The evolution of medium voltage power cables up to 36 kV

by Patrick O’Halloran, City Power

This paper will cover the evolution of MV power cables over the last century and will cover some pros and cons of all the different types of insulation mediums utilised for MV power cables. In South Africa most utilities still install three-core paper insulated lead covered (PILC) cables and are considering three-core cross-linked polyethylene (XLPE) insulated cables. No utilities install three-core ethylene propylene rubber (EPR) insulated cables which are extensively utilised in the mining industries.

This is not the case internationally, where utilities predominantly only install either single- or three-core MV XLPE or EPR cables and have programmes to replace their existing PILC cables networks.

New HV cable projects in South Africa are all single-core XLPE insulated. The old existing fluid filled HV power cables are being replaced because of the intensive maintenance requirements of these pressurised systems.

**Background**

Ever since electricity was first transmitted over a century ago via MV power cables, their insulation mediums and designs have evolved. MV power cable networks make up the biggest asset that most utilities have to operate and maintain. These MV power cable networks are buried out of sight 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 need to ensure reliability of supply and therefore MV cable designs have also evolved. MV power cable insulation ages due to the electrical stress and operating conditions that they are exposed to. The cable experts will also remind users how critical it is not to overload their MV power cables, as increased temperatures are the quickest ageing mechanisms to reduce the remaining life of a MV power cable. When MV power cable faults occur they contribute to large area interruptions of supply and the fault may take time to be located and can be very expensive to repair. Depending on the MV network design, 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 designs and higher voltages and loads that are required to transmit the increased power demands that utilities are required to supply. The exact remaining life of an existing MV power cable network is complicated to predict. However, by performing regular condition assessment tests on the existing cables, the results will give utilities a good indication as to when the cable insulation system has reached its end of life and repeated failures can be expected.

On-line and off-line diagnostic testing can be applied to try and predict the remaining life of existing installed MV power cable networks.

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

Another big concern is the lack of jointer skills to repair all the cable faults utilities experience. Utilities are losing all their experienced jointers either to retirement or industry. Utilities now make use of contractors to perform the critical joints and terminations.

To what standard should jointers be trained to and who can provide the required training?

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

Although Vulcanised rubber had been patented by Charles Goodyear in 1844, it was not applied to cable insulation until the 1880s, when it was used for lighting circuits. Rubber-insulated power cable was used for 11 kV circuits in 1897 in the Niagara Falls power project. Mass-impregnated paper-insulated lead covered medium voltage cables were commercially practical by 1895.

During World War II several varieties of synthetic rubber and polyethylene insulations were applied to MV power cables.

In the late 1960s cross-linked polyethylene (XLPE) insulation was introduced as MV power cable insulation and this technology changed MV power cable systems, but like any new technology had many teething problems and manufacturers spent lots of time and money in resolving the problems that were experienced in the industry.

The currently available MV power cables 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, the compulsory specification for the safety of medium voltage electric cables:

- 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 polyethylene (XLPE) insulated cables for rated voltages 3,8/6,6 kV to 19/33 kV.

Further to the above standards the Electricity Suppliers Liaison Committee (ESLC) has published the NRS 013 specification for MV cables. This specification makes recommended rationalised options for PILC and XLPE MV power cables.

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

**Fig. 2:** Typical three-core PILC MV power cable.
MV power cable construction

The construction of MV power cables needs to be understood to really appreciate the major technical differences between the two different technologies. Both are available in single or three-core and as armoured or unarmoured. The conductors are either stranded copper or aluminium depending on the end user’s preference or power needs. The copper conductor has been preferred over aluminium for many reasons. The extruded outer sheaths vary depending on the final applications. Polyvinyl chloride (PVC) is typically flame retardant but can also contain low halogen for mining applications.

Cables intended for underground use or direct burial in earth will have heavy plastic or metal, most often lead sheaths, or may require special direct-buried construction. When cables must run where exposed to mechanical impact damage, they may be protected with flexible steel tape or wire armour, which may also be covered by a water resistant polyethylene outer sheath.

