation base in South Africa and internationally. These cables have had many design changes over the last 100 years. Many of these cable improvements introduced were to make the cable's performance more reliable at higher voltages. When PILC MV power cables were first utilised, they were only used on 6,6kV or 11kV voltages.

Paper insulation on its own does not provide a good enough insulation for power cables for the following reasons;

- absorbs atmospheric moisture,
- susceptible to cracking with ageing, and
- when continuously subjected to local ionisation (partial discharge) during load cycling can result in irreparable damage during cable handling.

The paper insulation is currently impregnated with a non-draining compound. It is now referred to as Mass Impregnated Non-Draining (MIND) cables. In the past, the oil-based

Picture 2: Typical three-core PILC MV power cable.

compounds used were susceptible to draining (e.g. rosin oil). When the compound drained due to gravity and temperature, the paper insulation would dry out, and many failures at terminations were experienced.

There are two types of "non-draining" compounds used by various manufacturers;

- Compound processed from a mineral-based amorphous crystalline wax, and
- Recently, a synthetic compound better known as Polyisobutylene (PIB) compound.

However, three-core cables have a sector-shaped conductor and initially had a "Belted" construction design, and one of the first improvements was introducing an "individually screened" construction. This design equalises electrical stress on the cable insulation. Martin Hochstadter patented this technique in 1916; the Screen is sometimes called a Hochstadter screen. The individual conductor screens of a cable are connected to earth potential at the ends of the cable, and at locations along the length of voltage rise during faults would be dangerous. When a cable is screened, it can be touched safely without risking a potential build-up.

An unscreened Belted design is a three-core cable in which additional insulation (the belt insulation) is applied over the laid-up core assembly. If air is introduced in a belted-designed cable, the potential for partial discharge (PD) to be initiated is increased. This is typically what happens at dry-type terminations. If the air is removed, such as in a compound-filled cable box or joints, no PD should occur, and therefore no crutch failure.

Screened cables ensure that the radial electric field surrounding the conductor in each core is individually screened and contained in the core insulation (by a non-magnetic conducting tape that is in electrical contact with the metal sheath). In the case of three core cables, in direct contact with the screens of the other two cores. This type of screened cable design reduces the risk of crutch failure. Special steps must be taken to ensure that the electrical stress at the ends of the core screens is graded to prevent PD. Typically, stress relieving mastic or stress control tubes are used.

Belt papers are removed when jointing and terminating. This reduces the phase voltage to earth to 5.5kV at all accessories. Screened-designed cables are, therefore, more reliable when jointed or terminated, and only earth faults, rather than symmetrical faults, can be expected (i.e. lower fault currents).

Figure 1 depicts the electric field lines in belted, unscreened and individually screened three core cables.

Unscreened cable (belted design) insulation comprised of core paper insulation and belt paper insulation

- Only "collectively" screened
- Reduced core insulation when compared to screened cables
- Only up to 11kV

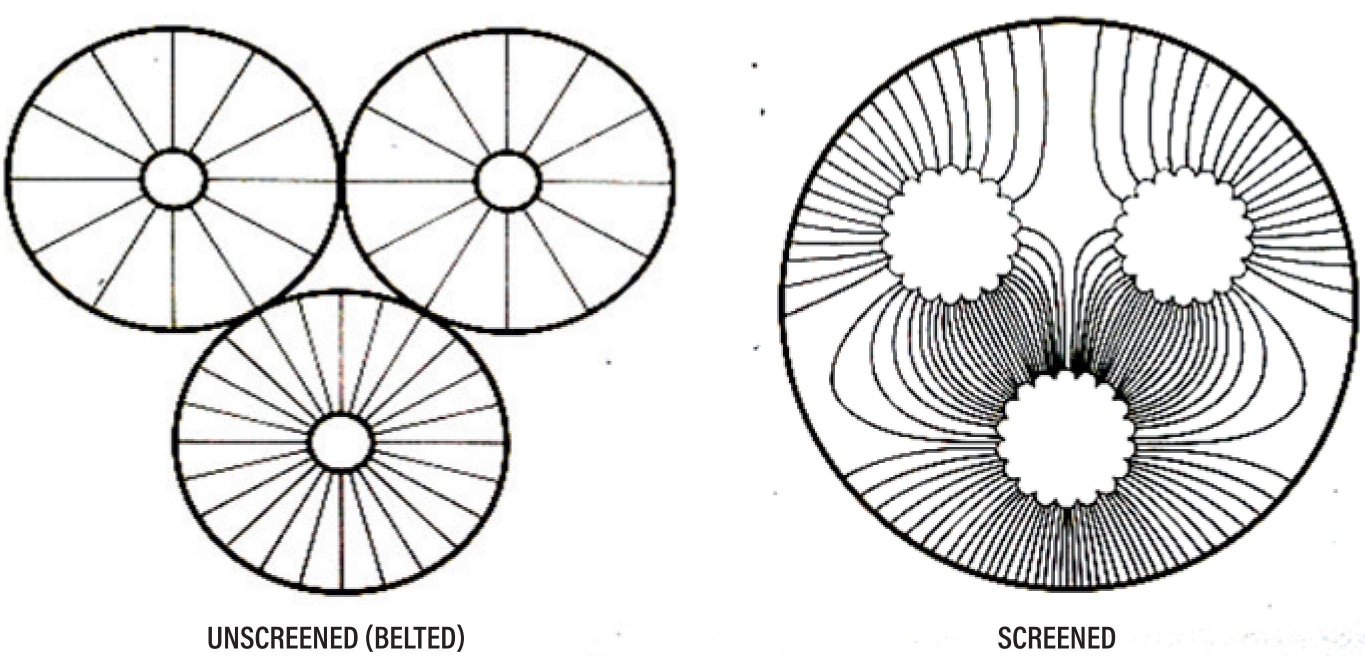


Figure 1: Unscreened (belted) cable and Screened cable PILC MV power cable.

Many cable improvements were developed to make the PILC cable performance more reliable at higher voltages. When PILC MV power cables were first used, they were on 6,6kV or 11kV voltages only. For voltages above 11kV, only screened designed cables are available.

All single-core PILC cables have round conductors and an individually screened design. PILC MV power cables are highly susceptible to moisture ingress. Once moisture has penetrated through the lead sheath, the paper insulation is rapidly affected, leading to insulation failure. This moisture then quickly travels down the cores and eventually affects a larger PILC MV power cable section. It is, therefore, critical to prevent moisture from entering the cable at all costs.

It is also very important to perform a moisture crackle test on the paper insulation before any termination joint is installed. If moisture is detected, the cable with moisture ingress should be replaced to prevent further failures. It is also, therefore, critical that the PILC MV power cables be sealed with the appropriate sealing caps. The sloppy use of a plastic bag or a plastic half-litre cold drink bottle is not acceptable and will lead to moisture ingress.

XLPE insulated MV power cables have not been around for as long as PILC MV power cables. When XLPE insulated power cables were first manufactured in the late 1960s, they experienced many premature failures in the field. These failures were due to incorrect manufacturing processes, leading to impurities and contaminants within the XLPE insulation. These failures gave XLPE-insulated MV power cables a poor reputation in the industry. In South Africa, most utilities rapidly changed back to PILC MV power cables.

Picture 3: Typical single and three-core XLPE insulated MV power cables.

Subsequently, the XLPE insulation cleanliness designs and manufacturing production process technologies have evolved considerably. The manufacturers began to understand the importance of making XLPE cables more reliable with extended life expectancy. The three critical layers in XLPE insulated MV power cables are now applied simultaneously and referred to as triple extruded.

These three critical layers are;

- The conductor screen, which is at Uo phase voltage,
- The XLPE insulation, and
- The core screen, which is at 0V (needs to be kept at earth potential)

The conductor and the core screen are semi-conductive materials, and the XLPE insulation is the pure insulating material. XLPE insulated cables always have a screened design and are round to ensure equal stress distribution in the XLPE insulation - Figure 2.

Further improvements have now been made regarding the XLPE insulation materials. For MV power cables, tree retardant (TR) XLPE compounds (TR-XLPE) are now utilised to successfully pass the wet ageing type test and the required breakdown strength criteria specified in SANS 1339.

The quality of XLPE insulated cables is so high that it is becoming the preferred insulation at 500kV since XLPE insulation has lower dielectric losses and higher operating temperatures. This means higher ampacities and lower environmental impact. Un-aged XLPE insulation for MV power cable has typical breakdown strength of 50kV/mm.

City Power has changed its MV power cable specifications to longitudinally water-blocked XLPE insulated cables as a standard. The concept is like a baby's nappy, where water swellable compounds and tapes are included in the areas where water could flow in the cable once it has entered the cable for whichever reason. (Damage Sheath, lugs, existing cables, storage, etc.)

The water penetration type test, as per SANS 1339, shall be conducted to prove the design. This design will extend the life of the cable since when water enters, it is stopped at that point. This then also prevents the old problem of XLPE cables becoming water pipes.

Areas in a three-core XLPE cable, which have to be water blocked, are;

- Conductors
- Core(s) and metallic screening
- Laid up cores for 3-core designs
- Armouring

The international trend is to use single-core cables rather than three-core cables. This is because it is simple and easy to longitudinally block a single core cable since it does not have large

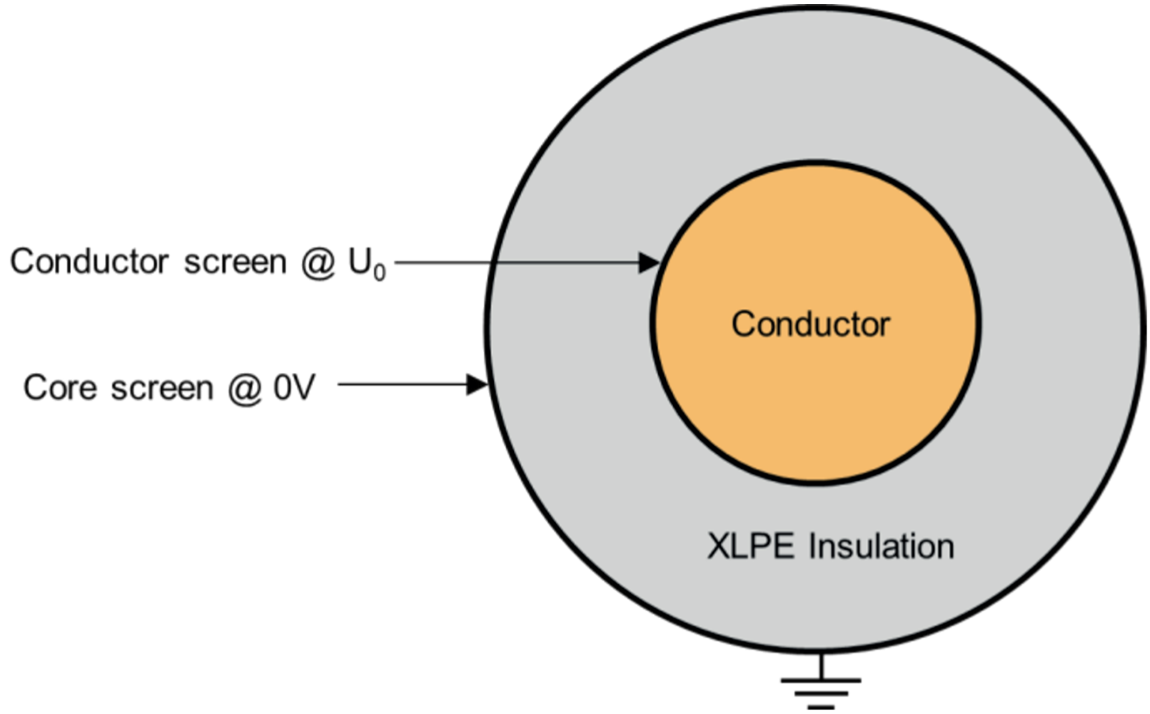


Figure 2:The three critical layers in an XLPE insulated MV power cables which are applied as a triple extrusion.

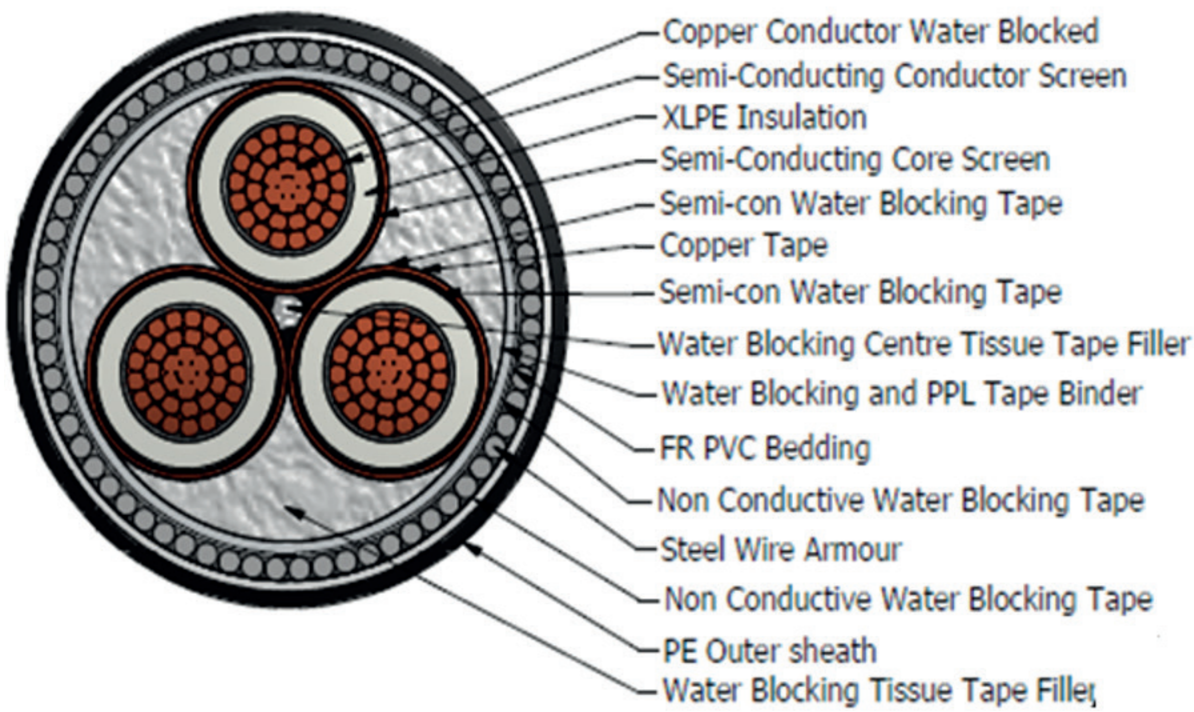


Figure No. 3: CBI Electric African Cables longitudinal water blocked XLPE MV power cable design.

fillers between the cores. The risk of moisture entering all three phases is also reduced when three single-core cables are utilised compared to a three-core design.

In 2014 the first 400kV Extra High Voltage (EHV) XLPE insulated cable was installed in South Africa. The cables and the accessories were imported for this project. Our local market-leading HV cable company has invested in a new EHV XLPE production line to be able to manufacture cable up to 275 kV. This is exciting for future projects; we will no longer have to import 275kV EHV cable since it can be made locally. We can also purchase HV cables with conductor sizes up to 2500 mm².

The risk of DC pressure testing is also better understood these days, and it is no longer recommended to use DC pressure test equipment on XLPE-insulated MV power cables. DC pressure testing has been proven only to test the resistive properties of the cable and is not really effective. DC pressure testing has been around for many years, like PILC cables, but is slowly being replaced by AC, DAC and VLF source test equipment. AC source test equipment tests the permittivity properties of the cable systems.

DC source equipment is required for fault-finding, but this is different from voltage withstand testing.

Suppliers are now putting in special markers with serial numbers to prevent cable theft in South Africa. With the inclusion of these serial numbers, end users can identify cable ownership. Furthermore, end-users are also utilising these serial numbers for their asset register.

Table 1 summarises the key differences between PILC and XLPE-insulated MV power cables.

OTHER FACTORS INFLUENCING CABLE TECHNOLOGIES

With the improvements in insulation mediums and cable terminations, MV switchgear has drastically reduced in actual size. This means that the sizes of cable boxes have been reduced, and special bushings have been introduced to accommodate the new cable terminations.

If the wrong equipment has been specified and purchased, things get really exciting onsite. Typically, most equipment has long lead times, and instead of stopping the project, people make plans onsite to terminate the cable into the switchgear that is supplied on

CABLE CONSTRUCTION	PILC-INSULATED CABLE	XLPE-INSULATED CABLE
Conductors (Either Copper or Aluminium)	Usually shaped conductor, but may be circular / oval	Only circular
Insulation	Wrapped Impregnated paper insulation	'Solid' extruded dielectric XLPE insulation
Screen	Belted collectively or individually screened (Wrapped metallised paper tapes)	Always Individually screened (Extruded semi-conductive semicon with either copper tapes or copper wires)
Metallic sheath	Essential, typically lead	Optional, either lead or Al
Bedding layer	Extruded or Fibrous (if armoured)	Extruded bedding (if armoured)
Armouring	DSTA / SWA / AWA (optional)	SWA / AWA (optional)
Outer sheath	Extruded (PVC/PE) / Fibrous	Extruded (PVC/PE)
Continuous operating temperatures	70°C	90°C
Short Circuit temperatures	160°C	250°C
Longitudinally water blocked	No, normally only radially due to metallic layer	Yes, if specified, since it is a special requirement in SANS 1339
PD free design	No	Yes
Diagnostic testing possible	▪ Tan Delta diagnostic, which is a measurement of the overall circuit condition. ▪ Pre-failure faults can't be located without breaking down the insulation system by applying a high voltage source	▪ Tan Delta and Partial discharge diagnostic possible. ▪ Pre-failure faults can be located without breaking down the insulation system ▪ Jointer errors can be identified before energising the cable

Table 1: Comparison between PILC and XLPE MV power cables.

