AGENDA

• Introduction: Who are we?

• Recent Developments: DV Power, Gossen

• MV and HV testing options, both On-Line and Off-Line as a means of Preventative Maintenance

• Closer Look: Transformer, MV Cable Testing

• Questions
WHO ARE WE

- Incorporated in 1982
- International Ties
- Projects in Guatemala, Oman and Ireland
- Specialist projects:
  - Oil Cable Leak location – Sandton: Unique Technology
  - Off Line Cable Diagnostics – TD and PD
  - On Line Diagnostics – Eskom 400kV cables
  - Overhead Line Fault location – Eskom, Nampower, EDM, BPC
  - Transformer Rewind Test Facility – Rotek: 800MVA
  - Motor Rewinding – Actom
  - Traction Motor facilities - Transnet
INTERNATIONAL TIES

USA & Canada
Through HVD the IEEE, Georgia Tech, EPRI, Hydro Quebec & major utilities

Australia & New Zealand
Massey University, University of Canterbury and University of Auckland as well CIGRE

Middle East
University of Riyadh
CPRI (initial phases)

HV TEST
SANS, Nefta, Eskom Technologies, Hatch

Europe
Berlin University, EDF, National Grid and Western Power
INTERNAL DIVISIONS OF HV TEST

HV Test Pty Ltd

- PRODUCTS
- COMMISSIONING AND AUDITING SERVICES
- TRAINING CENTRE
- REPAIR AND CALIBRATION
RECENT DEVELOPMENTS

We recently added the following Manufacturers to our stable:

- DV Power (Sweden)
- Gossen Metrawatt (Germany)
DV POWER

- Swedish Company
- 3 Year Warranty
- Battery Testing
- Circuit Breakers
- Transformer / Motor
- CT’s and VT’s
- Handheld Devices

H.V. TEST (PTY) LTD
Leaders in High Voltage Test Equipment
GOSSSEN METRAWATT

- German based Company
- Quality Multimeters
- 5kV and 10kV Insulation
- Substation Earthing
- 3 Phase Socket Factories
- Solar Panel Efficiency
CABLE FAULT FINDING

• Thumping / Surge Testing
• SSG500, SSG1500
• 16kV, 11kV networks
• 32kV, 11-33kV networks
• 500J, 1100J – 3000J
CABLE FAULT FINDING

- Wheatstone /
- Murray Bridge
- Shirla
- Great for 0 Ohm faults
- Build into the Shirla
CABLE FAULT FINDING

- Pre-Location
- IRG2000 / IRG4000
- TDR
- ICM
- SIM / ARC Reflection
CABLE FAULT FINDING

- Pin Pointing
- Protrac
- Bluetooth
- Receiver
- Ground Microphone
- Headset

H.V. TEST (PTY) LTD
Leaders in High Voltage Test Equipment
CABLE FAULT FINDING

- Cable Tracing
- Ridgid SR-24
- Transmitters 10W, 5W
- 4” Clamp – Live Cables
- GPS – marking location
- Bluetooth to Android device
CABLE FAULT FINDING

- Cable Identification
- EZID
- Phasing is also possible
- Must have access to one side
- Best to ID dead cables
CABLE FAULT FINDING

• Cable Spiking
• Schermer (Utilities)
• Picoup400 (Mines)
• Hydraulic as optional
• This saves lives !!
• Remote firing of the
CABLE FAULT FINDING

- Sheath Fault Location
- Shirla
- 5kV DC Test
- Spikes
CABLE FAULT FINDING

- PFT Oil Leak Location
- The oil cable is “Tagged”
- A GC is used to locate the leaking gas
- De-gassifier Trailers
CABLE TESTING

• Pressure Testing
• DC
• AC, 50Hz
• VLF, 0.1Hz
• Testing the insulation
• Test according to the std.
CABLE TESTING

- DC Hipot
- PGK50
- Still used on PILC cable
- Cheaper Equipment
- Meaningless on AC cables
CABLE TESTING

- AC 50Hz
- Equipment is large
- Expensive
- 44kV cables and up
- Back energise on open-circuit

Variable Frequency, 265 kV, 22 MVA
CABLE TESTING

- VLF 0.1Hz
- Using VLF or 0.1Hz pure sine
- Only test for XLPE up to 33kV
- Commissioning
- Maintenance
- Joints and Terminations
CABLE TESTING