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

PILC MV power cables have been around for more than 100 years and subsequently make up the prominent installation base in South Africa and internationally. These cables have had many design changes over the last 100 years. Many of these changes were improvements to make the cable’s performance more reliable at higher voltages. When PILC MV power cables were first utilised they were on 6.6 or 11 kV voltages only.

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.
- 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. They are now referred to as mass impregnated non-draining (MIND) cables. In the past, oil-based compounds susceptible to draining (e.g. rosin oil) was employed. When the compound drained with 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.
- Recently a synthetic compound better known as polyisobutylene (PIB) compound.

All single-core PILC cables have round conductors and an individually screened design. However, three-core cables have sector shaped conductors and initially had a “belted” construction design and one of the first improvements was to introduce an “individually screened” construction design. This equalises electrical stress on the cable insulation. This technique was patented by Martin Hochstader in 1916; the screen is sometimes called a Hochstader screen. The individual conductor screens of a cable are connected to earth potential at the ends of the cable, and if voltage rise during faults would be dangerous, at locations along the length. When a cable is screened, it can be touched safely without the risk of a potential build up occurring.

Unscreened belted design

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 as in a compound filled cable box joint, no PD should occur and therefore no crush failure.

Screened cable

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

Belt papers are removed when jointing and terminating. This reduces the phase voltage to earth to 5.5 kV at all accessories. Therefore screened designed cables are more reliable when being jointed or terminated.

Fig. 3 shows the electric field lines in belted unscreened and individually screened three-core cables.

Characteristics of 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 useable up to 11 kV.

Many of these cable improvements were made to improve the PILC cables at higher voltages. When PILC MV power cables were first utilised they were on 6.6 or 11 kV supplies only. For voltages above 11 kV only screened designed cables are available.

PILC MV power cables are very susceptible to moisture ingress. Once moisture has penetrated through the lead sheath, the paper insulation is affected immediately leading to insulation failure. This moisture then quickly travels down the cores and eventually affects a bigger section of the PILC MV power cable. Therefore it is critical to prevent moisture from entering the cable at all. It is also very important to perform a moisture crinkle test on the paper insulation prior to any joint of termination being installed. If moisture is detected, the cable with moisture ingress should be replaced to prevent further failures. It is also critical that the PILC MV power cables are sealed at all times with the appropriate sealing caps. The use of a plastic bag or a plastic half litre cold drink bottle is not acceptable and will lead to moisture ingress.

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 leading to the presence of impurities and contaminants within the XLPE insulation. These failures gave XLPE insulated MV power cables a poor name in the industry and most South African utilities quickly changed back to PILC MV power cables.

Subsequently the XLPE insulation cleanliness, designs and manufacturing production process technologies have considerably evolved. The manufacturers began to understand what was important when it came to making XLPE cables more reliable and with extended life expectancy. The three critical layers in a XLPE insulated MV power cables are now applied at the same time and is referred to as triple extruded.

These three critical layers are:
- The conductor screen which is at Uo phase voltage.
- The XLPE insulation.
- The core screen which is at 0 V (needs to be kept at earth potential).

The conductor and the core screen are both made of conductive materials and the XLPE insulation is the pure insulating material. XLPE insulated cables always have a screened design and are round to ensure the equal stress distribution in the XLPE insulation.

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

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The quality of XLPE insulated cables is so high that it is becoming the preferred insulation at 500 kV, as XLPE insulation has lower dielectric losses and higher operating temperatures thus higher ampacities and lower environmental impact. Unaged XLPE insulated MV power cable has a typical breakdown strength of 50 kV/mm.

City Power and Eskom have changed their MV power cable specifications to longitudinally water blocked XLPE insulated cables as a standard. The concept is comparable to water blocked XLPE insulated cables as a power cable specification to longitudinally block water pipes. The concept is comparable to a baby’s nappy, where water swellable compounds and tapes are included in areas where water could flow in the cable should it enter for reasons such as damaged 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 as water entering the cable it is stopped where it enters. This also then prevents the old problem that XLPE cables had of becoming water pipes.