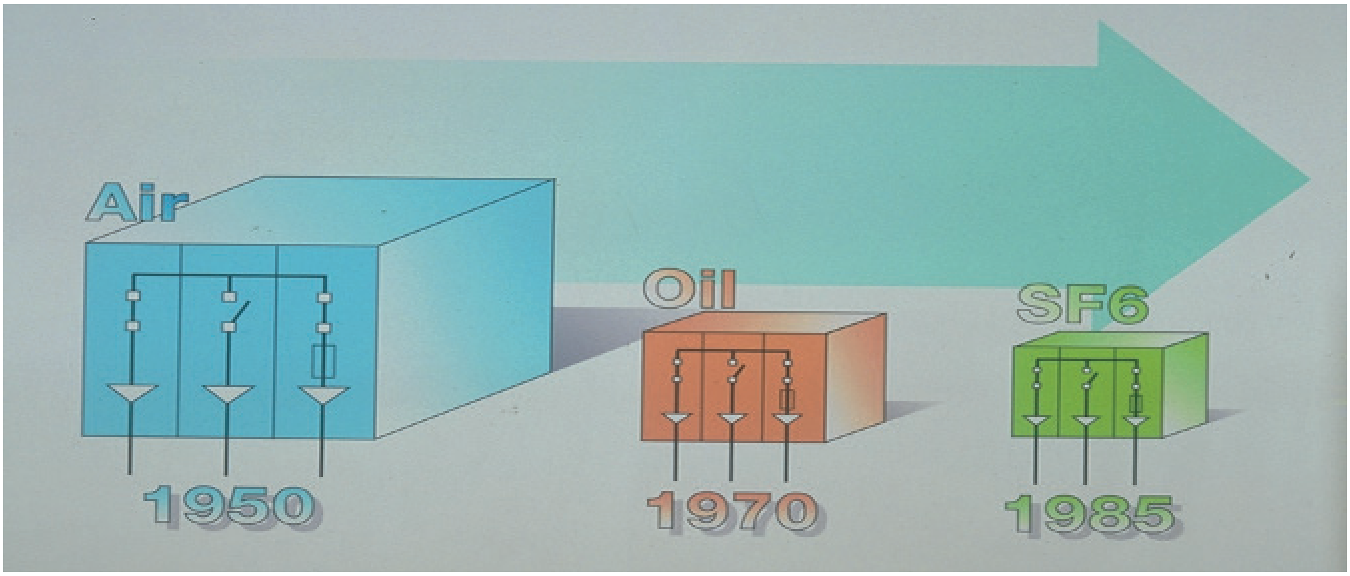


Figure 4: MV switchgear trend as insulation mediums evolved.

site. Therefore, the installation is wrong from day one, and premature failures can be expected. These failures can be costly to repair and could also involve the replacement of the switchgear, and staff or the public could be injured or killed from any resulting explosion.

Picture 4: Compound filled cable boxes.

Picture 4 shows a very old compound-filled cable boxes. These were designed for PILC belted, unscrewed MV power cables and filled with hot pouring compound. This ensured that there was no PD in the critical crutch of a PILC-belted unscrewed MV power cable as all air was removed in the critical areas.

Due to a variety of reasons, these compound-filled terminations are no longer preferred, and most end users prefer to install conventional dry-type terminations. These are referred to as either Heat Shrink or cold applied products.

CABLE TERMINATION BEGINNINGS (EARLY 1900 – 1950s)

In the early days, electrical equipment, such as switchgear and transformers, was designed to have compound-filled metal cable boxes. This way of cable terminating was technically good, except it was very difficult and hazardous to field staff. At that time, the MV paper insulated (PILC) cables had a belted construction and used wiped earth connections.

Compound-filled cable boxes are designed to exclude air, so creepage was not a major consideration when designing the cable bushing. This explains why compound-filled cable box bushings are small compared to the air-filled cable box bushings found in metal-clad switchgear and outdoor transformers.

Compound boxes were filled with many different compounds, but a hot pouring compound was mainly used. This hot pouring compound was difficult to manage and gave off harmful fumes when heated before pouring—compound-filled boxes were made of a metal housing with porcelain bushings where the cables exited the compound box.

Some drawbacks of compound-filled cable boxes are;

- Compound top-up is required to ensure proper insulation (no air voids),
- Long installation times, and
- Cable box failures caused major damage when ruptured (hot burning compound could be expelled).

New technology cold pouring compounds are now available. These are environmentally friendly and safe to install.

AIR INSULATED MV CABLE TERMINATIONS (1950 – 2000s)

With the introduction of tapes, heat shrink and later cold shrink terminations, over time, compound-filled boxes have been replaced with air-insulated terminations. 95% of our South African market use this type of MV cable termination.

Screened paper insulated cables were introduced to control the electrical stresses within the cable designs, especially where increased voltage cable ratings were required. The screened cable design provides improved MV cable termination performance, especially in the crutch, where the crutch is a high-stress area in belted cables. Belted design paper insulated cables are currently limited to 12kV. Screened paper insulated cables are normally rated up to 36kV, as per SANS 97.

The belted design of the paper-insulated cable is more likely to have crutch failures than the improved screen design paper-insulated cable, where the complete crutch area is screened. This is because of the permittivity properties of the materials and the introduction of air between the unscreened insulated conductors.

International market trends (which are mainly 24kV rated systems) produce smaller and smaller switchgear. This, in turn, leads to reduced busbar clearances and cable boxes.

Figure 4 shows how switchgear sizes have reduced with new insulating technologies. Air was the first insulating medium for busbars. It was replaced with oil, and then with the introduction of SF6 insulation, busbar clearances could be reduced tremendously. This allowed the cable box sizes to be reduced. Along with the reduced cables boxes sizes came the reduced clearances between phases and phase-to-earth. This reduction in clearances required new designs of MV cable terminations.

When switchgear manufacturers designed smaller air-filled cable boxes with reduced clearances, MV cable accessory manufacturers then had to redesign the bushings and MV cable terminations to make the cable box and cable termination compatible with these reduced clearance requirements.

In South Africa, we have standardised on a 'type C' 630A bushing with M16 thread. This 'Type C' bushing is found on all the news SF6 insulated switchgear, which currently is only used by City Power, Eskom and similar utilities and industries.

The 'Type C' bushing allowed end users to move from traditional putty and tape shrouds to factory-made, fully insulated shrouds. These shrouds are installed the same way every time, ensuring that cables are terminated correctly on Type C bushings. This product is designed to be used on our South African PILC cable systems.

PILC cables are susceptible to moisture ingress, causing insulation breakdown; hence, users are forced to find alternative new cable designs. With the introduction of screened XLPE cables, MV terminations have also evolved.

It was decided internationally to standardise the cable interface and introduce screened cable terminations. Screened MV cable terminations should preferably only be used on MV XLPE cables. When installed, this eliminates the creepage, tracking and erosion problems, and clearances experienced by most air-insulated MV cable terminations. The terminology 'Screened' means earthed. Once a cable termination is completely screened, it can be completely submerged in water without any flashover.

Screened connectors are required when connecting to new 24 and 36kV compact switchgear.

Our South African market mainly uses 3-core cable designs for several reasons. International Utilities have changed away from 3 core cables and now utilise single core XLPE insulated cables. This is not an easy change to make, as all electrical aspects of the network must be reviewed, and staff need to be trained to install and terminate single-core XLPE insulated cables.

The design of the screened connector controls the electrical stress from the XLPE cable through the 'Type C' bushing and into the switchgear. Because the surface of the cable and the screened connector is screened, there is no leakage current along the surface of the screened connectors. With these screened connectors installed in the cable box, the size of the cable box and all electrical clearances can be drastically reduced. The life expectancy of screened MV cable terminations is double the expected life expectancy of unscreened cable terminations, especially with reduced clearances inside new reduced cable boxes.

To eliminate failures from occurring in the MV cable compartment, the following two national standards have been published;

- SANS 876 - Cable terminations and live conductors within air-filled enclosures (insulation co-ordination) for rated ac voltages from 7,2 kV and up to and including 36 kV
- SANS 1332 - Accessories for medium-voltage power cables (3,8/6,6 kV to 19/33 kV)

These two standards are not yet compulsory, so it is up to the end-user to specify them when purchasing any MV switchgear and MV cable accessories.

All MV cable accessories should comply with the requirements of SANS 1332.

With the introduction of air in the cable boxes, we now have to consider the following;

- Creepage distances,
- Tracking and Erosion, and
- Clearances (Phase to Phase and Phase to Earth)

The above three technical considerations must be correct if an air-filled termination is to last more than 30 years. If adequate creepage, tracking, erosion properties, and air clearances are not provided, the MV cable termination will fail prematurely. Failure of MV cable terminations is dangerous and can lead to long power interruptions.

SANS 876 has been developed to address the challenges which have been identified. This standard is critical to understanding and correctly specifying when ordering new switchgear to accommodate the cable technology that will be installed.

In SANS 876, the following type of terminations are specified;

- Type 1 termination - lugs connected onto bushings or post insulators, uninsulated (bare) at the terminal fixing point, figure 4
- Type 2 termination - lugs connected onto bushings or post insulators with a shrouded (unscreened) insulation termination, figure 5
- Type 3 termination - unscreened separable connector terminations, figure 6
- Type 4 termination - screened separable connector terminations – outside cone, figure 7 and
- Type 5 termination - screened separable connector terminations – inside cone, figure 8

All critical dimensions and definitions are given in SANS 876.

TYPE 1 BARE TERMINATION (AIR INSULATED)

In a Type 1 termination, the interfaces are bare and;

- Cable cores terminated with stress control appropriate to the cable design and voltage
- Air is the sole insulation medium for the terminal connections
- The minimum distance from any live bare metal (e.g. bushing, post insulator, live conductor, lug, fitting etc.) to an adjacent phase or earth is determined by the impulse to withstand voltage requirement

TYPE 2 SHROUDED TERMINATION

In a Type 2 termination (see Fig 5), the interfaces are shrouded with unscreened interfaces are;

- Cable cores terminated with stress control appropriate to the cable design & voltage
- Unscreened local insulation enhancement at the terminal connections
- The minimum distance from any unscreened, shrouded, live metal (e.g. shrouds, cable cores etc.) to an adjacent phase or earth determined by power frequency (e.g. corona inception and extinction) and impulse withstand voltage considerations

TYPE 3: UNSCREENED SEPARABLE CONNECTOR TERMINATION (USC)

In a Type 3 termination, the interfaces are unscreened but utilise specially designed USC and;

- Cable cores terminated by stress control appropriate to the cable design & voltage

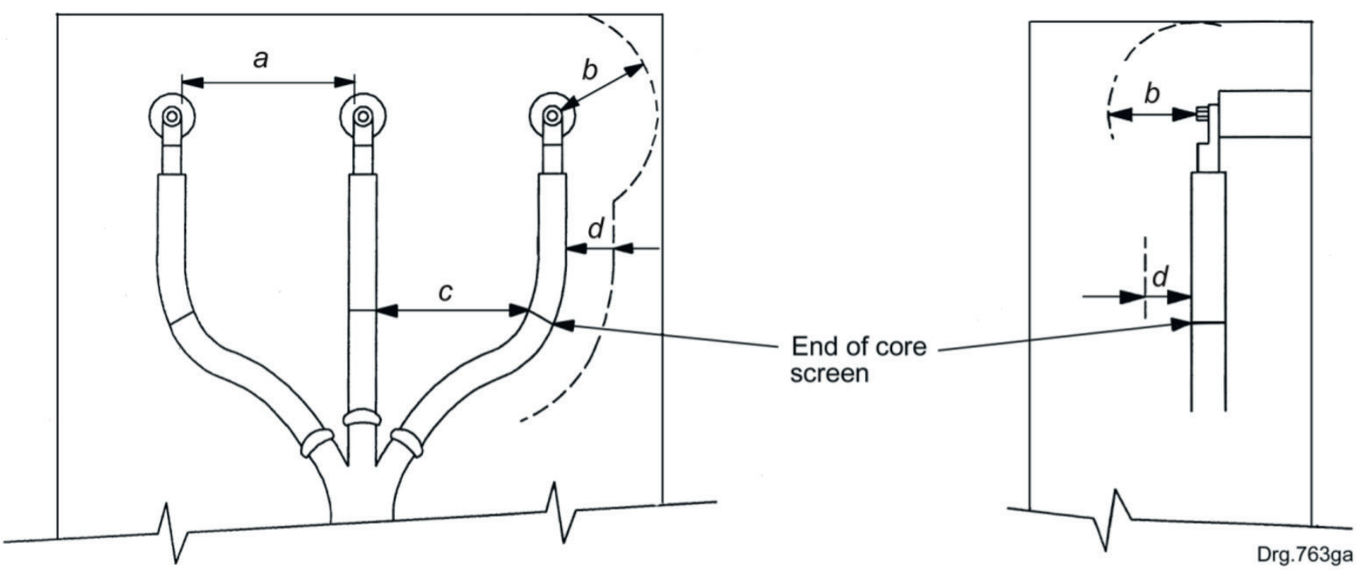


Figure 4: Bare termination Air-insulated (type 1).

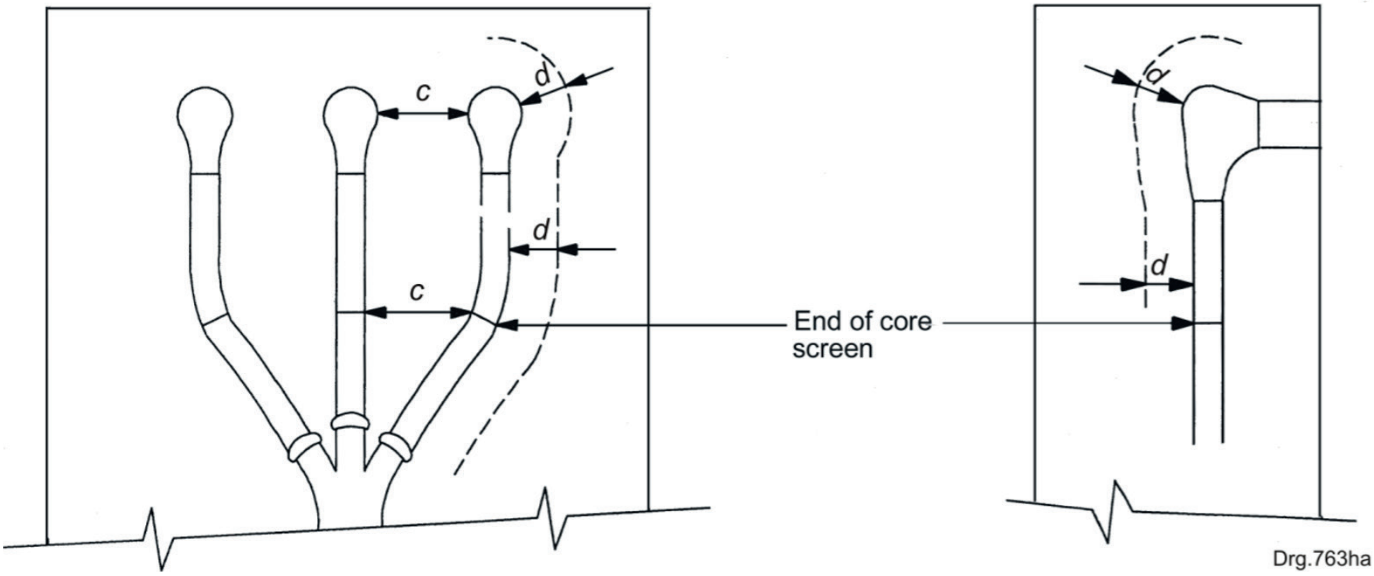


Figure 5: Shrouded termination (type 2).

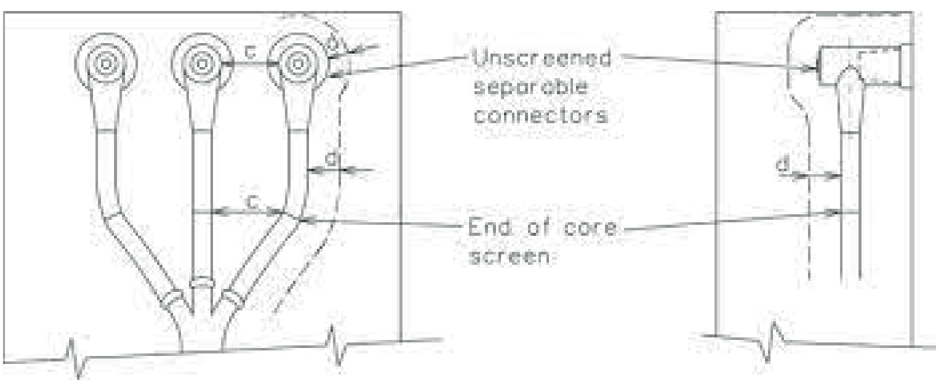


Figure 6 — Unscreened separable connector termination (type 3).