- Cable Diagnostics
- Combine a Tan-Delta test
- Footprint
- Indication of deterioration
- PD Test
CABLE TESTING

- Online Tan Delta
- TD Guard
- absolute Tan-δ values in on-line permanent monitoring
- Innovative instrument for Capacitance, Tan-δ and Δtan-δ recording, storage & processing

H.V. TEST (PTY) LTD
Leaders in High Voltage Test Equipment
• Online Partial Discharge
• PD detection at 50Hz
• Can’t increase the voltage
• Cable Voltage not Relevant
CABLE TESTING

- Offline Tan Delta
- Tests are performed at 0.1Hz, Voltage is manually controlled
- Foot printing and cable deterioration
CABLE TESTING

- Offline Partial Discharge
- Inception and Extinguishing voltage
CABLE TESTING

- Jointing- and Splicing tools

**H.V. TEST (PTY) LTD**
Leaders in High Voltage Test Equipment
POWER TRANSFORMERS

- Turns Ratio
- Comparing the ratio can easily show faults
- Field or Maintenance Test
- 1 Phase or 3 Phase Testing
POWER TRANSFORMERS

- Winding Resistance
- DC Resistance Test
- Temperature Measurement Possible
- 1 Phase or 3 Phase
POWER TRANSFORMERS

- Tap Changer
- Dynamic Resistive plot of the taps
- 3 Phase option with Winding
POWER TRANSFORMERS

- Insulation Resistance
- Metriso Prime10
- 5kV, 10kV, 15kV options
- PI, DAR
- Megger
POWER TRANSFORMERS

- Variac and Multimeter
- Nameplate verification
- % Impedance
- Open & Short Circuit
POWER TRANSFORMERS

- Tan Delta
- Bushings
- Tank
- 2 Separate units
- 1 Dedicated TD unit
POWER TRANSFORMERS

- FRA
- Verify that the windings did not move around during transport
- Tests is performed before on loading
- Repeated after installation
- Sweep: 5Hz to 45MHz
POWER TRANSFORMERS

- Oil Dielectric
- 60kV, 75kV, 80kV, 100kV
- Water in Oil (Karl Fischer)

Test vessel 0.4 l in acc. with IEC 60156 Fig. II with cover
POWER TRANSFORMERS

- Oil Tan Delta
• Transformer Test Bay
CIRCUIT BREAKER

- Speed / Timing Tests
- Indoor / Outdoor
- 3 Channels / 1 Break / Ph
- 6 Channels / 2 Break / Ph
- 12 Channels / 4 Break / Ph
- On-Line

H.V. TEST (PTY) LTD
Leaders in High Voltage Test Equipment
CIRCUIT BREAKER

- Static Resistance
- CAT61 or CAT-P
- Typical 10A, 50A, 100A, 200A
- Up to 800A
- Loose equipment or build in to the Circuit Breaker Analyser
- Handheld up to 30C
CIRCUIT BREAKER

- Minimum Pick Up
- POB30
- Test to verify that the breaker coils will still fire even at 70% of station battery voltage
- Variac might damage the coil during the ramping
SUB STATION

- Earth Resistance Testing
- Soil Resisivity
- 4-Wire Method
- Step and Touch (current)
• Disturbance Recording
• 9, 18, 36 Analogue Channels
• 32, 64, 96, 128 Digital Channels
• IEC 61850
SUB STATION

- Power Quality
- IEC 61000-4-30 Class A
- 19” Rack / Portable
- PQ and DFR

H.V. TEST (PTY) LTD
Leaders in High Voltage Test Equipment
SUB STATION

- Voltage Detection
- Contact
- Non-Contact
- Up to 765kV
SWITCHGEAR

- AC Hipot
- Busbar Testing
- 50Hz Test
- 3mA per panel
- Consider the current
• **Primary Injection**
• Customer has to specify the max current
• 200A is still regarded as secondary injection
• 12000A or more
SWITCHGEAR

- CT Mag Curve, Ratio and Polarity
- Single or multiple tap
SWITCHGEAR

- Partial Discharge Monitoring
- Handheld
- Permanent monitor of GIS and transformers
- Cloud Storage
SWITCHGEAR

- Phasing Sticks
- Switchgear

For use on very HV overhead lines, both T and R shall obligatorily be equipped with their specific probe extension (white).