Areas that have to be water blocked in a three core XLPE cable are:
- Conductors
- Core(s) and metallic screening
- Laid up cores for three-core designs
- Armouring

The international trend is to use single-core cables rather than three-core cables, as it is simple and easy to longitudinally block a single-core cable, as it does not have the big fillers between the cores. The risk of moisture entering all three phases is also reduced when three single-core cables are utilised as compared to a three-core design.

Eskom will be installing the first 400 kV EHV XLPE insulated cable in South Africa in early 2014. The cables and the accessories will be important for this project. One local HV cable company has invested in a new EHV XLPE production line to be able to manufacture 275 kV cable. This is really exciting for future projects and we will no longer have to import 275 kV EHV cable as it can be made locally.

The risk of DC pressure testing is also better understood these days and it is not recommended to use DC pressure test equipment on XLPE insulated MV power cables. DC pressure testing has been proven not to test the true resistive properties of the cable and at the end of the day 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. DC source equipment is required for fault finding, but this is different to voltage withstand testing.

To prevent theft of cables in South Africa, suppliers are now adding special marking tapes with serial numbers, giving end users the ability to identify stolen cable. 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.

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

<table>
<thead>
<tr>
<th>Cable construction</th>
<th>PILC-insulated cable</th>
<th>XLPE-insulated cable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conductors (either copper or aluminium)</td>
<td>Usually shaped conductor, but may be circular or oval.</td>
<td>Only circular.</td>
</tr>
<tr>
<td>Insulation</td>
<td>Wrapped impregnated paper insulation.</td>
<td>“Solid” dielectric XLPE insulation.</td>
</tr>
<tr>
<td>Screen</td>
<td>Belted collectively or individually screened. (Wrapped metallised paper tapes).</td>
<td>Always individually screened. (Conductive semicon with either copper tapes or copper wires).</td>
</tr>
<tr>
<td>Metallic sheath</td>
<td>Essential, typically lead.</td>
<td>Optional, either lead or aluminium.</td>
</tr>
<tr>
<td>Bedding layer</td>
<td>Extruded or fibrous (if armoured).</td>
<td>Extruded bedding (if armoured).</td>
</tr>
<tr>
<td>Outer sheath</td>
<td>Extruded (PVC/PE)/fibrous.</td>
<td>Extruded (PVC/PE).</td>
</tr>
<tr>
<td>Continuous operating temperatures</td>
<td>70°C</td>
<td>90°C</td>
</tr>
<tr>
<td>Short circuit temperatures</td>
<td>160°C</td>
<td>250°C</td>
</tr>
<tr>
<td>Longitudinally water blocked</td>
<td>No, normally only radially due to metallic layer.</td>
<td>Yes, if specified as it is not a standard.</td>
</tr>
<tr>
<td>PD free design</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Diagnostic testing possible</td>
<td>- Tan delta diagnostic which is the overall circuit condition. - Pre-failure faults can be located without breaking down the insulation system by applying a high voltage source.</td>
<td>- 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.</td>
</tr>
</tbody>
</table>

### 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.

Things get really exciting on site if the wrong equipment has been specified and purchased. Typically most equipment has long lead times and instead of stopping the project,
people make plans on site to terminate the cable in to the switchgear that is supplied on site. Therefore from day one the installation is wrong and premature failures can be expected. These failures can be expensive to repair and could also involve replacement of the switchgear. Staff or members of the public could be injured or killed from the resultant explosion.

Cable termination beginnings (early 1900 – 1950s)

In the beginning, electrical equipment like switchgear and transformers were designed to have compound filled metal cable boxes. This way of terminating cables was not technically good, and was very difficult and hazardous to field staff. The MV paper insulated (PILC) cables at the time had belted construction and had wiped earth connections.