- USC at terminal connections
- The minimum distance from any unscreened, live metal (e.g. USC, cable cores etc.) to an adjacent phase or earth is determined by power frequency (e.g. corona inception and extinction) and impulse withstand voltage considerations
- Leakage current is limited by the quality of the interface between USC and bushing – interference fit

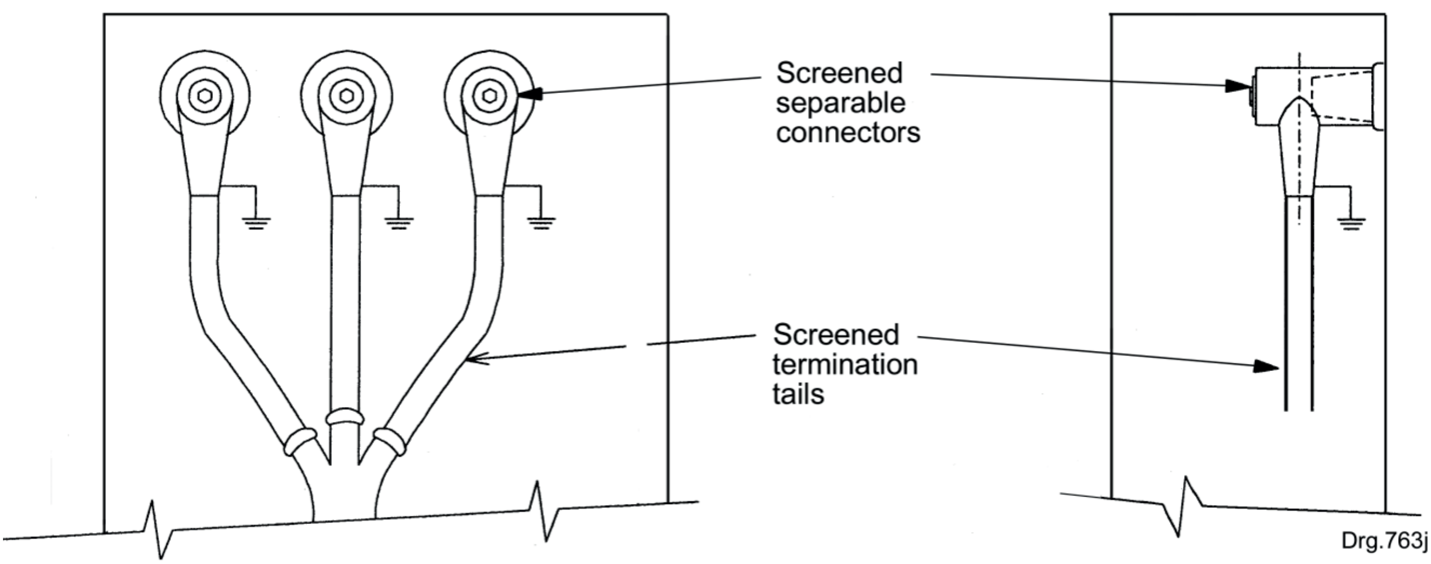


Figure 7: Screened separable connector termination – outside cone (type 4).

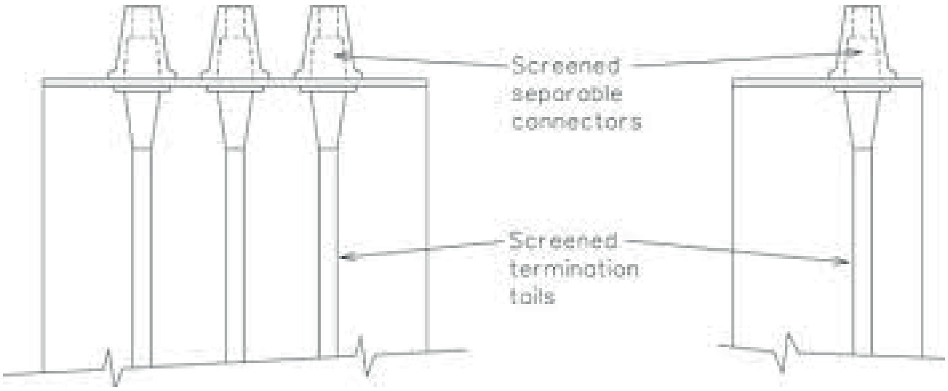


Figure 8: Screened separable connector termination – inside cone (type 5).

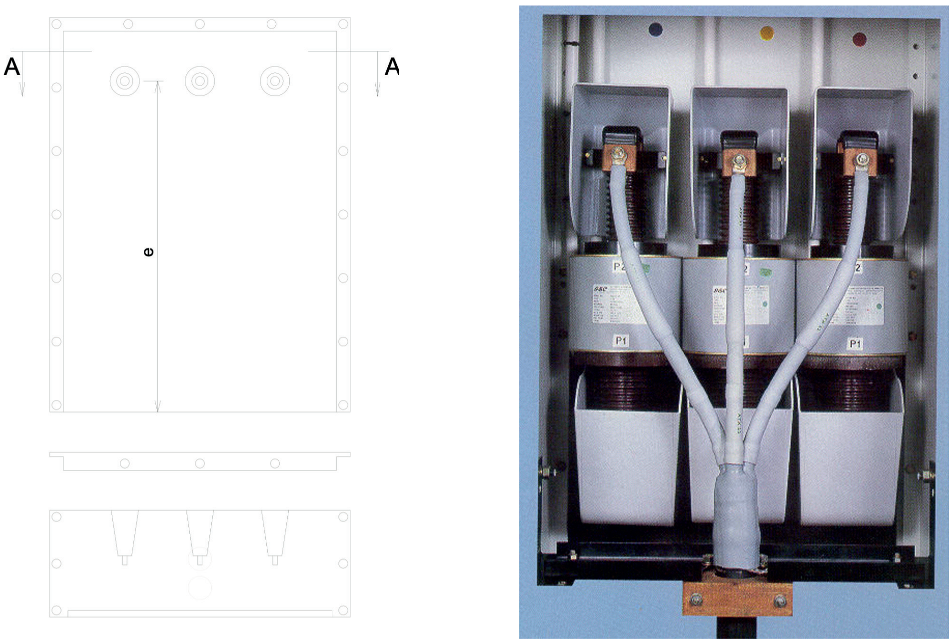


Figure 9: Height of the cable box.

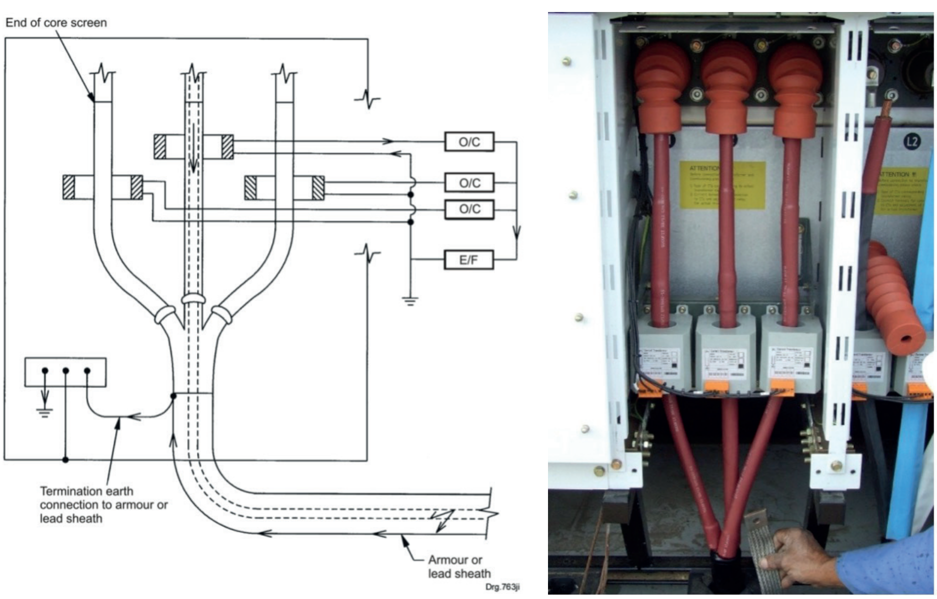


Figure 10: Illustration of the correct earthing for ring-type current transformers on each cable core used for overcurrent and earth fault detection.

TYPE 4 AND 5 SCREENED SEPARABLE CONNECTOR INTERFACES (SSC) – INSIDE OR OUTSIDE CONE

In a Type 4 and 5 terminations, the interfaces screened and utilised special designed SSC and;

- Clearances are determined by the mechanical clearance required to fit the SSCs within the cable box
- Safe to touch due to earthed surface
- Leakage current is limited by the quality of the interface between SSC and bushing (interference fit)
- NOTE –traditionally, PILC cables could not use SSC, especially above 11kV, because;
  - sector shape cores
  - loose core screen

CABLE BOX SIZES (HEIGHTS)

It is also important to ensure that the correct size cable boxes are supplied, as nearly all MV power cables installed are three cores, so extra space is required.

LOW VOLTAGE CURRENT TRANSFORMERS IN MV CABLE BOXES

As technologies have improved with the use of screened cables, the use of low voltage current transformers in MV cable boxes for metering and protection applications has been incorporated.

These low voltage current transformers must be installed in a screened area. Otherwise, discharge may occur if the air clearances are not adequate.

The dimensions in type 2 and 3 terminations cover the dimensions from the top of the low voltage current transformer to the screen cut.

CORE CROSSING FOR PHASING WITHIN MV CABLE BOXES

Core crossing for correct phasing within MV cable boxes is not recommended. However, many crossed terminations exist in our networks. The risk with crossed cores in side unscreened type

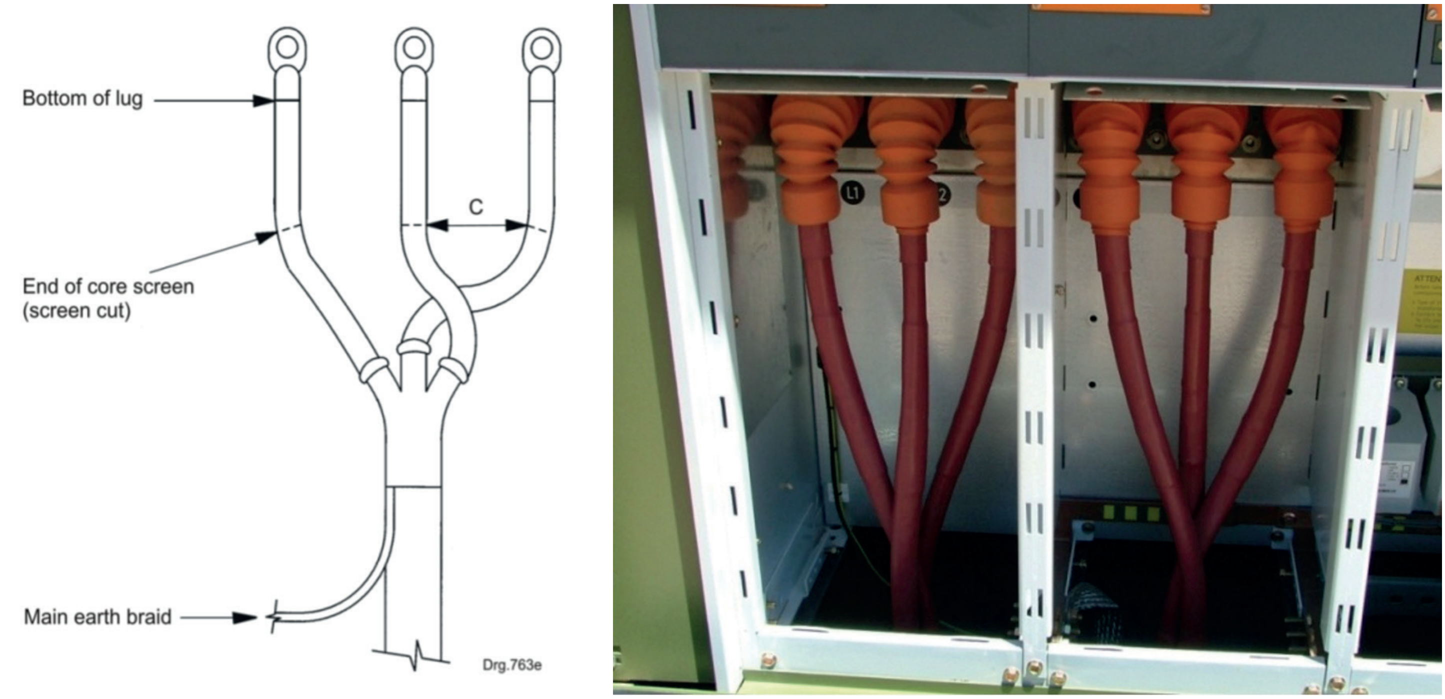


Figure 11: Example of a cable termination where the core crossing is made below the end of the core screen.

terminations is that adequate clearances become reduced, leading to increased electrical stress and partial discharge.

SANS 1332 requires all terminations to be done with a top-down principle. If the top-down principle is followed, the screened metallic area is increased, and core crossing can be done easily without any risk of partial discharge.

However, with a belted design cable, there is no metallic screen, and core crossing is very risky. In Figure 11, the strip back dimensions can be seen.

The evolution of MV Power cables, switchgear and cable accessories has considerably reduced the size of cable boxes. Figure 12 clearly shows the extra base that needs to be supplied with compact switchgear to ensure the correct three-core cable height is attained. This would not be the case for three single-core cables.

The bending radius of three core cables also has to be considered, and in the picture below, special removable front covers of the RMU and plinth have been designed to make the jointer's life easier. Implementing this will hopefully reduce jointer errors.

Picture 5 shows a clever way of terminating the core XLPE MV power cables into small, compact switchgear. Three single-core cables are achieved by performing a tri-furcating termination

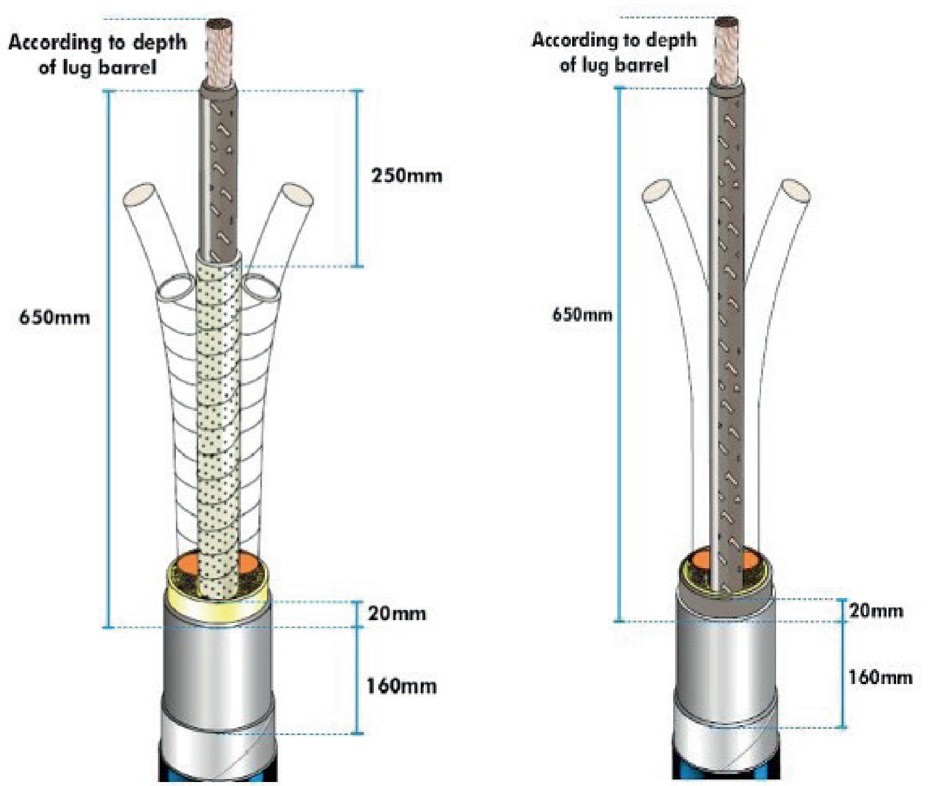


Figure 12: Example of screened and belted PILC cable termination prepared from the top-down principle.

Picture 5: Example of SF6 RMU with an additional raising plinth and removable front sections.

Picture 6: Example of tri-furcating termination into compact MV switchgear.

in the duct or ground. Terminating single core terminations in such small cable boxes is recommended. This small cable box has two cables terminated in it, and there is no risk that a failure could occur. The core crossing is done under the cable box in the duct or ground. Special attention should be paid to using the right single cable clamps and gland plate material.

Picture 6 shows a good example of where things have gone wrong in the past. This often happens, and it is all because the wrong products were ordered or because end users have not understood the new technologies or wanted to stay with old technologies. The SF6 insulated ring main unit pictured below was installed with additional metering, low voltage and protection current transformers (CT).

We were able to locate this problem before a failure accorded by using the EA Technologies handle-held UltraTev Plus detectors. These tests are non-intrusive and should be done online. No interruptions of supply are required.

The installation should have been done with type 4 terminations and single-core XLPE cables. Instead, a type 3 termination was installed, and the CTs were installed over the unscreened areas of the termination.

This installation would have failed if nothing had been done. PD takes a long time to cause a failure in terminations, but it is guaranteed to fail one day.

TESTING TO ENSURE RELIABLE

Most end-users still use direct current (DC) cable pressure test equipment, which gives no diagnostic results. The test method involves applying a high DC voltage to the cable cores for a predefined period. The cable is declared healthy to energise if nothing trips

INCORRECT WAY

CORRECT WAY

Picture 7: Example of incorrect and correct termination into compact MV switchgear with LV CTs

during the test. This type of equipment has been available for many years, is portable and is affordable.

This is referred to as "Go or No go" testing. Why do failures of the cable, joint or terminations still occur after energising?

The answer is well documented; dc testing only tests the resistivity properties of the cable system. However, when energised with alternating current (ac) at 50Hz, the cable system permittivity properties of the components are stressed.

To ensure that future cable system failures are avoided and to make an informed decision on the remaining life concerning possible replacement of the faulted or aged MV power cable, we need to do our testing differently.

With the improved technologies available in testing voltage sources, we can test the permittivity properties of the cable system and simulate the same stresses as in service with ac system conditions. The following alternative test waveforms exist;

- Very Low Frequency (VLF),
- Damped Oscillating Waveform Test Voltage (DOWTS), and
- Alternating Current @ power frequency.

A diagnostic test should also be conducted before energising a new cable or after a repair has been made to a failed cable system.

Off-line Tan Delta (TD) and Partial Discharge (PD) results can be taken during the pressure test. The results are available onsite, and an informed decision can be taken concerning the health of the MV Power Cable system.
TD test results will give an overall cable system condition result. It will not isolate the problem area.

PD test results will give the distance to the PD source (potential failure point). Because the new XLPE insulated MV power cable is PD free, if PD is detected, it is typically in the joints or terminations where jointers have made errors. This means that these joints need to be identified and corrected before energising. We all know that PD will never go away and will just intensify and eventually lead to failure.