For use in switchgears, both T and R shall obligatorily be equipped with their safety electrode extension (grey).

H.V. TEST (PTY) LTD
Leaders in High Voltage Test Equipment
SWITCHGEAR

- Recloser Test Bay
- 0 – 7.50, 2500A
- 19kVA, 47kVA

H.V. TEST (PTY) LTD
Leaders in High Voltage Test Equipment
PROTECTION RELAYS

- Single Phase Injection
- CDG Electromechanical relay
- High VA relays
- Manual Testing
PROTECTION RELAYS

- Three Phase Injection
- 3 Currents 3 Voltages
- 3 Currents 4 Voltages
- 6 Currents 4 Voltages
- 6 Currents 6 Voltages
- IEC 61850
- Transcope
• Battery Resistance
• Battery Resistance
• Test a string of cells
• Record results to a database
BATTERIES

- Battery Discharge
- Additional load units available
OVERHEAD LINES

- Distance To Fault Recorders (NAMPOWER)
- FL8 and FL1
- For Lines of voltages 66kV and up
- +/- 120m accuracy
- Software automatically calculates distance to fault
- Save money on costly Line investigations
OVERHEAD LINES

- Earth Tower Footing Resistance
- ER25K
- Measuring earth resistance of electrical pylons
- High frequency measurement current (25kHz)
OVERHEAD LINES

• Surge Arrestor
• SCAR10
• True rms of the total current.
• Peak value of the total current.
• True rms of the third harmonic

H.V. TEST (PTY) LTD
Leaders in High Voltage Test Equipment
OVERHEAD LINES

- Contact
- Non-Contact
- Up to 765kV
- Voltage Detection

H.V. TEST (PTY) LTD
Leaders in High Voltage Test Equipment
OVERHEAD LINES

- PGK50
- AC / DC Pressure Testing

H.V. TEST (PTY) LTD
Leaders in High Voltage Test Equipment
MOTORS & GENERATORS

- Resonance
- We can provide
- 50Hz pressure test
- PD Test
- Recent work includes Ingula, Drakensberg
SAFETY AND SMALL PRODUCTS

- Multimeters
- Entry Level
- Mid Range
- High End
- Calibrators
- 1kV Insulation Testers
SAFETY AND SMALL PRODUCTS

- Clamp-on Meters
- Non-Invasive Current Measurement
SAFETY AND SMALL PRODUCTS

- Photovoltaic Meters
- PV condition
- Insulation measurement
- Polarity testing
- Ground fault testing
- Protective conductor continuity
SAFETY AND SMALL PRODUCTS

- Portable Appliance Testers
- Testing for N-PE reversal
- Tripping test with nominal residual current, trip time measurement
- Earthing Resistance RE
- Selective Earthing Resistance RE
- Earth Loop Resistance RE loop
- Soil Resistivity Rho

H.V. TEST (PTY) LTD
Leaders in High Voltage Test Equipment
SAFETY AND SMALL PRODUCTS

- Substation Rescue Equipment
- Electrical safety kit 25kV 36kV

H.V. TEST (PTY) LTD
Leaders in High Voltage Test Equipment
SAFETY AND SMALL PRODUCTS

- Tools for Explosive Environment
- Voltage, Resistance, Current, Frequency
- Intrinsically safe electric circuits up to 1000 V
- CAT IV, 1000 V
SAFETY AND SMALL PRODUCTS

- Live Line Testing Bays
- 1 or 2 Gloves
- Complete Bay

Model TGM-022
TRANSFORMER & CABLE TESTING

Reasons for Preventative Maintenance Testing:

- Extend the life of the asset
- Prevent unexpected outages
- Prevent catastrophic failures
Different tests have been implemented for different scenarios. They consist of routine testing, type testing and special testing. We will be looking at a summary of routine testing.

