Presentation outline

- Introduction to City Power
- MV power cable construction
- Factors influencing cable technology changes (Evolution)
- Cable testing techniques to better determine reliability and remaining life
- Conclusion

Hopefully this presentation evolves your thoughts on MV power cables!
City of Johannesburg: Orientation & Electricity Supply Rights

South Africa

7304 km of MV power cable Installed in City Power
More than 6000 failures in 3 years
Our business model

National Energy Regulator of South Africa (NERSA)

We are in the business of buying electricity and selling it to customers
City Power’s Vision

A World Class Electricity Utility
Typical example of MV power cable network

- HV/MV sub-station
- Metal-clad switchgear
- Switching station
- Primary feeders
- Secondary distribution network
- Secondary feeders
- MV LPU supply
- Sub-switching station
- N/O points
- Mini-subs
- Sub-ring feeder

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Slide 6
Evolution of MV Power Cables

Evolution, what should be use?
The first power distribution system was developed by Thomas Edison in the early 1880’s in New York City.

A power cable constructed from copper rods, wrapped in jute and placed in rigid pipes filled with a bituminous compound.
Evolution of MV Power Cables

- The range of voltage and the capacity of power transmitted through cables are showing a steady increase over the years.
- Environmental concerns, aesthetic issues, lack of servitudes and difficulty in routing overhead lines in urban areas are some of the reasons for the growth of cable technology.
- Due to physical limits on cable lengths for manufacturing and packaging, joints in cables become inevitable, particularly in the context of the utility sector.
- Various types of switchgear exist and hence many different ways of terminating need to be considered and understood.
- Loss of skills to install cable systems, especially joints and terminations.
• SANS 97 - Electric cables – Impregnated-paper-insulated metal-sheathed cables for rated voltages 3,3/3,3 kV up to 19/33 kV

• SANS 1339 - Electric cables – Cross-linked polyethylene (XLPE)-insulated cables for voltages from 3,8/6,6 kV to 19/33 kV

• VC 8077 - Compulsory specification for the safety of medium voltage electric cables

• NRS 013 – Medium-voltage cables
MV Power cable construction
Paper-insulated cables (PILC)

Armoured
Unarmoured
The paper insulation is impregnated with a non-draining compound. Mass Impregnated Non-Draining (MIND) cable mass impregnated using a “non-draining” compound.

Older mass impregnated cables were “draining” and used oil-based compounds susceptible to draining (e.g. rosin oil)

There are two types of “non-draining” compounds used by various manufacturers:

- a compound processed from a mineral based amorphous crystalline wax.
- more recently a synthetic compound better known as Poly-Iso-Butylene (PIB) compound.
MV Power cable construction
Paper-insulated cables (PILC)

PILC Cable – Belted design

PILC Cable – Screened design (Improved design)
• Electric field lines in belted and individually screened three core cables
MV Power cable construction
Paper-insulated cables (PILC)

PILC Belted cable – for “earthed” system design (6,35/11 kV)

PILC Belted cable – for “unearthed” system design (11/11 kV)
MV Power cable construction
Cross-linked Polyethylene (XLPE)
MV Power cable construction
Insulation (PILC & XLPE)

PILC Cable

XLPE Cable

insulation
### MV Power cable construction

#### Insulation (PILC)

<table>
<thead>
<tr>
<th>Cable Voltage</th>
<th>Insulation Thickness (SANS 97)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Screened</td>
</tr>
<tr>
<td></td>
<td>Core</td>
</tr>
<tr>
<td>3,8/6,6 kV</td>
<td>N/A</td>
</tr>
<tr>
<td>6,6/6,6 kV</td>
<td>N/A</td>
</tr>
<tr>
<td>6,35/11 kV</td>
<td>3,2 mm</td>
</tr>
<tr>
<td>11/11 kV</td>
<td>N/A</td>
</tr>
<tr>
<td>12,7/22 kV</td>
<td>5,8 mm</td>
</tr>
<tr>
<td>19/33 kV</td>
<td>7,1 mm</td>
</tr>
</tbody>
</table>

Typical paper insulation thicknesses – SANS 97
The polymer chains then combine
Chains that were "loose" before are now bound together
CROSS-LINKED polymers
Typical XLPE insulation thicknesses – SANS 1339 and these are the same as IEC 60502-2