These results provide us with a fingerprint of the current condition of the MV power cable system. The results can be compared when future diagnostic tests are conducted, and the cabling ageing rate is confirmed.

The revised SANS 10198-13 code of practice for MV power cable testing recommends integrated voltage withstand and diagnostic testing. These tests do not take long to perform since they are now integrated into the available new test equipment.

CONCLUSION

MV Power cables have evolved over many years. The new third-generation XLPE-insulated MV power cables are now reliable and make it possible to connect to the new compact switchgear currently being installed.

The following recommendations need to be considered in the future to ensure improved reliability of MV cable systems;

- If PILC cables are being installed, the preference should be screened rather than belted designed cables,
- Select and specify the correct termination types up-front when purchasing switchgear since it makes no sense to install the wrong terminations from day one,
- Where three core cables are being installed, ensure that the switchgear cable boxes are suitably designed as per SANS 876,
- To minimise the risk of termination failures when three single cores are installed in compact switchgear, Tri-furcating terminations are recommended to convert three core cables to three single core cables, and then the single core terminations can easily be installed,
- It is also recommended to install a tri-furcating transition joint from a three core PILC to three single core XLPE cables,
- Ensure clearances are kept at all costs if type 4 and 5 terminations are not installed,
- Ensure jointers are well trained in installing the MV power cables and accessories to prevent unnecessary failures,
- Testing for moisture in PILC cables is critical as moisture badly affects the paper insulation. Where moisture is detected, the cable should be cut back until no moisture is present,
- For XLPE cables, the correct screen removing tools should be utilised to prevent cable insulation failures,
- Consider using single-core cables instead of large 3-core cables, and lastly
- Always perform combined voltage withstand and diagnostic testing so that the actual condition of the cable system is known and future faults can be avoided. wn

A Reliability Assessment Model for an Outdoor 88 kV XLPE Cable Termination

By Samantha Chimunda, Cuthbert Nyamupangedengu
University of the Witwatersrand, Johannesburg , School of Electrical and Information Engineering

A metropolitan power utility has been experiencing systematic and premature failures of a particular type of XLPE cable terminations operating at 88 kVrms. The Utility therefore desired to understand the modes of failure with an aim of evaluating the risk of failure of the remaining in-service cable terminations. Failed terminations were forensically analysed.

The knowledge on failure modes obtained from the forensic analyses would be used in redesigning and retrofit repair of the terminations. During operation, the conditions of the in-service terminations were evaluated through various techniques such as visual inspections and online partial discharge (PD) diagnosis.

Those terminations that were deemed to be on the verge of failure were decommissioned and also forensically analysed. The in-service terminations would then be repaired where possible by in-situ retrofit. In the present study, the forensic evidence together with the failure-time statistics of the terminations are used in formulating a reliability model that enables a knowledge-based estimation of the probability of failure of the remaining in-service terminations.

In the literature, there has been sustained research efforts in the development and application of various models for determining reliability of power cables [1]–[6]. It is notable that through the efforts of researchers such as Mazzanti Marzinotto [1], there has been progressive development towards comprehensive reliability models for power cable systems. The models take into account the synergistic nature of electro-thermal stresses.

The present work therefore builds on the existing reliability models but modified

to take into account the additional modes of degradation identified through forensic analyses in the case study.

The rest of this article is structured as follows: Firstly, an overview of the power system portion containing the terminations is presented. The detailed design structure of the termination is explained including the forensic evidence of the possible degradation mechanisms.

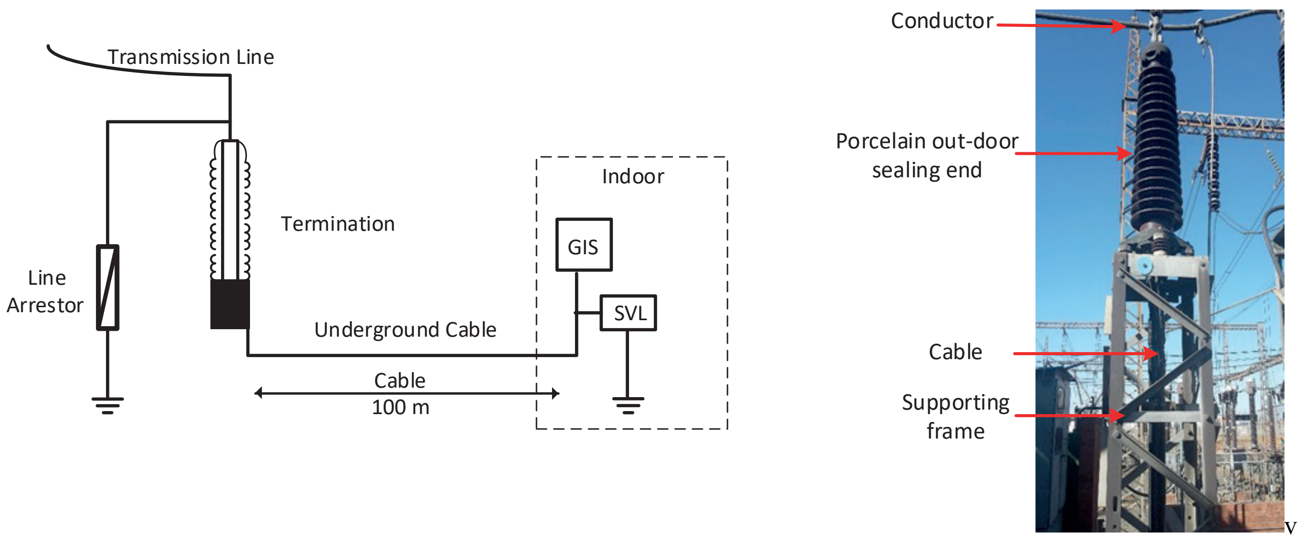
Using the weakest link principle, a reliability model of the termination that incorporates the degradation modes; electro-thermal, corrosion and thermo-mechanic fatigue stress factors is then developed and discussed. The sensitivity of the model is tested including using the model to evaluate the modified termination designs.

Read the paper on the next page.

An Overview of the 88 kV XLPE cable termination system

The power cables in the substations under study link up outdoor equipment (transformers and overhead lines) with the indoor switchgear equipment as schematically illustrated in Figure 1(a). Each phase has two cables connected in parallel. The typical cable length in the link is in the order of 100 m. One of the important conclusions drawn out from the research literature on power cable systems reliability modelling thus far is that reliability is diminishes with the increasing number of accessories as well as cable length [1]. In the present study therefore with a cable length of 100 m, the reliability of the cable system is assumed to be mainly dependant on that of the two cable terminations.

The 88 kV cable termination on the outdoor end (as shown in Figure 1(b)) of the cable link is connected to a metal oxide surge arrestor. The power cable is a single core aluminium CSA (corrugated seamless aluminium) with a voltage rating of 76/132 kV but operating at a normal ac voltage of 50.8/88 kV. The indoor end of the cable terminates into an SF_6 gas insulated switchgear indoor board. The system is solidly bonded at the outdoor termination end. The indoor end is ungrounded but with a sheath overvoltage Sheath Voltage Limiters (SVL). It is important to note that due to the prevalent copper theft problems, there are system irregularities that have unfortunately become the norm and these include the missing ground connections on the outdoor surge arrester as well as the SVL. Such irregularities have a direct impact on the ageing stresses of the termination as will be discussed later. The substations are equipped with onsite 'black box' data measurement and acquisition system that uses Sapphire Elspec™ software to continuously log power quality parameters such as power frequency current and voltage as well as transients at microsecond resolutions [5].



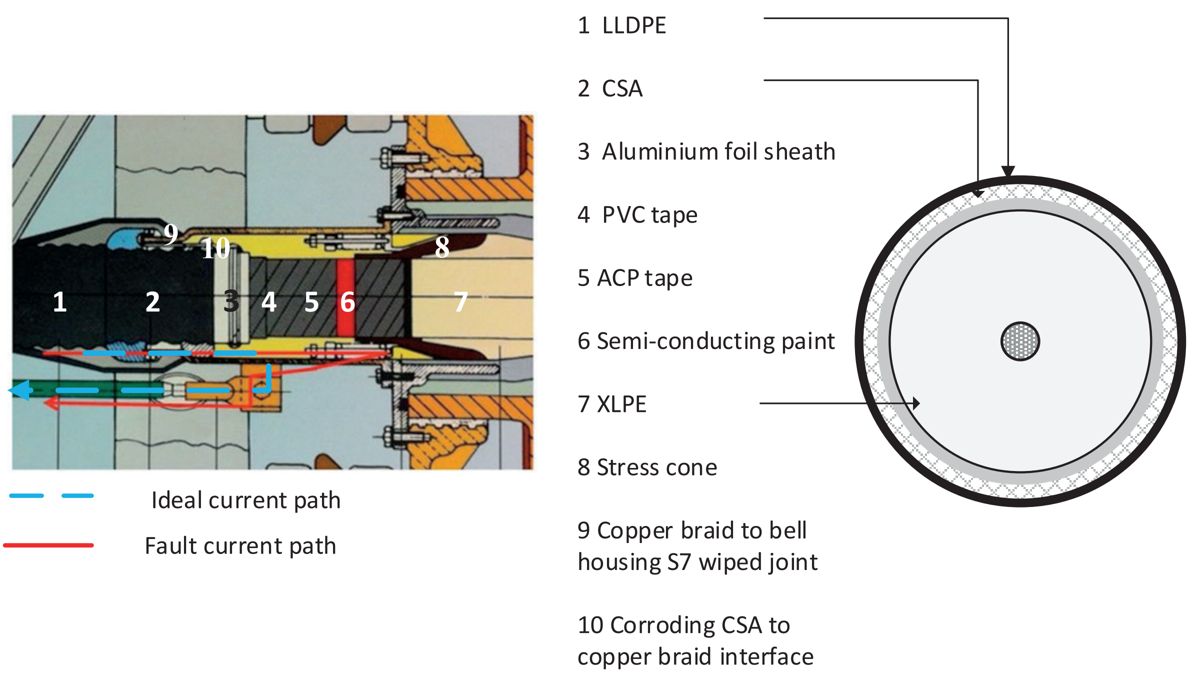
(a) Cable System Circuit **(b) Cable Termination**

Figure 1.(a) Substation system where there are 88 kV XLPE cable terminations (b) An image of an 88 kV cable termination in the case study substation

The termination structure and forensic evidence of the degradation modes

After 29 years in operation with no significant problems, the cable terminations began failing prematurely and yet the expected service life is at least 40 years. Within less than a year, 9 terminations out of a random set of 12 terminations had failed and this caused major unusual blackouts. Forensic analyses of the failed terminations revealed the presence of three categories of degradations that caused the premature failure of the cable terminations [7]. The cable structure and termination details are illustrated in Figures 2(a) and (b) respectively. In Figure 3, images of some typical evidence of failure degradations in the cable terminations are presented. In addition to inherent electro-thermal degradation of the insulation, there is evidence of thermo-mechanic fatigue cracks and galvanic corrosion degradation of metallic interfaces in the termination.

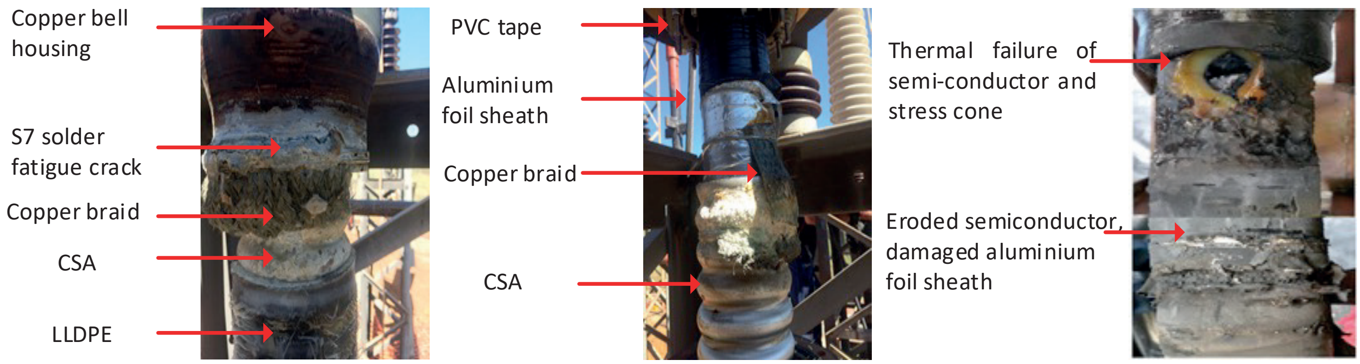
With reference to the termination structure as depicted in Figure 2(a), the soldered interface, comprising of S7 (35% tin 65% lead solder) between tinned copper braid and the copper bell housing makes up the path of the fault current to ground. This wiped metallic interface suffers mechanical fatigue fracture caused by cyclic temperature changes within the plastic range of the solder resulting in cracks as can be seen in the image of the dissected failed termination in Figure 3(a). When the fatigue fracture crack occurs on the S7 solder and there is moisture ingress there is galvanic corrosion at the interface of tinned copper braid and the CSA as shown in Figure 3(b). Excessive degradation through fatigue and corrosion diverts the fault current path from the normal route (illustrated in Figure 2(a) as a blue dashed line) to an undesired path (indicated as red solid line). Consequently the outer semiconducting layer is exposed to excessive thermo-electric stresses. The already electro-thermally aged insulation eventually is further degraded to complete failure of the termination with catastrophic effects. The above outlined sequence of degradation is not necessarily sequential as some processes can occur simultaneously and synergistically.



(a) **(b)**

Figure 2. Cross-sectional views of (a) the lower section of the termination and (b) the XLPE power cable. Sections 10 and 11 are subjected to thermo-mechanic fatigue and corrosion respectively. The failure of metal interfaces results in diversion of the fault current to undesired areas of the termination.

The thermo-mechanic fatigue stress and the galvanic corrosion stress herein identified as part of the failure modes of the termination are used to expand the existing model by Mazzanti and Marzinotto [1] using the Weakest Link Principle.



(a) Fatigue fracture **(b) Galvanic corrosion** **(c) Thermo-electric failure**

Figure 3. Degradation mechanisms in cable termination (a) Fatigue fracture at Sn35Pb65 solder joint between copper braid and copper bell housing, (b) Galvanic corrosion of CSA and copper braid interface, (c) Electro-thermal degradation and erosion of semiconductor

The reliability model formulation

The failure data of a randomly selected set of terminations were fitted into a Weibull distribution. The resultant shape parameter, β, and scale parameter, α_0, are used to fit the degradation models within Weibull distribution probabilistic framework. The data sample comprised of 12 terminations where 3 were still fully functional and 9 had failed. In this study, failure is defined as either when there is high partial discharge activity being a symptom of imminent failure or when the termination catastrophically failed. The Weibull distribution in accordance with the standard IEC62539 [11] and computed in Equation 1 was used to fit the right censored data; data that includes failed and operational terminations at the time of data collection.

$$P_W(t) = 1 - exp\left(-\left(\frac{t}{\alpha_0 \cdot \alpha}\right)^{\beta}\right) \qquad (1) \qquad [1]$$

Where $P_W(t)$ is the probability of failure at any given time, α is the degradation mechanism acceleration factor, α_0 is the statistical distribution scale parameter which represents the 63.2^{th} percentile time of failure, β is the shape parameter which is the gradient of the distribution and *t* is time [8]. The shape and scale parameter values give an indication of the possible cause of failure. When the shape parameter is less than one, the terminations fail prematurely due to either manufacturing or installation defects. A shape parameter equal to one shows failure due to random causes such as lightning strikes. A shape parameter greater than one depicts failure due to ageing [9]. In the present case study the shape parameter is 3.5 and the scale parameter is 29.87 years. The scale factor being greater than one confirms that the failure of the accessories is due to ageing. Assuming no manufacturing or installation defects the reliability of the termination can be obtained from subtracting the probability of failure from 100 % reliability as shown in Equation 2. This reliability estimates the likelihood of the terminations still in operation at the time the data was collected exceeding the designed life.

$$R(t) = 1 - P_W(t) \qquad (2)$$

The overall reliability is then obtained by substituting the Weibull distribution function given in Equation 1 into Equation 2 as shown in Equation 3.

$$R(t) = 1 - \left[1 - exp\left(-\left(\frac{t}{\alpha_0 \cdot \alpha}\right)^{\beta}\right)\right] \quad \text{or} \quad R(t) = exp\left(-\left(\frac{t}{\alpha_0 \cdot \alpha}\right)^{\beta}\right) \qquad (3)$$

Where R (t) is the reliability at any given time under the influence of a degradation mechanism characterised by the life factor, α. In the case of the cable termination, the forensically identified degradations comprise of three mechanisms; electro-thermal, thermo-mechanic and galvanic corrosion. The resultant form of the reliability model using the Weakest Link Principle (WLP) can therefore be presented by Equation 4 [1], [10].

$$R_{E,T,N,C}(t) = R_E(t) \cdot R_T(t) \cdot R_N(t) \cdot R_C(t) \qquad (4)$$

Where R_E is the electric stress reliability, R_T is thermal reliability, R_N is thermo-mechanic fatigue reliability and R_C is corrosion reliability. In the next sections the analytical reliability model for each degradation mechanism is formulated after which the overall reliability model of the termination is constructed.

The degradation stresses and corresponding life factors

Electric stress life factor, $\alpha(E, E_i)$

While in some electro-thermal life models only the effect of the steady state electric stress is considered [10], Montanari et al [11] have included the effect of impulse stress and impulse count on the electric stress life of cable insulation. The resultant electric life due to both steady state and impulse stresses can be expressed using the Inverse Power Law [9] as shown in Equation 5.