Routine tests are tests required for each individual transformer.
TRANSFORMER TESTING

- Test Standards:
  - IEC 60076-1, IEC 60076-2, IEC 60076-3,
  - IEC 60076-4, IEC 60076-5, IEC 60076-6,
  - IEC 60076-7, IEC 60076-8, IEC 60076-9,
  - IEC 60076-10, IEC 60076-11
Transformer Ratio Test

- The ratio test ensures that the transformer windings have the proper turns to produce the voltages required. The ratio is a measure of the voltage applied to the primary terminals to the voltage measured at the secondary terminals.
Vector Group and Polarity

- The polarity and vector group of the transformer must be tested and checked to match the vector group on the nameplate.
Impedance Test

- Also known as, Load or short circuit test.
- This test is performed to ensure the stated nameplate impedance and the measured transformer impedance match.
No-Load Test (Magnetisation)

- This test verifies the design and core performance by indication of the no load current drawn by the transformer.
- The magnetisation current is a factor of losses in the electric circuit, losses in the magnetic circuit, and losses in the dielectric circuit.
Winding Resistance

- The winding resistance is performed to determine the resistance of the conductors in the transformer winding, and the tap-changer contacts resistances.
Tap-change Continuity

• The tap-changer contacts are tested for electrical continuity during tap-changing.

• By applying a constant current while tapping the tester looks for open circuit transients during tap-changing.
Insulation Resistance Test (Popular Test)

- The purpose of this DC test indicates the degree of dryness of the insulation and ground circuits that may exist.
ROUTINE TESTING

Dielectric Absorption (DA) and Polarization Index (PI)

• Evaluating the windings for the following:
  o Build up of dirt or moisture.
  o Gradual deterioration of the insulation (comparing results)
  o Suitability for operation.
Tan Delta Test on the transformer and the Bushings (where possible)

• The Tan Delta is a measure of the insulation loss

• The bushings of the transformer are tested before fitting and/or transport
Frequency Response Analysis (FRA) Test

- This technique is designed to detect winding shifts through non-destructive methods, before and after transport of the transformer.
Other Tests

- Oil Testing - Dielectric Strength
- Dissolved Gas Analysis
- Water Content
- Acidity

These are usually sent away to a lab.
PRACTICAL TESTING OF MV CABLES

• Introduction

• The new Standard (SANS 10198-13:2016) overview

• Testing On Site
Recommended methods of Testing

- 50 Hz Testing
- Very Expensive

- Very low Frequency (VLF) Testing
VLF Wave Shapes:

- **Cosine Rectangular Waveform**

  ![Cosine Rectangular Waveform Diagram]

  - **Disadvantage:** No diagnostic possible
PRACTICAL TESTING OF MV CABLES

VLF Wave Shapes:

• Sinusoidal Wave form

- Wave Shape are equally positive and negative.
- **Advantage:** Diagnostic possible
Direct Current (DC) Testing:

**SANS 10198: 2016 Part 13 excludes DC Testing**

“D.C. Overvoltage is likely to cause irreversible damage on aged cables”

- Why exclude DC from PILC Cables?
  - Because we are using “solid dielectrics” (Heat Shrink) on joints or terminations (almost 90%)
Summary of Changes (SANS 10198-13:2016):

- Incorporates all cables up to less than 33kV
  - PILC – screened and bolted
  - XLPE
  - EPR
  - Bundle
  - PVC

- Additional Test: Conductor Resistance

- Insulation Resistance Test: before and after testing
Recommended Test Requirements (Commissioning)

- Insulation Resistance Test (DC 1000V)
- Conductor Resistance Test (DC)
- Overvoltage Test
- Outer Sheath Test
- Diagnostic Tests: (fingerprinting & future trending)
- Insulation Resistance Test (DC 1000V)
Conductor Resistance Test:

- This is a new requirement (check Joints).
- Use two cores, loop for end, and divide result by 2
- Instrument to use is the “Ductor” – 4 wire method
- Aberdare and CBI Cable Brochures provide conductor resistance tables

Example:
10km of 240mm2 Cable is 7.8 Ohm
**Cable Sheath Testing:**

After overvoltage testing cable sheath testing is recommended:

- 5 kV for 1 minute (Recommended)
- NB: Lift the far end of the earth bar!
- Roughly guide 1 mA per km test source
Overvoltage Commissioning Testing:
Newly Installed Individual screened (Radial field) (cores) on M.V. Cables