<table>
<thead>
<tr>
<th>Cable Voltage</th>
<th>Insulation Thickness (SANS 1339, IEC 60502)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3,8/6,6 kV</td>
<td>≥ 2,5 mm</td>
</tr>
<tr>
<td>6.35/11 kV</td>
<td>3,4 mm</td>
</tr>
<tr>
<td>12,7/22 kV</td>
<td>5,5 mm</td>
</tr>
<tr>
<td>19/33 kV</td>
<td>8,0 mm</td>
</tr>
</tbody>
</table>
### MV Power cable construction

**Insulation operating temperatures**

<table>
<thead>
<tr>
<th>PILC Cable</th>
<th>XLPE-insulated Cable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous operating temperature = 70°C</td>
<td>Continuous operating temperature = 90°C</td>
</tr>
<tr>
<td>Short circuit temperature = 160°C</td>
<td>Short circuit temperature = 250°C</td>
</tr>
</tbody>
</table>
MV Power cable construction
Core (insulation) screening

PILC Cable

XLPE Cable

core screening
MV Power cable construction
Core (insulation) screening

Strippable core screen (normal design)

Fully bonded core screen
MV Power cable construction
Stress Control

Stress control at the screen cut
Stress control is required at the screen cut
• City Power and Eskom have changed their MV power cable specifications to longitudinally water blocked XLPE insulated cables as a standard.

• Concept is like a babies nappy, where water swellable compounds and tapes are included in the areas where water could flow in the cable once it has entered in the cable for which ever reason. (Damage Sheath, lugs, existing cables, storage, etc.

• 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 when water enters, it is stopped where it enters. In so doing also stopping the old problem of XLPE cables becoming water pipes.
Areas that have to be water blocked:

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

Pictures provided by CBi Electric
MV Power cable construction
Longitudinally water blocked

- CBI's non-conductive water blocking tissue tape yarn in center interstice to block water
- Semi-con printed water blocking tape on each core to block water
- Non-conductive water blocking tape & PPL binder tape with open overlap to block water
- FR PVC bedding
- Steel Wire Armour
- Non-conductive water blocking tape over armour very effective in blocking water
- Polyethylene Outer sheath
- Full water blocked conductor with CBiD 1 (anti-theft tape)
- XLPE insulation
- Copper tape screen
- CBI's unique non-conductive water blocking tissue tape fillers in large interstices capable of absorbing high volumes of water
- Non-conductive water blocking tape under armour very effective in blocking water
- CBiD 2 (asset management tape)
MV Power cable construction
Longitudinally water blocked

CBi’s unique water blocking tissue tape filler design
MV Power cable construction
Longitudinally water blocked

Water penetration type test as per SANS 1339

Test Rig for water penetration test

All layers removed till water blocked conductors for type testing

Slide 42
MV Power cable construction
Longitudinally water blocked

Water penetration type test as per SANS 1339
Partial discharge (PD) measured in MV cable systems (International Statistics)
Common consequence of failures:

- Loss of supply – cost of unserved energy to customers
- Decreased network reliability:
  - network performance
  - quality of supply (NRS 048)
- Cost of repairs (cable joints and terminations)
- Typical time of failure – never at a convenient time
- Electrical and mechanical stress on system due to faults
Cables and joints:

- Alternative sources of supply (back-feeding) options not always available (e.g. with radials / spurs)
- Requires network switching to isolate faulty section (network reconfiguration to restore supply)
- Emergency way-leaves required for breakdowns
- Excavations cause disruptions to traffic flow
  - public inconvenience
  - drain on resources!
Terminations:

- Termination failure often results in catastrophic damage to equipment:
  - followed by equipment failure
  - additional costs to replace equipment
  - degree of damage dependant on effectiveness of protection systems
  - common mode failures result when fault spreads to adjacent switchgear panel compartments (ionisation of air)
- Safety risk to staff and general public from internal arc
MV Power cable construction
Consequences of failure
Impregnated paper-insulated cables inherently contain microvoids but these are generally not serious as the insulation is considered to be “self-healing”.

Localised discharges melt the impregnating compound locally resulting in the quenching and healing of the partial discharge site.