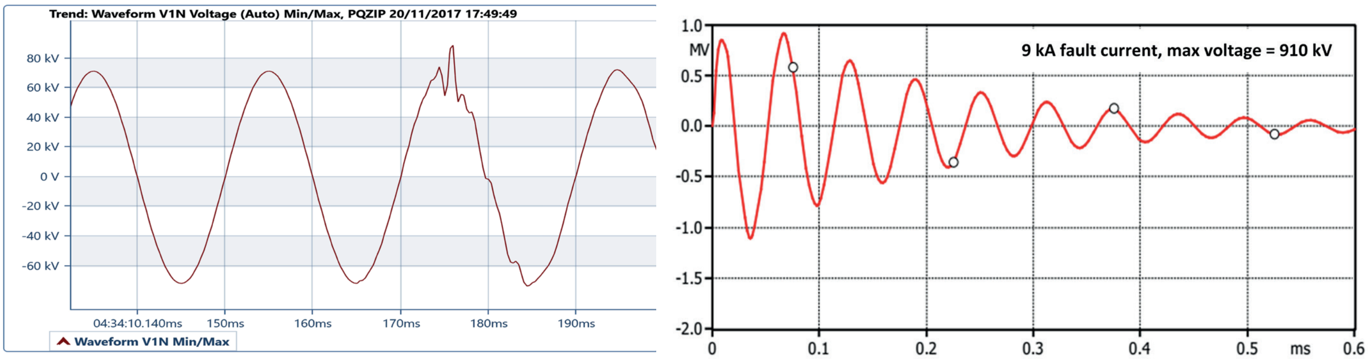
$$\alpha(E, E_i) = \left[\left(\frac{E}{E_0}\right)^{-n} \cdot \left(\frac{E_i}{E_{io}}\right)^{-n} \cdot \frac{f_0}{f_i}\right] \qquad (5)$$

The symbols and corresponding values used in the case study electric life model are listed in Table 1. In the case at hand there was no evidence of lightning strikes, therefore the maximum impulse stress E_i used in Equation 5 is that associated with switching and fault current surges. Up to 56 switching surges per month were identified in the records and this translate into frequency of occurrence, f_i, of 2.24 x 10^{-5} Hz.

Table 1. Electric stress model life parameters

Description	Symbol	Value
Electric stress life factor (obtained using Equation 5)	$\alpha(E,E_i)$	1.175 x 10^6
Maximum continuous stress (Obtained through FEMM simulations at maximum operating peak voltage)	E	5.35 kV/mm
Design stress (76/132kV XLPE Al core CSA cable)	E_o	6.8 kV/mm
Maximum impulse stress (Switching impulse stress at maximum switching voltage)	E_i	64.4 kV/mm
BIL stress	E_{io}	50 kV/mm
Voltage endurance coefficient	n	2.33
Power frequency	f_o	50 Hz
Frequency of impulses (impulse count obtained from the data measurement system)	f_i	2.24 x 10^{-5} Hz

The switching surges include circuit breaker operations of the GIS (Gas Insulated Switchgear). Figure 4 shows an example of a transient incident recorded and a fault current surge simulated in ATPdraw™.



(a) Transient incident recorded by data measurement system **(b) Simulated Fault Current Surge**

Figure 4. Switching transients recorded in the substation black box system

The absence of a grounded connection on the surge arrestors in the termination exposes the terminations to transient overvoltages emanating from lightning, switching and fault current surges. A phase-to-ground fault current of 9 kA results in a maximum voltage of 910 kV as calculated using Equation 6 for the metallic sheath [12].

$$E_{sh} = 107 \cdot \left(\frac{S}{d}\right)^{0.369} \cdot l_c \cdot I_c \qquad (6)$$

Where E_{sh} is the maximum induced sheath voltage at the non-grounded end. S is the centre to-centre cable spacing of 36.12 cm, d is the mean sheath diameter 98 mm, l_c is the cable length of 100 m and I_c is the conductor current. When the SVL (sheath voltage limiter) at the GIS side of the cable is faulty there is a higher induced sheath voltage at the termination end. Furthermore, when the metallic interfaces in the cable termination fail due to corrosion or thermo-mechanic fatigue the fault current ground path is disrupted therefore the single point bonding of the cable system is also open circuited. The compromised ground connection on the cable termination together with a non-grounded station surge arrestor and SVL (due to cable theft) result in a relatively high sheath voltage of up to 15.6 kV under fault current conditions instead of the maximum allowable value of 6-7 kV [12].

Thermal stress degradation life factor, α (t, T)

In the present case study, the material with the least thermal strength in the termination is the XLPE insulation [14]. The rate of thermal degradation of the termination depends on the maximum temperature, its duration as well as the activation energy required to initiate thermal degradation in XLPE insulation. Cyclic load profiles, fluctuating ambient temperatures and the thermal capacities of interfacing materials affect the overall temperature changes in the termination [14]. The thermal stress life is modelled using Arrhenius law [15]. The summation of life fractions lost at each temperature step are modelled using Miners rule [9]. The combination of Miner and Arrhenius laws give an estimate of thermal stress life as shown in Equation 7. The parameters used in Equation 7 are expressed in Table 2.

$$\alpha(t, T_i) = \sum_{i=1}^{N} \left\{ \int_0^{\Delta t_i} \frac{dt}{exp\left(\frac{\Delta W}{k_B}\right) \cdot (1/T_o - 1/T_i)} \right\} \qquad (7)$$

In the case study, the highest load current was recorded during the winter seasons. A typical winter day hourly current step profile obtained from the data measurement system combined with the hourly winter external temperatures are used to calculate the transient temperatures in the critical layers of the cable termination. Using IEC60853-2 standard [13] and the Cigré two loop network [16], the transient temperature changes of the conductor corresponding to each step current are calculated using Equation 8.

Table 2. Thermal life model parameters

Description	Symbol	Value
Electric stress life factor (Calculated using Equation 7)	$\alpha(t,T_i)$	3.49
XLPE thermal degradation activation energy [8]	ΔW	117.12 eV
Boltzmann's constant	k_B	8.617 x 10^{-5} eV/K
Maximum operating temperature	T_o	93.53 °C
Step operating temperatures	T_i	*See figure 3
Temperature steps (Hourly)	N	24
Hourly average winter temperatures T_{Ei} in degrees celcius	8,7,7,6,6,5,5,6,8,11,12,13,14,15,14,14,13,12,9,9,8,8,9,8	

$$T_{ci} = W_d\ [T_a(1-e^{-at}) + T_b(1-e^{-bt})] + \frac{T_a(1-e^{-at})+T_b(1-e^{-bt})}{T_a+T_b} \cdot T_{Ei} \qquad (8)$$

Where T_{ci} is the conductor temperature change above the surface temperature of the cable due to each current step change. W_d is the heat losses, T_a and T_b are the thermal resistances of the cable, a and b are the time constants of the first and second thermal network respectively and T_{Ei} is the hourly environmental daily average temperature during the winter season. Assuming one directional heat flow, isotropic heat flow and a constant thermal conductivity for each material in the termination, the transient temperature changes in the XLPE insulation and subsequent layers of the cable were computed using the Fourier heat equation [17] shown in Equation 9. The thermal conductance, thickness as well as the distance away from the conductor heat source determines the temperature changes of each layer.

$$T_{n(i+1)} = T_{ni} + \frac{I^2 R \cdot \ln\left(\frac{r_{n(i+1)}}{r_i}\right)}{-K_i \cdot 2\pi L} \qquad (9)$$

Where $T_{n(i+1)}$ is the temperature change of layer $n(i+1)^{th}$ due to the temperature change $T_{ni,}$ at the i^{th} layer, I is the cyclic load current, R is the conductor resistance, K_i is the thermal conductance, L is the cable length, r_{i+1} and r_i are the thicknesses of the interfacing layers. Operating load profiles over a year obtained from the substation data measurement system show that the worst load cycle profile occurs in winter. Using Equation 8 and 9, Figure 5 shows the calculated changes in the main layers of the cable due to cyclic current on a typical winter day.

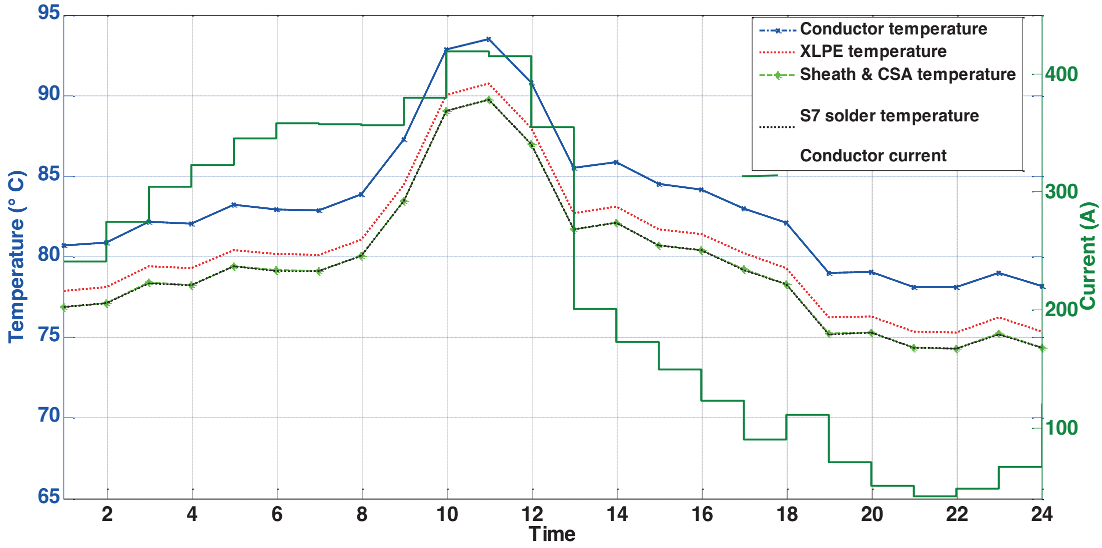
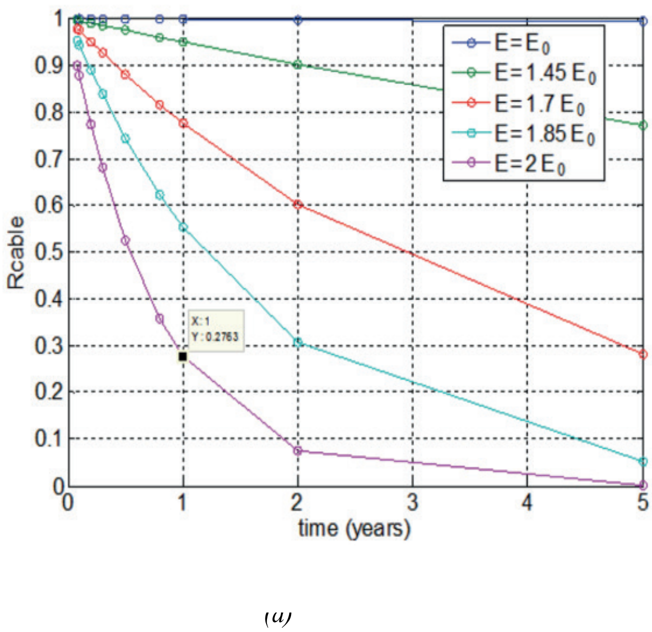


Figure 5. Temperature changes with worst case load profile trend.

Electro-thermal reliability, R(E,T)

An alternating electric field causes dipole relaxation within the insulation and this resulting in gradual expansions of the air pockets within the insulation thereby degrading the insulation. At a critical electric field stress when the heat generated by dipole relaxation exceeds the heat dissipated from the insulation, there is permanent damage [9]. Due to a synergistic relationship between electric and thermal degradation the effect of the two failure modes can be combined. The results obtained in a model by Mazzanti et al are compared to those obtained for steady state electric stress conditions in the case study terminations. These results are shown in Figure 6 below.



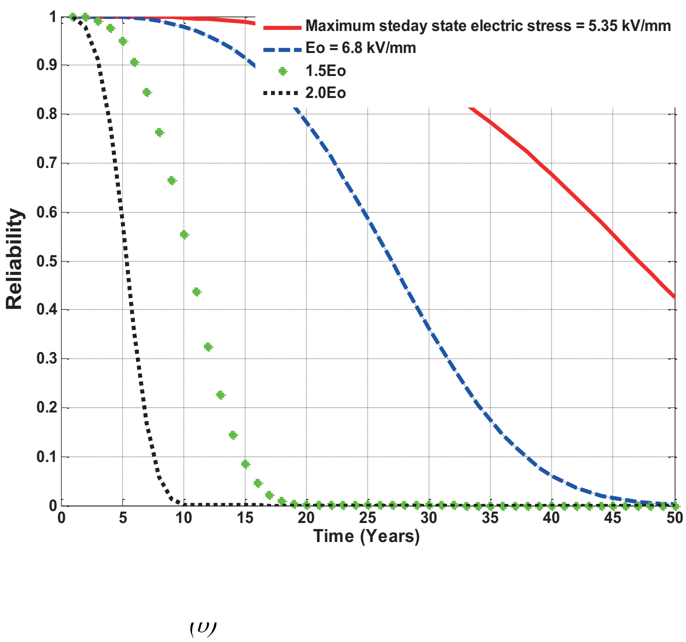


Figure 6. (a) Existing electro-thermal model (reproduced with permission from Mazzanti [1] for an HVDC cable system (b) Steady state electro-thermal reliability of case study cable terminations at XLPE temperature (min ≈ 75 °C, max ≈ 91 °C).

The two models produce comparable trends showing reduced reliabilities with time at higher electric field stresses. The specific values are however different since the rate of life lost is a function of site and system specific conditions as manifested in the Weibull shape and scale parameters. In the present case study, at a steady state operating electric field stress of 5.35 kV/mm and in the absence of switching and lightning surges, the electro-thermal reliability depicted after 29 years in operation is above 90 %, which would not be a cause for concern. This shows that electro-thermal degradation on its own is not the dominant degradation stress within the termination and there are no installation or manufacturing defects. The model also shows that increasing maximum continuous electric field stress beyond the design stress of 6.8 kV/mm results in a life-span that is lower than 40 years. Switching and lightning impulses are therefore expected to lower the reliability substantially in the absence of a grounded station surge arrestor and SVL.

In the study a switching frequency of occurrence of 2.24 x 10^{-5} Hz in the absence of a station surge arrestor or SVL produced comparable results to those obtained under steady state conditions. However, in GIS substations, VFT (Very Fast Transients) that are caused by the switchgear operations introduce high resultant stress conditions especially due to the travelling wave voltage reflection phenomena [18]. In Figure 7 the effect of switching electric fields at a frequency of occurrence of 2.24 x 10^{-5} Hz on the average projected reliability of the termination is presented. A switching stress of 105.5 kV/mm will result in a 50% average reliability after 29 years in operation.

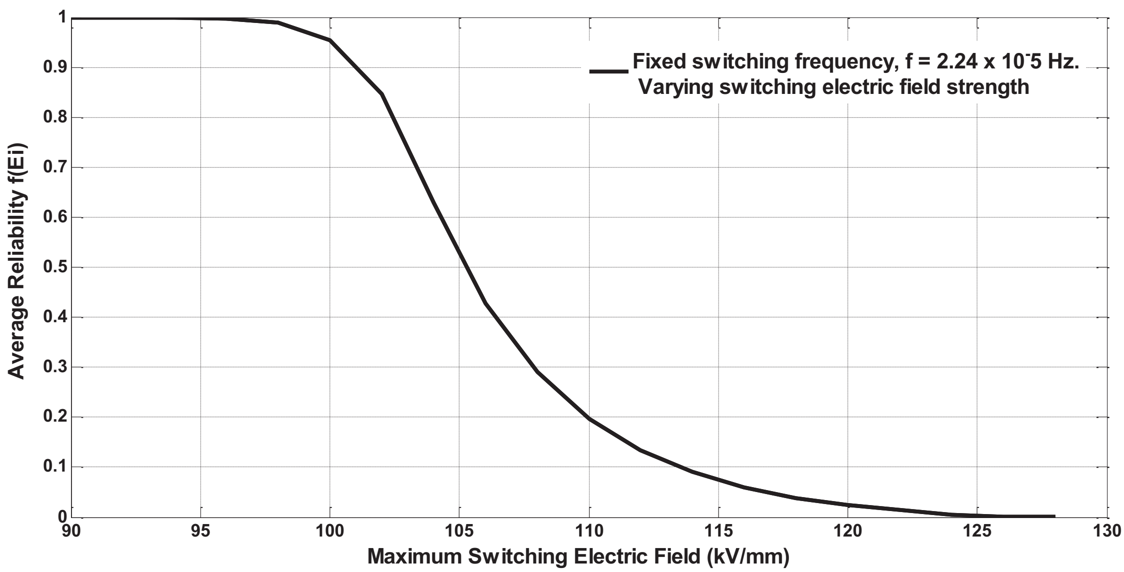


Figure 7. Effect of varying switching electric field strength and impulse count on reliability for terminations in the case study substation after 29 years in operation.