Table 1 – Commissioning test voltages for newly installed individually screened MV cables

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cable operating voltage kV</td>
<td>VLF Test voltage sine kV</td>
<td>VLF Test voltage cosine rectangular kV</td>
<td>Power-frequency test voltage kV</td>
</tr>
<tr>
<td>6.6</td>
<td>11</td>
<td>16</td>
<td>8</td>
</tr>
<tr>
<td>11</td>
<td>19</td>
<td>27</td>
<td>13</td>
</tr>
<tr>
<td>22</td>
<td>38</td>
<td>54</td>
<td>25</td>
</tr>
<tr>
<td>33</td>
<td>57</td>
<td>80</td>
<td>38</td>
</tr>
</tbody>
</table>

NOTE 1
The voltages given are root mean square (r.m.s.) values. The r.m.s. value of a cosine rectangular voltage is equal to the peak voltage.

NOTE 2
Where the test levels cannot be achieved or where limitations are placed on the maximum test voltage by the equipment (for example, switchgear) connected to the cable, a reduced voltage for an extended duration may need to be considered and agreed to.

Notes:
- Test time 60 minutes/core
- Only for individual screen cables (radially stressed)
- This table applies to XLPE, EPR and PILC (non-belted and individual screen cables).
- More than one core can be tested simultaneously provided the test set has the capacity.
Overvoltage Maintenance Testing:
Individual screened (Radial field) (cores) on M.V. Cables

Table 7 – Commissioning test voltages for individually screened MV cables

<table>
<thead>
<tr>
<th>1 Cable operating voltage kV</th>
<th>2 VLF Test voltage sine kV</th>
<th>3 VLF Test voltage cosine rectangular kV</th>
<th>4 Power-frequency test voltage kV</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.6</td>
<td>8</td>
<td>11</td>
<td>5</td>
</tr>
<tr>
<td>11</td>
<td>13</td>
<td>18</td>
<td>9</td>
</tr>
<tr>
<td>22</td>
<td>25</td>
<td>35</td>
<td>17</td>
</tr>
<tr>
<td>33</td>
<td>38</td>
<td>54</td>
<td>25</td>
</tr>
</tbody>
</table>

NOTE 1
The voltages given are root mean square (r.m.s.) values. The r.m.s. value of a cosine rectangular voltage is equal to the peak voltage.

NOTE 2
Where the test levels cannot be achieved or where limitations are placed on the maximum test voltage by the equipment (for example, switchgear) connected to the cable, a reduced voltage for an extended duration may need to be considered and agreed to.

NOTE 3
The test used for maintenance are two-thirds (2/3) of the test voltages for newly installed cables.

Notes:
- Test time is 60 minutes/core
- Only for individual screen cables (XLPE + PILC)
- Not Belted PILC cable
- Multiple cores can be tested simultaneously provided the test set has the capacity

H.V. TEST (PTY) LTD
Leaders in High Voltage Test Equipment
PRACTICAL TESTING OF MV CABLES

Diagnostic Testing (TD)

- Not specified as mandatory but recommended
- TD is an excellent and easy test
  - Simple and today part of Pressure Test Set
  - Very meaningful for ageing cables
  - Excellent “Fingerprint”
  - Temperature, site conditions, moisture sensitive
  - Water trees are only detected by T.D. (not P.D.)
  - TD is an indication of the TD of the whole cable
  - Unlike P.D. - location of poor T.D. source is not possible
Diagnostic Testing (PD)

• Not specified as mandatory but recommended
• PD provides location of source of discharge
• PD requires highly skilled technician with experience
TD Variables

➢ **Tan Delta (TD)**
  • Calculate the TD using the average value calculated at $U_o$.

➢ **Delta tan delta (DTD)**
  • Calculate the DTD using the average values calculated at $0.5U_o$ and $1.5U_o$.