Moisture is another destructive factor if present in insulation. The paper used in paper-insulated cables is known to be hydroscopic (i.e. absorbs water)
• water is removed during manufacturing, and
• prior to jointing and termination (Crackle test)

!!TEST FOR MOISTURE ALWAYS!!
Poorly manufactured XLPE-insulated cables may also contain microvoids that, depending on their size, may be detrimental to the cable life:

• after the discharge is extinguished, the voltage across the void increases again and a new discharge will ignite. This occurs several times until the insulation is completely broken down.
• however, all new XLPE-insulated cables undergo partial discharge routine testing (< 5 pC)
MV Power cable construction
Destructive factors XLPE

• XLPE insulation used to suffer from water treeing especially in the older generation of XLPE cables manufactured pre 1980
• Modern manufacturing uses dry-curing methods (nitrogen) for cross-linking as opposed to old steam curing which introduced moisture during manufacture.
• Improved XLPE compounds, clean manufacturing processes and improved triple extruded designs. (TR, Super Clean etc.)
• Accelerated wet aging type tests required (SANS 1339)
• Proper cable installation is required to prevent damage to the cable’s protective outer layers and correct tools to remove core screen layer. (No Stanley knives!)
• Longitudinal water blocking materials prevent moisture migration along the cable

!!THIRD GENERATION XLPE CABLES!!
Evolution of MV Power Cables
Factors influencing cable technology changes
Evolution of MV Power Cables
Switchgear trends due to insulation medium improvements
Compound-filled boxes;

- Original way of termination PILC cables
- Completely filled system (no voids or air present)
- Varied bushing types
- No environmental pollution on bushing or termination
Air-filled cable boxes (Unscreened and screened interfaces)

1) Unscreened interfaces;
   • Requires special attention to clearances due to air
   • Varied bushing types – especially in older type boxes
   • Standardised bushings required for unscreened separable connectors
   • Exposed to environmental pollution - tracking and erosion may occur
2) Screened interfaces;

- Fully insulated and screened system (no environmental issues)
- Standardised bushings required for screened separable connectors (SSC)
- Inner-cone or outer-core options
## Evolution of MV Power Cables

### MV cable termination tail lengths

<table>
<thead>
<tr>
<th>Cable type</th>
<th>Termination tail length (mm)</th>
<th>Rated voltage $U_o/U$ (kV)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Three-core (indoor)</td>
<td>650</td>
<td>650</td>
</tr>
<tr>
<td>Three-core (outdoor)</td>
<td>1200*</td>
<td>1200*</td>
</tr>
<tr>
<td>Single-core (indoor and outdoor)</td>
<td>350 (max.)</td>
<td>350 (max.)</td>
</tr>
</tbody>
</table>

*Eskom: 1600 mm outdoor termination tails length*
• Measurements are made from the top down in order to maximize the length of the metallic core screen.

• Longer metallic core screen requires less stripping of the semi-conductive core screen (XLPE-insulated cables).
Evolution of MV Power Cables
MV cable termination tail lengths
top down principle

Example of 11 kV
3-core PILC
termination
dimensions

TANK Industries
Evolution of MV Power Cables
MV cable termination core crossing

- Longer metallic core screen allows cores to be crossed safely in the screened section without the risk of discharge between unscreened cores.
Evolution of MV Power Cables

MV cable termination core crossing (Correctly done)
NRS 012 specifies the following requirements for cable termination and live conductors in air:

- Definitions
- Insulation co-ordination
- Rated insulation levels
- Types of terminations
- Clearances
- Creepage distances
- Cable termination enclosures (boxes)
5 types of terminations:

- Type 1: Bare
- Type 2: Shrouded
- Type 3: Unscrened Separable Connectors (USC)
- Type 4: Screened Separable Connectors – external plugin (SSC)
- Type 5: Screened Separable Connectors – internal plugin (SSC)
Evolution of MV Power Cables
NRS 012 – Type 1 : Bare (air-insulated)

• Cable cores terminated with stress control appropriate to the cable design and voltage
• Air being 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 determined by the impulse withstand voltage requirement
Evolution of MV Power Cables
NRS 012 – Type 1: Bare (air-insulated)
• 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 to earth determined by power frequency (e.g. corona inception and extinction) and impulse withstand voltage considerations
Evolution of MV Power Cables
NRS 012 – Type 2 : Shrouded

End of core screen
Evolution of MV Power Cables
NRS 012 – Type 2 : Shrouded

- Shroud
- Unscreened
- Stress control
- Screened area
Evolution of MV Power Cables
NRS 012 – Type 3 : USC

- Cable cores terminated by stress control appropriate to the cable design & 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 the same as for a shrouded Type 2 termination.
Evolution of MV Power Cables
NRS 012 – Type 3 : USC

Unscreened separable connectors

End of core screen
• Clearances determined by the mechanical clearance required to fit the SSC’s within the cable box
• Safe to touch due to surface being earthed
• Leakage current limited by quality of the interface between SSC and bushing – interference fit
• NOTE – traditionally PILC cables could not use SSC
  – sector shape cores
  – loose core screen
Evolution of MV Power Cables
NRS 012 – Type 4 : SSC outer
Evolution of MV Power Cables
NRS 012 – Type 4 : SSC outer