Thermo-mechanic fatigue life factor, α (N)

Forensic evidence shows thermo-mechanic fatigue induced cracking at the S7 wiped interface of the tin-plated copper braid and the copper bell housing [19]. Fatigue fracture occurs in the presence of plastic strain, cyclic and tensile stress. Cyclic load cycle temperature range and frequency affect the rate of fatigue fracture growth. Equation 10 shows the fatigue stress life acceleration factor evaluated using Landzberg and Norris model that is based on Arrhenius and Coffin-Manson laws [9].

$$\alpha(N) = \left(\frac{f_{T0}}{f_T}\right)^{-a} \cdot \left(\frac{\Delta T}{\Delta T_0}\right)^{-b} \cdot exp\left(\frac{A_E}{k_B} \cdot (1/T_{T0} - 1/T_{max})\right) \qquad (10)$$

Table 3. Thermo-mechanic parameters

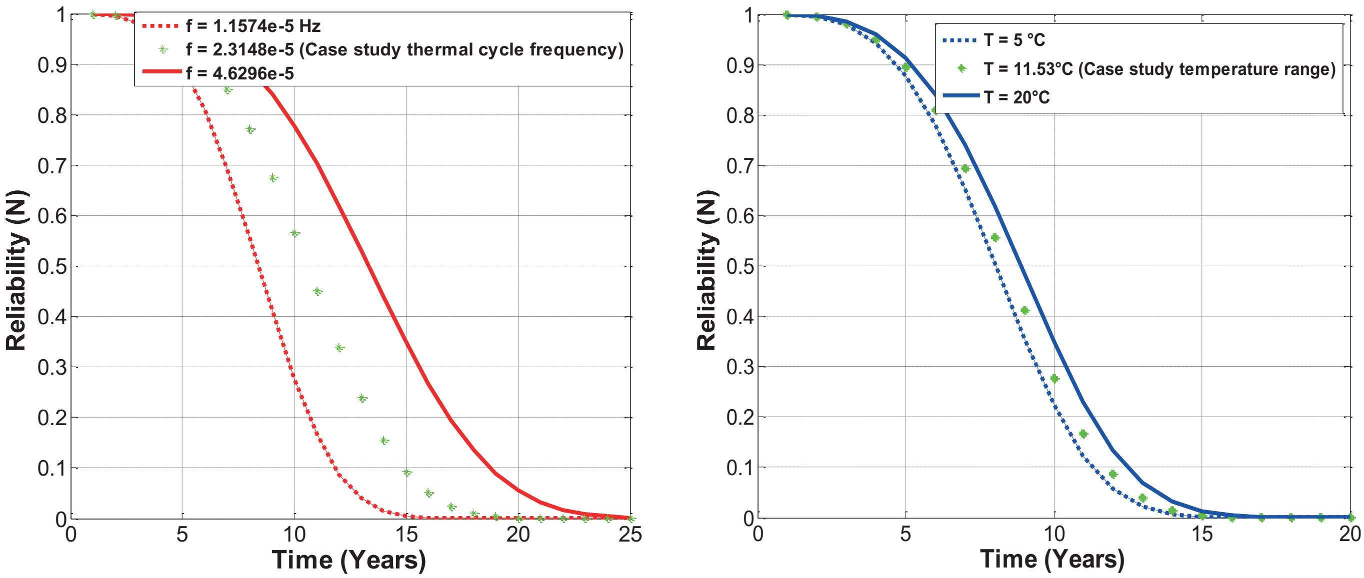
Description	**Symbol**	**Value**
Thermo-mechanic fatigue stress life factor	$\alpha(N)$	0.72
Design thermal cycle frequency (Based on the assumption that there are two thermal cycles per day)	f_{TO}	2.314 x 10 $^{-5}$ Hz
Thermal cycle frequency (Obtained from the thermal cycle frequency of Figure 5)	f_T	1.157 x 10 $^{-5}$ Hz
Solder operating temperature range (Obtained from Figure 5)	ΔT	11.53 °C
S7 (35/65, Sn/Pb) temperature range [20]	ΔTo	223 °C
Temperature steps in a 24 hour day	N	24
S7 material constant [20], [21]	a	1/3
S7 material constant [20], [21]	b	1.9
S7 activation energy to reach fracture [21]	A_E	0.12 eV
Boltzmann constant	k_B	8.617 x 10 -5 eV/K
Design maximum temperature [21] (Melting point of Sn35Pb65 solder	T_{T0}	183 °C
S7 maximum operating temperature (Obtained from Figure 5)	T_{max}	89 °C

The ratio of operating temperature range, ΔT, to the maximum design temperature range, ΔT_o, as well as the ratio of design thermal frequency, f_{T0}, to operating thermal frequency, f_T, are critical in fatigue fracture. The design thermal cycle frequency is assumed to be at least 2 cycles per day for a 40-year life span. This assumption is taken from winter load cycle trends where peak consumption occurs twice a day during the morning and evenings.

Thermo-mechanic fatigue reliability, R(N)

The resilience of thermal cycle frequency and temperature range on S7 solder reliability is shown in Figure 8. By holding the thermal cycle frequency constant at 1.157 x 10^{-5} Hz and varying the temperature from 5 to 20 °C, Figure 8(a) shows that the reliability changes marginally. If however the temperature is held constant at 11.53 °C and cycle frequencies varied from f = 1.157 x 10^{-5} Hz to f = 4.6296 x 10^{-5}, the changes in reliability are relatively more significant as shown in Figure 8(b). The model therefore shows that the S7 solder reliability is more sensitive to thermal cycle frequency in comparison to changes in temperature range. However, the thermo-mechanic fatigue model underestimates the rate of crack formation and growth in the S7 solder because it does not take into account the effect of rate of temperature variation (ramp time) and the durations (dwell time) of the maximum and minimum temperature [20]. Ramp and dwell time can introduce creep simultaneously with fracture. The effects of creep are indirectly observed from the trend shown in Figure 8, where an increase in thermal cycle frequency and temperature range gives a lower likelihood of failure with time this is because at lower frequencies the termination may be exposed to high temperatures for a longer period which causes more synergy between creep and fatigue.

The effect of IMC (Intermetallic Compound Growth) has been omitted as it is only prevalent at non-cyclic temperatures above 200° C. It is evident that in the design of the termination, the thermal cycling strengths of materials used may not have been considered. Thermal tests on cables are only focused on the primary components of the cable, while the secondary materials added on during installation such as solders, PVC and ACP tape are not adequately tested to ensure full functionality under operating conditions. Such an anomaly needs to be corrected in modern designs.



(a) *(b)*

Figure 8. Thermo-mechanic fatigue at (a) ΔT = 11.53 °C and different thermal cycles (b) f = 1.157 x 10 $^{-5}$ Hz (1 cycle per day) *and different temperature range.*

Galvanic corrosion life factor, α(C)

When overlaying materials are weakened by thermal expansion and contraction, fissures develop through which moisture ingress occurs. In the terminations under study, the funnel shape of the copper bell housing together with the gradual roll-back of the protective materials create conducive conditions for channelling water flow through fissures into the cable termination. The electron affinity difference between the tinned copper braid and CSA interface in the presence of moisture results in galvanic corrosion [22]. Pourbaix's theory on the thermodynamics of corrosion states that an optimum hydrogen concentration and voltage facilitates corrosion [23]. A combination of Pecks and Arrhenius laws can be used to model the corrosion stress life in the form of Equation 11. The symbols and assigned values are presented in Table 4.

$$\alpha(C) = \left(\frac{RH}{RH_0}\right)^{-M} \cdot exp\left\{\frac{A_c}{k_B}(1/T_{CO} - 1/T_{max})\right\} \qquad (11)$$

Table 4. Corrosion model parameters

Description	**Symbol**	**Value**
Corrosion stress life factor (Computed in Equation 11) Feinberg et al [22]	*α(C)*	0.67
Maximum annual site humidity (Site average annual humidity)	*RH*	59 %
Critical threshold humidity	RH_0	40 %
Corrosion metal constant from Feinberg et al[22]	*M*	2.66
Aluminium galvanic corrosion energy [7], [24]	A_c	0.8 eV
Boltzmann constant	k_B	8.617 x 10 -5 eV/K
Design maximum operating temperature	T_{CO}	90°C
Maximum temperature, Aluminium and Copper interface (From Figure 5)	T_{max}	89 °C

The activation energy of corrosion is also known as Gibbs free energy. It is a function of applied voltage, Faradays constant and the available number of electrons in the electrochemical cell [22]. When the free energy is negative, corrosion occurs spontaneously and when it is positive the process occurs provided there is a sufficient temperature increase in the galvanic cell. The galvanic action results in the resistance of the aluminium sheath and CSA increasing significantly in comparison to that of copper [25]. Alternating voltage and current at the sheath surface results in intermittent corrosion, where in either the positive or negative half cycle (depending on the galvanic cell polarity) corrosion is aided or hindered.

The complex thermodynamic nature of corrosion is a non-continues process where the galvanic cell changes with alternating sheath voltage and changing ionic concentration. The process is therefore sometimes active and sometimes inactive, however, its by-products drastically increase the contact resistance between the CSA and tinned copper braid and gradually destroys the critical fault current path [25]. The physical position of the metals (aluminium and copper) relative to each other is important. If copper (cathode) is placed above the aluminium (anode) and the water flows down from the copper to the aluminium, it will result in weak copper salts dropping onto the aluminium, thus drastically reducing the aluminium with time. If the aluminium is placed above the copper then the corrosion rate is much slower, as the natural flow of water opposes that of the electrical connection between copper and aluminium. The electrolytic concentration is not known and may vary with time, therefore there will be a varying activation energy of corrosion. In the presence of acidic or chloride ions the activation energy is much reduced [26]. The optimum humidity for corrosion to occur also varies with temperature and electrolyte concentration. It is therefore difficult to evaluate the sensitivity or optimism of the corrosion model. In the present work model, only galvanic action is considered, however it is likely that other forms of corrosion are present such as pitting and crevice corrosion [27]. Galvanic action is only considered as there are two metals with different affinities in contact and forensic evidence shows the presence of galvanic action by-products.

Corrosion reliability, R(C)

The effect of humidity and the corrosion activation energy on reliability under corrosion is depicted in Figure 9. The activation energy of corrosion is a function of the potential difference between the interfacing materials, Faradays constant and the number of free electrons in the cell [22]. Figure 8 shows that humidity has a greater effect on the rate of galvanic corrosion in comparison to the activation energy. From Figure 9, in order for the termination to withstand corrosion beyond its design lifespan, not more than 20% humidity should reach the copper braid and CSA interface.

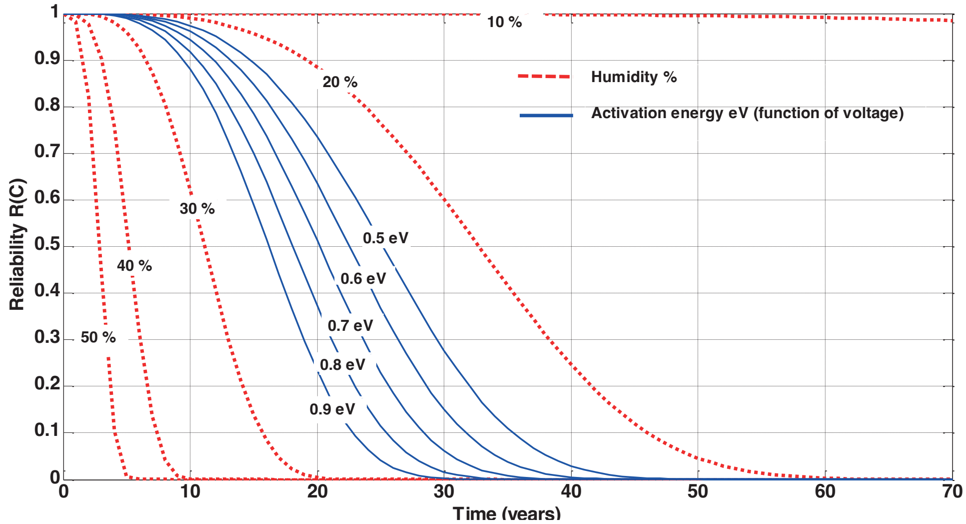


Figure 9. Effect of corrosion humidity and activation energy on reliability

Overall reliability

In the preceding sections, the reliability models for individual degradation stress type have been presented. The sensitivities of each model to changes in the influencing parameters were evaluated. For a system made up of various components such as a termination, each with its own life model, the overall reliability of the termination system is the product of reliabilities due to each degradation mechanism. This ensures that the most prevalent degradation mechanism determines the overall reliability of the system. Mazzanti and Marzinotto [1] developed an electro-thermal reliability model for a power cable system where the overall reliability is a product of reliabilities of each component in the system in accordance with the Weakest Link Principle [1]. In the present work the sample principle is employed where the overall reliability is obtained by substituting the acceleration factor of each degradation mechanism as shown in Equation 12 [10].

$$R_{E,T,N,C}(t) = exp\left[-\left(\frac{t}{\alpha_0 \cdot \alpha_{E,T}}\right)^{\beta}\right] \cdot exp\left[-\left(\frac{t}{\alpha_0 \cdot \alpha_N}\right)^{\beta}\right] \cdot exp\left[-\left(\frac{t}{\alpha_0 \cdot \alpha_C}\right)^{\beta}\right] \quad (12)$$

Where $\alpha_{E,T}$ is the Electro-thermal life factor, α_N is the Thermo-mechanic life factor and α_C is the corrosion life factor. A plot of Equation 12 is presented in Figure 9 and is the overall reliability of the termination at the time of the study. In the same Figure, plots of individual reliabilities corresponding to electro-thermal, thermo-mechanic and galvanic life factors are plotted. The results show that electro-thermal stress does not reduce the reliability of the termination below the design operating life. However, the thermo-mechanic and galvanic degradation each reduce the termination life to less than 30 years.

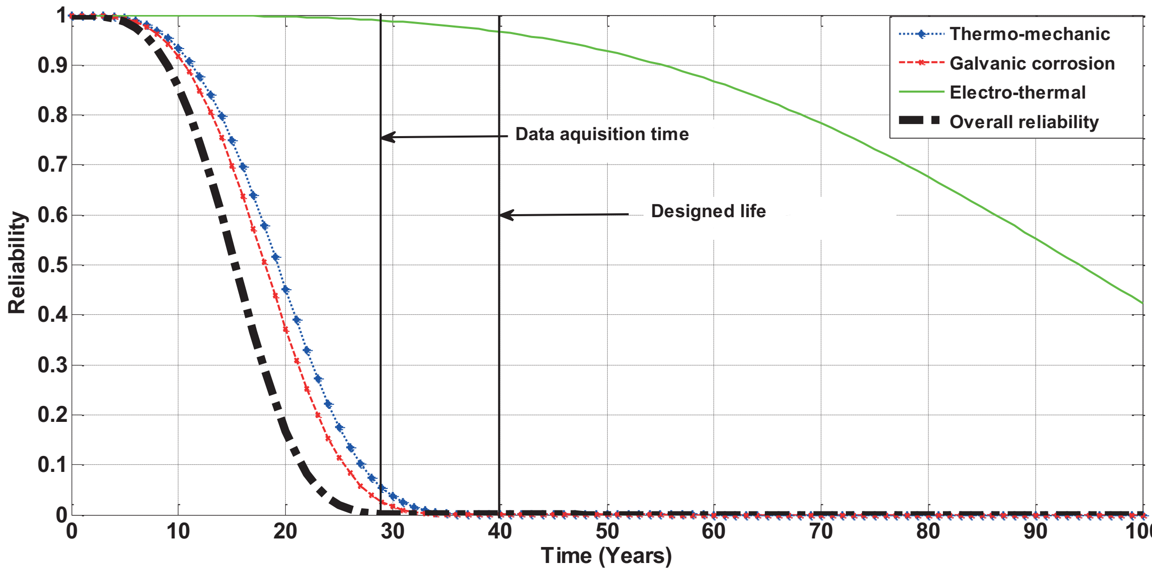


Figure 10. Reliability under thermo-mechanic, electro-thermal, galvanic corrosion and overall reliability for case study substation

Thermo-mechanic fatigue and corrosion are therefore the predominant modes of failure. Corrosion increases the resistance of the fault current path while fatigue fracture disconnects the fault current path [19]. When the fault current flows through an alternative path across the semiconductor towards the stress cone, it further enhances the electro-thermal stresses. Consequently, as shown in Figure 10, the overall life of the cable system is reduced to below 30 years as galvanic corrosion and thermo-mechanic stress become the life determining factors. The use of maximum stress magnitudes in the model and omission of stress durations provides a balanced sensitivity. Some stresses occur alternately while others, such as corrosion, are complex and change with the pH levels and voltages resulting in the reversal of electron flow between the copper braid and CSA.

Reliability evaluation of the improved termination design

The cable terminations in the case study substation have metallic interfaces that are exposed to prevalent thermo-mechanic fatigue and corrosion. Elimination of galvanic corrosion by ensuring a water tight termination and using low or lead free solder may improve the reliability of the metallic interfaces. If a Sn60Pb40 solder is used there will be a minor improvement in reliability as shown in Figure 11 below. However, when water is restricted from entering the cable termination, the corrosion reliability is immensely improved such that the termination will exceed its design life. In this light, design changes may improve cable termination reliability.

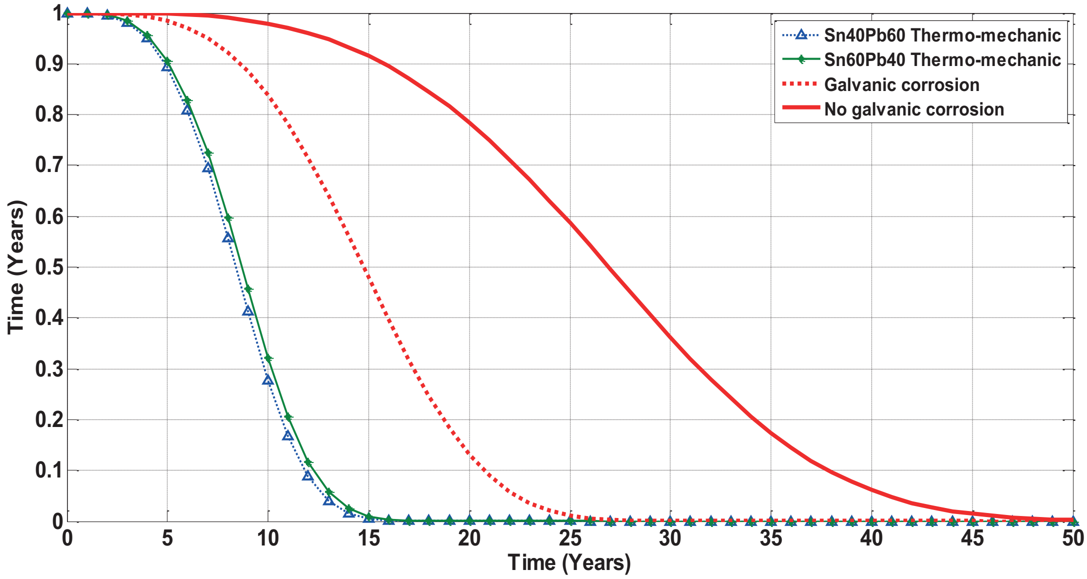


Figure 11. Effect of Sn60Pb40 solder and absence of galvanic corrosion on reliability of the termination

The results obtained in this case study give a projection on the likelihood of the terminations reaching their design life at 29 years in operation. The trends shown are subject to change with time as 3 terminations were still operational and their time of failure would change the scale and shape parameters of the Weibull distribution, thus giving a different reliability projection with time. This model is therefore valid for specific designs where possible degradation mechanisms have been identified. In this light the accelerated life laboratory test results could provide the preliminary parameters that can be combined with online monitoring systems data to obtain a real-time computation of reliability with time.