➢ **Tan delta stability (TDS)**
  • Calculate the TDS using the following formula at $U_o$.
    
    $$TDS = \sqrt{\frac{\sum(TD-\overline{TD})^2}{(n-1)}}$$

  - TD : a measured TD point in the test series
  - $\overline{TD}$ : the average tan delta of the series
  - $n$ : the number of TD points in the test series
Table 3 – Guidelines for the condition assessment of cables based on 0,01 Hz VLF-TD, DTD and TDS for newly installed XLPE cables

<table>
<thead>
<tr>
<th>Condition Assessment</th>
<th>TD at Uo ([10^{-3}])</th>
<th>DTD ([10^{-3}])</th>
<th>TDS at Uo ([10^{-3}])</th>
</tr>
</thead>
<tbody>
<tr>
<td>No action required</td>
<td>&lt;2.5</td>
<td>&lt;0.6</td>
<td>&lt;0.2</td>
</tr>
<tr>
<td>Further study advised</td>
<td>2.5 to 5</td>
<td>0.6 to 1</td>
<td>0.2 to 0.5</td>
</tr>
<tr>
<td>Action required</td>
<td>&gt;5</td>
<td>&gt;1</td>
<td>&gt;0.5</td>
</tr>
</tbody>
</table>

* XLPE cables in operation for less than five years

Table 5 – Guidelines for the condition assessment of cables based on 0,01 Hz VLF-TD, DTD and TDS for newly installed PILC Cables

<table>
<thead>
<tr>
<th>Condition Assessment</th>
<th>TD at Uo ([10^{-3}])</th>
<th>DTD ([10^{-3}])</th>
<th>TDS at Uo ([10^{-3}])</th>
</tr>
</thead>
<tbody>
<tr>
<td>No action required</td>
<td>&lt;25</td>
<td>-20 to 20</td>
<td>&lt;0.5</td>
</tr>
<tr>
<td>Further study advised</td>
<td>25 to 50</td>
<td>-20 to -50 or 20 to 50</td>
<td>0.5 to 1</td>
</tr>
<tr>
<td>Action required</td>
<td>&gt;50</td>
<td>&gt;-50 or &gt;50</td>
<td>&gt;1</td>
</tr>
</tbody>
</table>

* PILC cables in operation for less than five years
## TD Testing (Maintenance)

Table 4 – Guidelines for the condition assessment of cables based on 0.01 Hz VLF-TD, DTD and TDS for aged (in service) XLPE Cables

<table>
<thead>
<tr>
<th>Condition Assesment</th>
<th>TD at Uo [10^{-3}]</th>
<th>DTD [10^{-3}]</th>
<th>TDS at Uo [10^{-3}]</th>
</tr>
</thead>
<tbody>
<tr>
<td>No action required</td>
<td>&lt;2.5</td>
<td>&lt;3</td>
<td>&lt;0.5</td>
</tr>
<tr>
<td>Further study advised</td>
<td>2.5 to 25</td>
<td>3 to 30</td>
<td>0.5 to 1</td>
</tr>
<tr>
<td>Action required</td>
<td>&gt;25</td>
<td>&gt;30</td>
<td>&gt;1</td>
</tr>
</tbody>
</table>

Table 6 – Guidelines for the condition assessment of cables based on 0.01 Hz VLF-TD, DTD and TDS for aged (in service) PILC Cables

<table>
<thead>
<tr>
<th>Condition Assesment</th>
<th>TD at Uo [10^{-3}]</th>
<th>DTD [10^{-3}]</th>
<th>TDS at Uo [10^{-3}]</th>
</tr>
</thead>
<tbody>
<tr>
<td>No action required</td>
<td>&lt;50</td>
<td>-35 to 10</td>
<td>&lt;0.5</td>
</tr>
<tr>
<td>Further study advised</td>
<td>50 to 200</td>
<td>-35 to -50 or 10 to 50</td>
<td>0.5 to 1</td>
</tr>
<tr>
<td>Action required</td>
<td>&gt;200</td>
<td>&gt;-50 to 50</td>
<td>&gt;1</td>
</tr>
</tbody>
</table>
PRACTICAL TESTING OF MV CABLES

- Notebook or PocketPC
- Wireless data transmission (Bluetooth)
- Direct connection to DUT or arbitrary adapters like MC, clamps, hooks,
- Device Under Test
- HVA 30/60 High Voltage Generators
- Direct fit into Generator, including 30 ft. (10m) connection cable
- Ground connection

H.V. TEST (PTY) LTD
Leaders in High Voltage Test Equipment
Thank you, any Questions?