- SSC boots (screened)
- Stress cone
- Screened (trifurcating kit)
Evolution of MV Power Cables
NRS 012 – Type 5: SSC Inner

Inner cone switchgear connection system
36 kV up to 1250A
Evolution of MV Power Cables
NRS 012 – cable box heights
<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Symbol for clearance</strong></td>
<td><strong>Cable type and size</strong></td>
<td><strong>Clearance mm</strong></td>
<td><strong>Voltage rating of enclosure kV</strong></td>
<td>7.2</td>
<td>12</td>
</tr>
<tr>
<td>e</td>
<td>Single-core cables: All sizes</td>
<td>600</td>
<td>600</td>
<td>700</td>
<td>850</td>
</tr>
<tr>
<td>e</td>
<td>Three-core cables: All sizes</td>
<td>800</td>
<td>800</td>
<td>800</td>
<td>950</td>
</tr>
</tbody>
</table>
Evolution of MV Power Cables
NRS 012 – cable box heights
Evolution of MV Power Cables

Trifurcating terminations (3 – 3x1)

- screened (copper tape)
- CFS
- secondary earth braids
- water block
- main earth braid
Evolution of MV Power Cables
Trifurcating terminations (3 – 3x1)
Evolution of MV Power Cables

Transition joint (3 – 3x1)

1 Connector
2 Oil barrier tubing
3 Stress-wedge and oil-blocking void filler
4 Insulation and screen tubes
5 Breakout and trifurcation (1C XLPE–3C PILC)
6 Solderless earth connection
7 Metallic screening
8 Outer sealing and protection
9 Moisture seal
10 Filler
11 Core separator
12 Main earth braid
What went wrong here?

Not designed for putty and tape!
What went wrong here?
What went wrong here?
What went wrong here?
What went wrong here?
What went wrong here?
• Most utilities use d.c. cable pressure test equipment with no diagnostic results. They have been available for many years, portable and cheapest pressure test equipment.

• A high d.c. voltage is applied for a predefined period. If nothing trips, the cable is declared healthy to energize.

• This is referred to as “Go or No go” testing.

• Why do failures of the cable, joint or terminations still occur after energizing?

• d.c. testing only tests the resistivity properties of the cable system. However when energized with AC 50Hz the cable system the permittivity properties of the components are experiianced.
To ensure future cable system failures are avoided and to make an informed remaining life decision with regards to possible replacement of the faulted or aged MV power cable.

With the improved technologies in testing voltage sources, we can test the permittivity properties of the cable systems, and simulate the as in service AC system conditions.

- Very Low Frequency (VLF)
- Damped Oscillating Waveform Test Voltage (DOWTS)
- Alternating Current (AC) @ power frequency
- Resonant Alternating Current (RAC)
Evolution of MV Power Cables
MV cable testing

- A diagnostic test should be conducted before energizing a new cable or after a repair has been made after a failure.
- Off line Tan Delta and PD tests can be performed at this stage. Results available on site.
- These results provide us with a fingerprint of the condition.
- So instead of just a “Go or No go” tests, we can now make an informed decision on the condition of the cable system.
- The revised SANS 10198-13 code of practice for cable testing, now recommends integrated voltage withstand and diagnostic test do not take longer to perform as they are now integrated in the new available test equipment.
The onsite testing of PILC cable systems is complicated due to the properties of the compound insulation:
- Lots of distributed PD in the cable by design
- Presence of moisture masks PD
- Tan Delta testing is a good indication, but finding the actual problem which a failure could occur from.

The onsite testing of XLPE cable systems is simplified due to the properties of the solid insulation:
- No PD in the cable, and
- Jointer mistakes and weak insulation problems can be located to the approximate distance.
MV power cable potential technology changes

- New composite Copper Clad Steel (CCS) or Copper Clad Aluminium (CCA) conductors
- Could deter cable theft
Evolution of MV Power Cables

Conclusion

- Install screened rather than belted designed PILC cables.
- Select and specify the corrected termination types up front.
- Ensure clearances are kept at all times.
- Ensure jointers are trained to install the MV cable accessories.
- If PILC cable are installed test for moisture always.
- If XLPE cable is installed utilise the right screen removing tool.
- Considered single core cables instead of large 3 core cables.
- Perform combined voltage withstand and diagnostic testing, so the actual condition of the cable system is now and future faults could be avoided.
THE END
(BUT NOT OF EVOLUTION)

IT ALWAYS SEEMS IMPOSSIBLE
UNTIL IT'S DONE.