Conclusion

Power cable terminations are designed to live for at least a specific life period. The terminations however mail fail before the expected end of life either because of installation faults or premature ageing. In cases where there is a population of similarly designed terminations installed within the same period, it is useful to periodically determine the life probability of the terminations at any given time. Informed appropriate asset management decisions can then be implemented. The procedure for the life modelling can be summarised as follows;

- Identify the population of the terminations of similar designs and installed during the same period.
- At a chosen time during the life period of the terminations, take a record of the total number of failed and healthy terminations. Compute the Weibull distribution analysis of the data to determine the corresponding shape and scale parameters.

- Determine the reliability (the probability that the termination will live up to the design life) as a function of each degradation mechanism life factor. Each life factor is modelled as an analytical expression being a function of the various factors that influence the specific degradation processes.
- The overall reliability at any given time, is a product of all the constituent reliabilities. wn

Acknowledgement

The authors would like to express gratitude to Mr Patrick O'Halloran for access to the data used in this study and also useful technical insight. Givemore Chitungo is also thanked for technical support on the lightning data. Furthermore, the authors would like to thank Hylton Dettmer for his assistance with the PQSCADA Sapphire Elspec software.

References

[1] G. Mazzanti and M. Marzinotto, 'Advanced Electro-Thermal Life and Reliability Model for High Voltage Cable Systems Including Accessories', *DEIS*, vol. 33, no. 3, pp. 17–25, May/June.
[2] M. Marzinotto and G. Mazzanti, 'Merging the electro-thermal life model for power cables with the statistical volume enlargement law', in *2014 IEEE Conference on Electrical Insulation and Dielectric Phenomena (CEIDP)*, 2014, pp. 502–505.
[3] G. C. Montanari, G. Mazzanti, and L. Simoni, 'Progress in electro-thermal life modelling of electrical insulation during the last decades', *IEEE Trans. Dielectr. Electr. Insul.*, vol. 9, no. 5, pp. 730–745, Oct. 2002.
[4] G. Mazzanti, 'The combination of electro-thermal stress, load cycling and thermal transients and its effects on the life of high voltage ac cables', *IEEE Trans. Dielectr. Electr. Insul.*, vol. 16, no. 4, pp. 1168–1179, Aug. 2009.
[5] M. Cacciari, G. C. Montanari, L. Simoni, A. Cavallini, and A. Motori, 'Long-term electrical performance and life model fitting of XLPE and EPR insulated cables', in *Proceedings of the 1991 IEEE Power Engineering Society Transmission and Distribution Conference*, 1991, pp. 135–142.
[6] G. C. Montanari, G. Pattini, and L. Simoni, 'Long - Term Behaviour of XLPE Insulated Cable Models', *IEEE Trans. Power Deliv.*, vol. 2, no. 3, pp. 596–602, Jul. 1987.
[7] P. O'Holloran, 'Site Visit, In Conversation', 2017.
[8] IEC62539, 'Guide for the statistical analysis of electrical insulation breakdown data', IEEE, 2007.
[9] W. Nelson, *Accelerated Testing Statistical Models, Test Plans and Data Analysis*. New Jersey: John Wiley & Sons, 1990.
[10] G. Mazzanti, 'Analysis of the Combined Effects of Load Cycling, Thermal Transients, and Electro-thermal Stress on Life Expectancy of High-Voltage AC Cables', *IEEE Trans. Power Deliv.*, vol. 22, no. 4, pp. 2000–2009, Oct. 2007.
[11] G. C. Montanari, D. Fabiani, and F. Ciani, 'Partial discharge and aging of AC cable systems under repetitive voltage transient supply', in *2016 IEEE Electrical Insulation Conference (EIC)*, 2016, pp. 379–382.
[12] 'IEEE Guide for Bonding Shields and Sheaths of Single-Conductor Power Cables Rated 5 kV through 500 kV', *IEEE Std 575-2014 Revis. IEEE Std 575-1988*, pp. 1–83, Sep. 2014.
[13] IEC standard 60853-3, 'Calculation of the cyclic and emergency current rating of cables - Part 3: Cyclic rating factor for cables of all voltages, with partial drying of the soil', IEC, Feb. 2002.
[14] Z. Zhang, P. Dieu Seul Assala, and L. Wu, 'Residual life assessment of 110 kV XLPE cable', *Electr. Power Syst. Res.*, vol. 7796, no. 0378, p. 9, 2018.
[15] D. Kececioglu and J. A. Jacks, 'The Arrhenius, Eyring, inverse power law and combination models in accelerated life testing', *Reliab. Eng.*, vol. 8, no. 1, pp. 1–9, Jan. 1984.
[16] S. B. Liu, 'Calculation of the Steady-State and Transient Temperature Rises of Round Cable Bundles', *IEEE Trans. Power Deliv.*, vol. 25, no. 3, pp. 1229–1235, Jul. 2010.
[17] J. Coulson, J. Richardson, and J. Backhurst, *Fluid Flow Heat Transfer and Mass Transfer*, 6th ed., vol. 1. 1999.
[18] M. Stosur, M. Szewczyk, W. Piasecki, M. Florkowski, and M. Fulczyk, 'GIS disconnector switching operation #x2014; VFTO study', in *2010 Modern Electric Power Systems*, 2010, pp. 1–5.
[19] K. Leeburn, 'Corrosion Report Delbank & Prospect', CBI Electric, Forensic report PT01115, Aug. 2015.
[20] H. Cui, 'Accelerated Temperature Cycle Test and Coffin-Manson Model for Electronic Packaging', in *Annual Reliability and Maintainability Symposium, 2005. Proceedings*, 2005, pp. 556–560.
[21] C. Basaran and J. Jiang, 'Measuring intrinsic elastic modulus of Pb/Sn solder alloys', *Elsevier*, vol. 34, pp. 349–362, Apr. 2002.
[22] A. Feinberg and A. Widom, 'On thermodynamic reliability engineering', *IEEE Trans. Reliab.*, vol. 49, no. 2, pp. 136–146, Jun. 2000.
[23] R. Baboian and S. Begum, 'Corrosion, Galvanic', in *Reference Module in Materials Science and Materials Engineering*, Elsevier, 2016.

[24] J. Skrovan, 'Activation Energy for the Corrosion of Aluminum Powders in Water', *ECS Trans.*, vol. 41, no. 25, pp. 143–154, May 2012.
[25] A. van Deursen, B. Kruizinga, P. Wouters, and E. Steennis, 'Impact of corrosion on the reliability of low voltage cables with aluminium conductors', presented at the UPEC Universities Power Engineering Conference, 2017, vol. 52.
[26] H. B. Peacock, R. L. Sindelar, and P. S. Lam, 'Temperature and humidity effects on the corrosion of aluminium-base reactor fuel cladding materials during dry storage', 2004.
[27] 'A Study of Corrosion Factors and the Electrochemical Theory', *Ind. Eng. Chem.*, vol. 17, no. 4, pp. 339–346, Apr. 1925.

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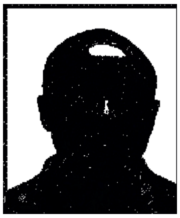
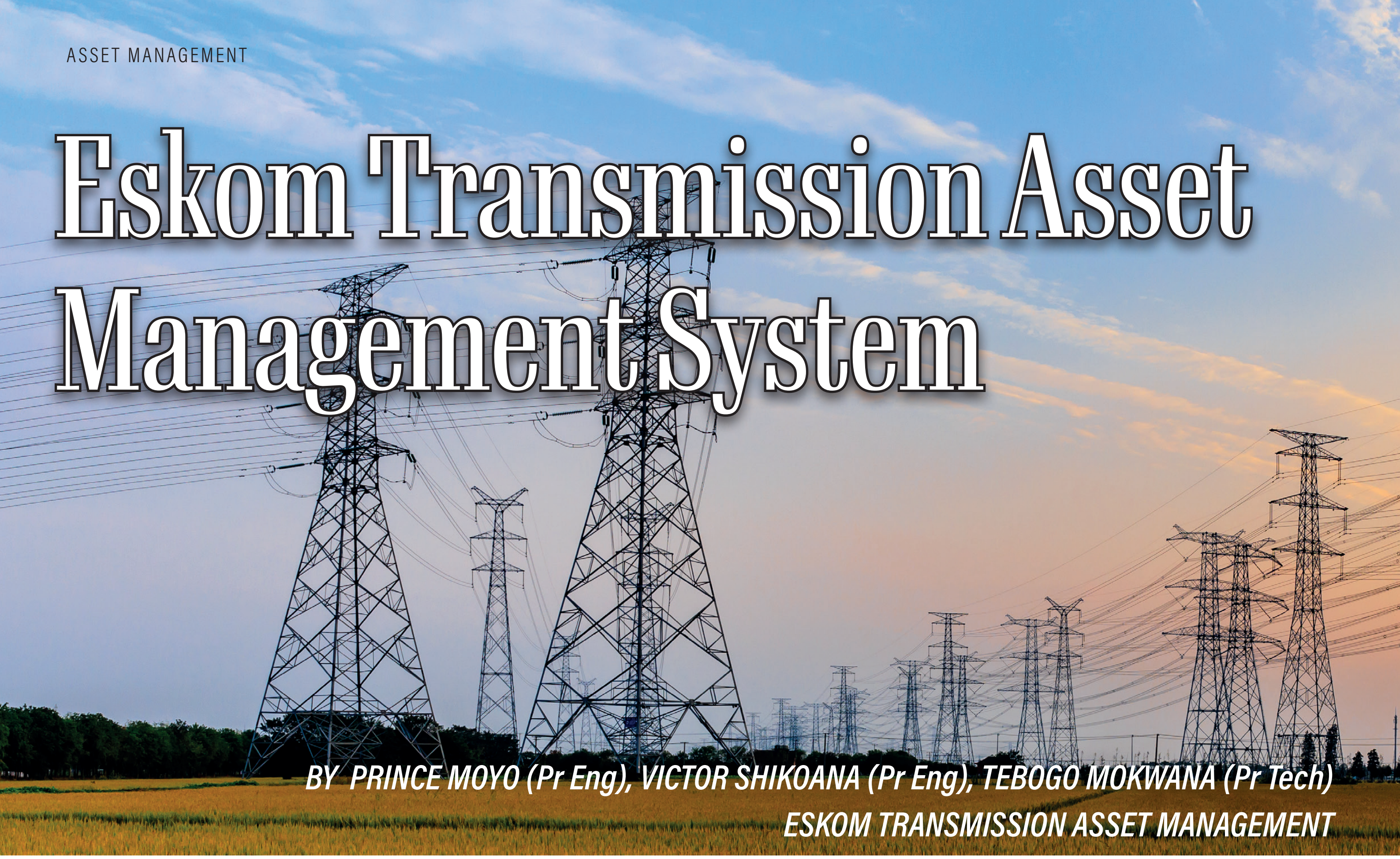


Cuthbert Nyamupangedengu was born in Zimbabwe. He received the Bachelors honours degree in electrical engineering from the University of Zimbabwe in 1994. At the University of the Witwatersrand, Johannesburg, in 2004, he was awarded the M.Sc. Engineering (with distinction) and in 2011, the Ph.D. He is an associate professor at the University. Before moving to the University of the Witwatersrand, Cuthbert was an engineer in the Zimbabwe Electricity Supply Authority from 1995 to 2005 in various capacities mainly in power system planning and development. His passion is research on development and diagnosis of high voltage insulation.

Eskom Transmission Asset Management System



BY PRINCE MOYO (Pr Eng), VICTOR SHIKOANA (Pr Eng), TEBOGO MOKWANA (Pr Tech)
ESKOM TRANSMISSION ASSET MANAGEMENT

Management systems come in a variety of forms to ensure that the various activities undertaken by an organisation are integrated and coordinated so that they can achieve specific objectives. These systems are most popular among organisations that seek to align with and ensure that their practices are aligned with international best-practice approaches for sustainably realising their goals.

The International Organisation for Standardisation (ISO) defines management systems as "a set of interrelated or interacting elements of an organisation to establish policies, objectives, and processes to achieve those objectives". These objectives can relate to several management focus areas, namely Quality, the Environment, Occupational Health and Safety, Risk and Asset Management, among many other compelling focus areas.

This article focuses on the system for Asset Management with which Eskom Transmission is aligning its practices to ensure the sustained realisation of value from its physical assets.

ESKOM TRANSMISSION

Eskom Transmission is a division of Eskom that transmits electric power from generating plants to distribution networks. The business is mandated to provide a reliable and efficient transmission network, a system operator, and energy market services in South Africa and designated electricity markets. The transmission network comprises high-voltage assets (power lines, cables, transformers, etc.) that transfer power to the distribution networks.

Transmission is a highly asset-intensive organisation that warrants having good asset management practices. The figure below illustrates some of the key Eskom Transmission assets, with a regulatory asset base of R111 billion as per NERSA's reason for its decision on Eskom's revenue application for the fifth Multi-Year Price Determination (MYPD5) in the 2022/23 financial year.

The operating model for the Transmission business is evolving as part of the Department of Public Enterprises' plan to reform South Africa's electricity supply industry. Eskom's unbundling will result in three legally separated entities (i.e. Generation, Transmission, and Distribution) wholly owned by Eskom. The Transmission Business Plan

Eskom Tx Asset Base (R111bn)	Number
HV Plant Assets	
Substations	182
Power Transformers	595
High Voltage Reactors	115
Circuit Breakers	3505
Isolators & Earth Switches	2 263
Instrument Transformers	16 987
Gas Insulated Substation	14
Capacitor Banks	157
Secondary Plant Assets	
Protection Systems	2 458
Metering systems	1 227
DC Systems	1 630
Network Lengths	
Overhead Powerlines (ckm)	32698
Telecomms	
Telecom Towers	874

Figure 1: Eskom Transmission Assets.

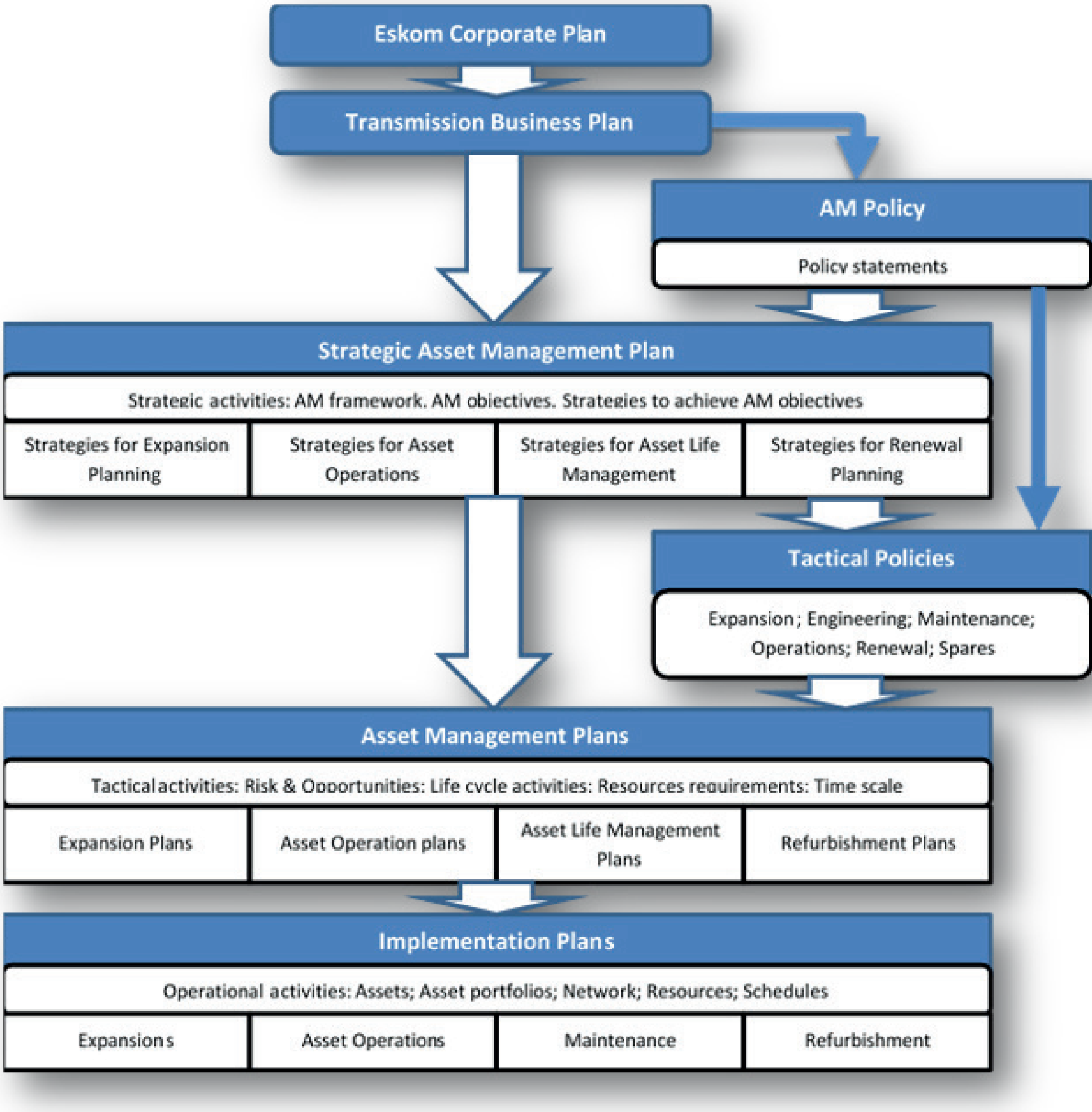


Figure 2: The Transmission Asset Management System.