Compound filled cable boxes are designed to have no air inside, so creepage was not a major consideration when designing the cable bushing. This explains why the bushings of compound filled cable boxes are small compared to air filled cable box bushings found in metal clad switchgear and outdoor transformers.

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

Some draw-backs of compound filled cable boxes are:
- Compound top-up is required to ensure proper insulation (no air voids).
- Long installation times.

- Cable box failures cause major damage when they ruptured (hot burning compound could be expelled).

New technology cold pouring compounds are now available, which are environmentally friendly, safe to install and re-enterable.

Air insulated MV cable terminations (1950 – 2000s)

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

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

The belt design paper insulated cable is more likely to have crutch failures than the newer screen design paper insulated cable where the complete crutch area is screened. This is because of resistivity of materials and the introduction of air between to unscreened insulated conductors.

International markets (which are mainly 24 kV rated systems) tend to require smaller and smaller switchgear. This in turn equals reduced busbar clearances and cable boxes. Air was the first insulating medium for busbars. This was replaced with oil and 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, came reduced clearances between phases and phase to earth. The reduction of clearances required new MV cable terminations. When switchgear manufacturers design smaller air-filled cable boxes with reduced clearances, MV cable accessory manufactures have to redesign the bushings and MV cable terminations to make the cable box and cable termination compatible for 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 new SF6 insulated switchgear that is currently used by City Power, Eskom and other utilities and industries. Type C bushing allows end users to move away from traditional putty and tape shrouds to factory made fully insulated shrouds. These shrouds are installed the same way every time and ensure that cables are terminated properly.
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 are screened there is no leakage current along the surface of the screened connectors. With these screened connectors installed in the cable box, the cable box and all electrical clearances can be reduced drastically. 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 try and eliminate failures from occurring in the MV cable compartment, the following two national standards have been published:

- **NRS 012/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.
- **NRS 053** – Accessories for medium-voltage power cables (3,8/6,6 kV to 19/33 kV).

These two standards are not compulsory yet, 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 NRS 053, soon to be SANS 1332.

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

- Creepage distances.
- Tracking and erosion.
- Clearances (phase to phase and phase to earth).

The above three technical considerations must be correct if an air-filled termination is to last in excess of 30 years. Inadequate creepage, tracking and erosion properties and air clearances will result in the MV cable termination failing prematurely. Failure of MV cable terminations are dangerous and cause long power interruptions.

NRS 012/SANS 876 has been developed to address these challenges. This standard is critical to understand and also to specify correctly when ordering new switchgear to accommodate the cable technology that will be installed.

In NRS 012/SANS 876 the following types of terminations are specified:

- **Type 1 termination** – lugs connected onto bushings or post insulators, uninsulated (bare) at the terminal fixing point (Fig. 9).
- **Type 2 termination** – lugs connected onto bushings or post insulators with a shrouded (unscreened) insulation termination (Fig. 10).
Type 3 termination – unscreened separable connector terminations (Fig. 11).

Type 4 termination – screened separable connector terminations – outside cone (Fig. 12).

Type 5 termination – screened separable connector terminations – inside cone (Fig. 13).

All critical dimensions and definitions are given in NRS 012/SANS 876.

Type 1: Bare termination (air insulated)

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

- Cable cores are 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 to earth is determined by the impulse withstand voltage requirement.

Type 2: Shrouded termination

In a Type 2 termination, the interfaces are shrouded with unscreened interfaces and:

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

Types 4 and 5: Screened separable connector interfaces (SSC) – inside or outside cone

In Type 4 and 5 terminations, the interfaces are screened and use specially designed SSC and:
Clearances are determined by the mechanical clearance required to fit the SSCs within the cable box.

- Are safe to touch due to surface being earthed.
- The leakage current is limited by the quality of the interface between SSC and bushing (interference fit).
- Note: PILC cables could not use SSC especially above 11 kV because of sector shape cores and loose core screens.