(2021 to 2024) highlights that creating an independent Transmission entity is expected to enable cost-efficient trade to meet demand, improve market transparency and reputation, provide universal access with ease and speed, and allow for value chain growth and linkages in the electricity industry.

As part of unbundling the organisation, Transmission has reorganised itself structurally to include asset management at the centre of the delivery of its mandate; hence the asset management practice has been adopted in the Transmission environment.

ASSET MANAGEMENT SYSTEM

In 2014, the ISO Technical Committee for Asset Management Systems published three standards (i.e. ISO 55000, ISO 55001, and ISO 55002) that are deemed a global consensus on what constitutes good asset management practice. This committee comprised representatives from 35 national standardisation bodies, various other asset management bodies, and experts.

The three standards that were developed covered the following:

- ISO 55000 Standard: Asset management Overview, Principles, and Terminology
- ISO 55001: Asset Management System Requirements,
- ISO 55002: Guideline for the Application of ISO 55001.

The standards are intended to ensure that the organisations can consistently realise value from their assets through the effective and efficient application of an Asset Management System.

Based on the interpretation of the ISO55001 requirements and the Cigre ISO series 55000 standards

2.2 Policy Statements

To meet the commitments made above, Transmission shall:

2.2.1 manage its **physical assets** so as to meet Eskom's strategic **goals, measures, and initiatives** as outlined in the **Transmission business plan**

2.2.2 operate assets **safely** within the prescribed limits, while complying with **relevant legislation**, licences, codes of practice and industry standards

2.2.3 **maintain asset information** in such a way that it **accurately reflects assets** in use in delivering its core function

2.2.4 apply contemporary **asset risk management** techniques at **least life cycle cost** to identify and effectively manage physical asset risks and opportunities

2.2.5 implement and continually **improve** asset management **processes** and **systems** in search of excellence

2.2.6 ensure that staff are **trained**, authorised, and **competent** to undertake their work activities

implementation guide for utilities, Eskom Transmission has defined its Asset Management System as illustrated in Figure 2. The organisation has made strides by publishing its Asset Management Policy and the Strategic Asset Management Plan. Work is currently underway to conclude the 29 Asset Management Plans that have been identified.

ASSET MANAGEMENT POLICY

Transmission developed the Asset Management Policy to initiate the Asset Management System, an apex document through which the top management demonstrates its commitment to and alignment with asset management practice. The Transmission Asset Management Policy defines the policy statements that must be applied to manage the network assets to achieve the Transmission business objectives. The policy is informed by the Transmission business objectives, as illustrated in Figure 2.

STRATEGIC ASSET MANAGEMENT PLAN

Following the development of the Asset Management Policy, the organisation has published the Strategic Asset Management Plan (SAMP), also referred to as the Asset Management Strategy. The SAMP sets out the approaches to realising Eskom Transmission's business objectives and the Asset Management Policy statement through asset management, outlines the approach to developing asset management plans, and defines the role of the Asset Management System in supporting the achievement of the asset management objectives.

Furthermore, the document establishes and maintains an asset management system in line with international best practices to ensure an optimum and sustainable balance between costs, performance, and risk.

The purpose of the Transmission SAMP is as follows:

- To align Transmission's asset management practices with industry best practices as guided by the international standard for asset management: ISO 55001: Management System for Asset Management.
- To achieve the asset management objectives that are aligned to and consistent with Transmission's business objectives;
- To set out the approach to implementing the Asset Management Policy statements;
- To define the scope of the Transmission Asset Management System;
- To inform the approach to developing the Asset Management Plans;
- To clarify priorities, align stakeholders, and deliver the best possible value to the organisation.

The SAMP informs the subsequent Asset Management Plans (see Figure 2) and influences the tactical policies to ensure the sustained attainment of the asset management objectives.

ASSET MANAGEMENT PLAN

Eskom Transmission has defined four distinct categories of Asset Management Plans (AMPs) that inform investments, i.e. network expansion plans to grow the business; asset operational plans to ensure network flexibility and resilience; maintenance plans to sustain the installed base; and refurbishment plans for asset renewal and replacement.

These documents further ensure the Transmission asset management practices are aligned with the industry's best approaches, as guided by the international standard for asset management: ISO 55001.

It is planned that a total of 29 AMPs will be concluded in the next two years.

TOOLS AND SYSTEMS THAT SUPPORT ASSET MANAGEMENT

The implementation of good asset management practices in asset-intensive organisations comes with a need for applying the technologies that leverage decision-making. These key digital platforms are illustrated in Figure 3 below, as summarised well by James Cooper (Asset Information Director at AMCL) at the 2019 IBM Maximo UK and Ireland User Group.

The Enterprise Asset Management (EAM) platform manages the asset maintenance activities such as maintenance planning, scheduling, execution, and resource management (e.g. material, tools, fleet, craft) throughout the asset life cycle.

It also houses key asset information such as asset location, master data (e.g. asset ratings, make and type), asset descriptions, the asset owner and asset maintenance history.

The Asset Performance Management (APM) tool optimises the performance of assets by developing maintenance strategies, monitoring asset health and performance, and continuously enhancing the recommendations for asset care. The Asset Investment Planning (AIP) tool assesses and prioritises asset investment decisions. The Project Portfolio Management (PPM) tool optimises allocating resources across projects to fulfil the organisation's objectives. Projects aligned with the strategic objectives are prioritised after considering cost, executability, and benefits.

The Geographic Information System (GIS) provides the geographic data and visualisation used to identify the asset location and other geographic attributes relevant to asset management. The reporting and visualisation tools (dashboards) provide a view of the indicators monitored at various levels of the business.

Eskom Transmission has employed some of these tools and defined a plan to acquire the balance as part of developing and implementing a fully-fledged asset management system. wn

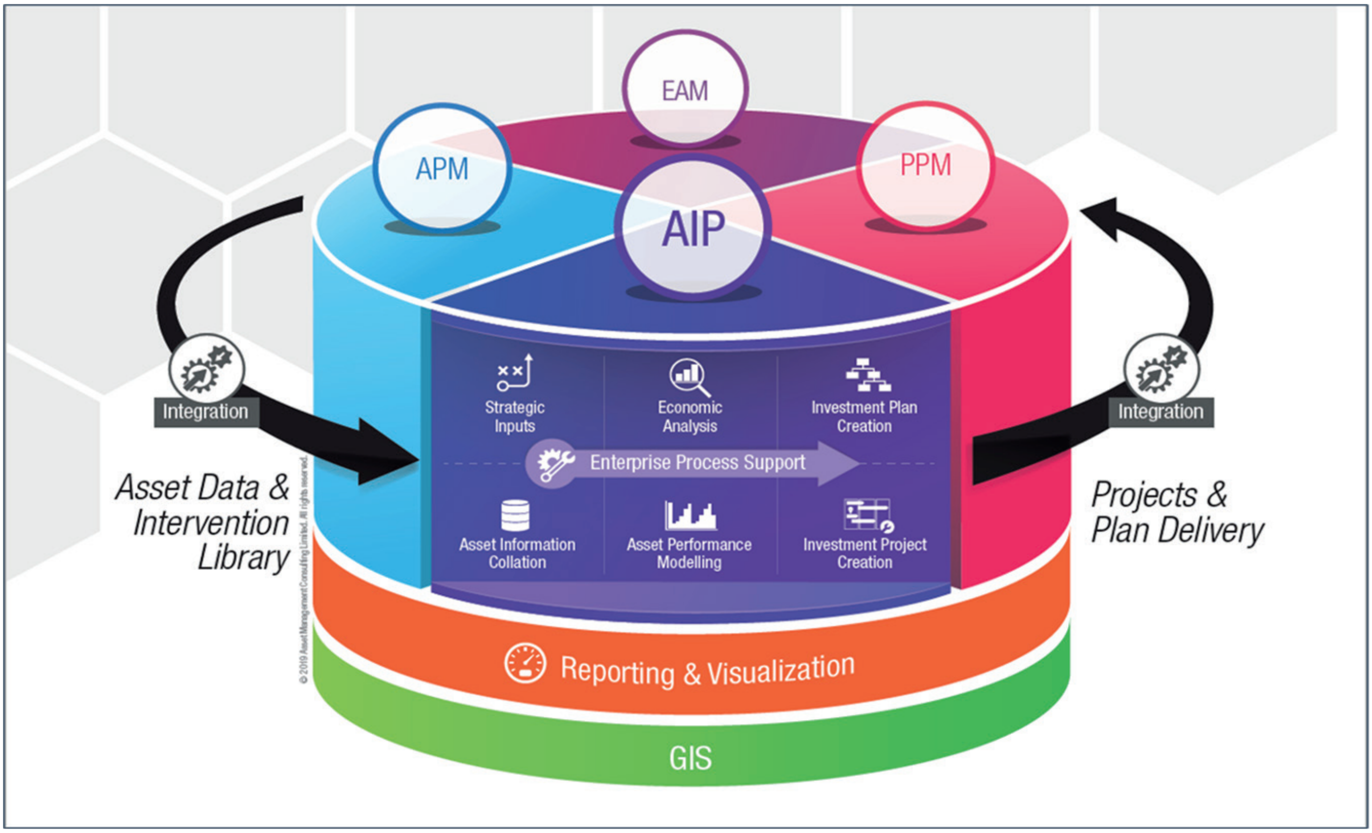


Figure 3: key digital tools supporting asset-intensive organisations

SOURCE: Cooper J, AMCL, IBM Maximo UK and Ireland User Group, 2019

The Abundance of Low Hanging Fruit

For years, I have heard people say that it is difficult to find more energy savings because they have tackled all the easy wins and that there is no more low-hanging fruit. This might be because it is more fun and seemingly easier to focus on renewables and new technology instead of actually getting out there and identifying energy savings. I am hoping this will help to set the record straight.

By Andrew Cooper Pr.Eng, MBA, B.Comm, CEM, CMVP Strategic Energy Management Specialist

When I was growing up, before the days of the remarkable illusionists, mentalists and magicians we see today, I was fascinated by the endless streams of ribbons a magician would pull out of their top hat.

I would watch as a dove after dove or rabbit after rabbit would miraculously appear out of the hat. I have found that the energy fruit tree is the magician's hat of energy savings.

As energy saving targets were set and achieved each year, I would wonder, "Where are we going to find more energy savings for next year?" I'd go to the energy fruit tree, and miraculously, there would be more low-hanging energy fruit.

As low-hanging fruit was plucked from the energy fruit tree, more energy fruit would grow in the low-hanging branches. There seemed to be an endless supply of low-hanging energy fruit, but there is a "but". You have to nurture and nourish that energy fruit tree. There are three ways to do this.

Firstly, you have to pick the low-hanging fruit that is already there. New fruit will not grow until the initial fruit has been picked. The nourishment you get from the initial low-hanging fruit will give you the "energy" you need to tend to and nurture the tree.

Secondly, you need to fertilize the tree, water it and remove the weeds around it. This will allow it to grow strong and healthy, providing the abundant low-hanging energy fruit you are looking for. You do this by implementing a Strategic Energy Management (SEM) system, where employee engagement and awareness and the energy aspects of operations, maintenance, finance and procurement are integrated into that system.

A Strategic Energy Management (SEM) system is a set of interrelated processes built into your existing operational and business systems to allow you to effectively manage your energy use, continually improve your energy performance each year and engage your employees in the process.

SEM is the lifeblood of the tree. Without it, you will pick some low-hanging energy fruit, and no more will grow. The consistent application of SEM, year after year, ensures a strong, healthy tree. ISO 50001 and the Mining Association of Canada's Towards Sustainable Mining (TSM) Climate Change Protocol are just two examples of SEM systems.

Thirdly, value feedback from your employees. Your employees are out there daily, month after month, year after year. They see where you can save energy. You have to make it possible for them to share that information.

Your employees are your tree's tap roots to an abundant supply of water to nourish your energy fruit tree. If you ignore your employees, you cut off your tap root, and the energy fruit tree will eventually wither and die.

Saying, "We've tackled all the low-hanging fruit", is just an excuse to avoid nurturing and tending to the energy fruit tree. It can be a self-fulfilling prophecy because if you believe there is no longer any low-hanging fruit, you will not do what you need to, and your tree will no longer bear fruit.

Tend to your tree, nurture it, and it will provide you with an abundant source of low-hanging fruit for years to come. wn

SAIEE South African Institute of Electrical Engineers

113 YEARS 1909-2022 SAIEE

MEMBERSHIP FEES EFFECTIVE 1 DECEMBER 2022

The Council meeting held on 2 September 2022 approved subscription & entrance fees as from 01 December 2022 as per schedule indicated below.

PLEASE NOTE: In terms of Bylaw 3.2 annual subscriptions are due on 1st December 2022

MEMBERSHIP FEES CAN BE PAID IN MONTHLY RECURRING PAYMENTS

Council agreed to a discount for fees paid before 31 March 2023. Members are therefore encouraged to pay promptly to minimize increase impact.

Grade of Membership	Annual Subscriptions paid before 31 March 2023		Annual Subscriptions paid after 31 March 2023		New Members FEES * see Notes 1 & 4 below.	
	RSA incl VAT (R)	Outside RSA excl VAT (R)	RSA incl VAT (R)	Outside RSA excl VAT (R)	RSA incl VAT (R)	Outside RSA excl VAT (R)
Student	165	143	198	172	198	172
After 6 yrs study	1 714	1 491	2 057	1 789	2 057	1 789
Associate	1 714	1 491	2 057	1 789	2 057	1 789
Member	1 895	1 648	2 274	1 977	2 274	1 977
after 6 years	2 214	1 925	2 657	2 310	2 657	2 310
after 10 years	2 317	2 015	2 780	2 418	2 780	2 418
Senior Member	2 317	2 015	2 780	2 418	2 780	2 418
after 6yrs/age 40	2 511	2 184	3 013	2 620	3 013	2 620
Fellow	2 511	2 184	3 013	2 620	3 013	2 620
Retired Member (By-law B3.7.1)	1 065	926	1 278	1 111	n/a	n/a
Retired Member (By-law B3.7.3)	nil	nil	nil	nil	n/a	n/a

1. The fee for all new applications is R3224.00, including an entrance fee of R950.00. On election to the applicable grade of membership, the new member's account will be adjusted accordingly, and refunds/additional payments will be made on request. The entrance fee for Students is free, and new Student applicants require payment of R198.00.
2. Transfer fee to a higher grade is R504.00 for all grades of membership (except Students within three months of qualifying).
3. Members are encouraged to transfer to a higher grade when they qualify. It will be noted that the fees of Member and Senior Member grades after 10 and 6 years, respectively, are equal to the fees at the next higher grade.
4. Members elected after May 2023 pay a reduced subscription fee.
5. By-law B3.7.1 reads, "Where a member in the age group of 55 to 70 years has retired from substantive employment in the engineering profession, such member may make written application to Council for recognition as a retired person and a reduced membership fee".
6. By-law B3.7.3 reads, "any member complying with the conditions of B3.7.1 but who has been a member of the Institute for not less than 25 consecutive years, shall be exempt from the payment of further subscriptions." Members who comply with the requirements of By-Law B3.7.3 may make written application to Council for exemption from paying subscriptions".
7. By-law B3.9 reads, "any member in good standing who has been a member for fifty (50) consecutive years shall be exempt from the payment of further subscriptions."
8. Members not in good standing by failing to pay their subscriptions by the end of June of each year will, subject to Council decree, be struck off the SAIEE membership role.
9. Members in good standing, no longer in substantive employment, and do not receive payment or salary for work done, may apply to Council for a reduction in their annual subscriptions.
10. The members' monthly magazine ("wattnow") is available online. Members who require a hard copy may acquire the same on request and for a nominal fee subject to minimum uptake numbers.
11. Members who wish to pay their membership fees in recurring payments should activate the payments on their banking portal. Members will only receive the early bird discount if their fees are fully paid by 31 March 2023.

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OCTOBER 2022

05/10/2022	Photovoltaic Solar Systems
11/10/2022	New Engineering Contract (NEC)
13/10/2022	High Voltage Measurement and Testing
13/10/2022	Fundamentals of Practical Lighting Design for Commercial and Industrial Applications
20/10/2022	Finance Essentials for Engineers
20/10/2022	Freestate Centre presents: Cast Resin Transformers - the path to a Greener Future
24/10/2022	Select, Maintain & operate your Rotating Electrical Machines like a Pro
25/10/2022	Water Security Driven by IR4.0 - 3-day virtual symposium - Day 1 - open to all
26/10/2022	Water Security Driven by IR4.0 - 3-day virtual symposium - Day 2 - open to all
26/10/2022	Power Systems Protection
27/10/2022	Water Security Driven by IR4.0 - 3-day virtual symposium - Day 3 - open to all
31/10/2022	Fundamentals of Medium Voltage Protection

NOVEMBER 2022

01/11/2022	Project Management for Engineers
01/11/2022	Planning Strategic Feasibility Studies
01/11/2022	Substation Design and Equipment Selection
02/11/2022	Fundamentals of Financial Evaluation for Projects
03/11/2022	Partial Discharge Detection and Measurement
08/11/2022	Incident Investigation and Management (Root Cause Analysis)
08/11/2022	Operating Regulations For HV/MV Systems – ORHVS
09/11/2022	Finance Essentials for Engineers
09/11/2022	Cable Theft webinar series - Combatting the scourge of cable theft - session 1
16/11/2022	Writing Good Technical Specifications
16/11/2022	Cable Theft webinar series - Combatting the scourge of cable theft - session 2
17/11/2022	ARC Flash
17/11/2022	Legal Liability: Occupational Health and Safety Act (OHS Act)
22/11/2022	Construction Regulations from a Legal Perspective
23/11/2022	Cable Theft webinar series - Combatting the scourge of cable theft - session 3
28/11/2022	Technical Report Writing
29/11/2022	Introduction to 5G Communication Networks
30/11/2022	Road to Registration
30/11/2022	An introduction to Artificial intelligence for Professionals

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