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.

LV current transformers in MV cable boxes

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

It is essential that these low voltage current transformers be installed in a screened area, otherwise discharge may occur if the air clearances are inadequate.

The dimensions from the top of the low voltage current transformer to the screen cut is covered by the dimensions in Type 2 and 3 terminations.

Core crossing for phasing within MV cable boxes

Core crossing for phasing within MV cable boxes is not recommended, however many crossed terminations exist in our networks. The risk with cross cores inside unscreened type terminations is that adequate clearances get reduced and this leads to increased electrical stress and partial discharge.

NRS 053 requires all terminations to be done with a top down principle. If the top down principle is followed, the screen’s 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.

Fig. 18 shows the extra base that needs to be supplied with compact switchgear to ensure that the correct three-core cable height is attained. This would not be the case for three single-core cables. The whole evolution of MV power cables, switchgear and cable accessories has made it possible to reduce cable boxes significantly. The additional bending radius of three-core cables also has to be considered. Fig. 18 shows the special removable front covers which have been designed to make the jointer’s job easier and in doing so will hopefully prevent jointer errors.

Fig. 19 shows a clever way of terminating three-core XLPE MV power cables into small compact switchgear. By performing a trifurcating termination in the duct or ground, three single-core cables are achieved. 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. 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.

Fig. 20 shows an example of where things have gone wrong in the past. The SF6 insulated ring main unit was installed with additional metering low voltage and protection current transformers (CT). This happens often and it is because the wrong products were ordered because end-users have not understood the new technologies or wanted to stay with older technologies. City Power was able to locate this problem before a failure occurred by using handheld detectors.

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 was done. PD takes a long time to cause a failure in terminations, but it is guaranteed to fail one day.
Most end-users still use direct current (DC) cable pressure test equipment which gives no diagnostic results. This equipment has been available for many years, is portable and is affordable. The current test method is to apply a high DC voltage for a predefined period to the MV power cable. If nothing trips during the test, the cable is declared healthy to energise. This is referred to as “go or no go” testing. Why then 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 the cable system is energised with alternating current (AC) 50 Hz, the permittivity properties of the components are stressed.

A diagnostic test should also be conducted before energising a new cable or after a repair has been made after a failure in a cable system. Off-line tan delta (TD) and partial discharge (PD) results can be taken during the pressure test. The results are available on site and an informed decision can be taken with regards to the health of the MV power cable system. PD 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 source of the PD (which is a potential failure point).

Because 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 now means that these joints need to be identified and corrected, prior to energising. We all know that PD will never go away and it will just intensify and eventually lead to a failure.

These results provide us with a fingerprint of the condition of the MV power cable system and when future diagnostic tests are conducted the results can be compared and the cabling ageing rate confirmed. The proposed revised SANS 10198-13 code of practice for MV power cable testing, now recommends integrated voltage withstand and diagnostic testing. These tests do not take longer to perform as they are now all integrated in the new available test equipment.

**Conclusion**

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

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

- Install screened rather than belted designed PILC cables.
- Select and specify the corrected termination types up front as it makes no sense to install the wrong terminations from day one.
- If three-core cables are installed, ensure that the switchgear is suitably designed per NRS 012/SANS 876.
- If three single-core cables are installed there is reduced risk of termination failures. Tri-furcating terminations are perfect to convert three-core cables to three single-core cables.
- It is also possible to install a tri-furcating transition joint from three-core PILC to three single-core XLPE.
- Ensure clearances are kept at all costs if screened terminations are not installed.
- Ensure jointers are well trained to install the MV power cables and accessories, to prevent unnecessary failures.
- If PILC insulated cable are installed always test for the presence of moisture and cut out affected sections.
- If XLPE insulated cable is installed utilise the right screen removing tool.
- Consider single core cables instead of large three-core cables.
- 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.

Contact Patrick O’Halloran,
City Power,
Tel 011 490-7485,
pohalloran@citypower.co.za