Presentation Content

- Standardization of Power Transformers in the network
- Design and design reviews
- Quality Control
- Testing
Interchangeability and standardization

Philosophy
All transformers are specified, designed, tested, maintained and operated to meet at least the expected operational life span of approximately 40 years when used in normal operation.
Interchangeability and standardization

- New transformers are specified to be designed for minimum maintenance requirements and oil leaks i.e. vacutap-minimum 300000 operation, and welded top covers
- All the units are easily interchangeable in terms of their electrical & physical parameters and must work optimally when connected in parallel.
Interchangeability and standardization

Eskom Transmission has standardized on all transformers and is reaping practical and economic benefits.

- All units are interchangeable, spares are common, less time is needed to check designs, performing design reviews, approval of drawings, test certificate and time is saved in preparing specifications & drawings for new Capital projects.
- Field maintenance staff have fewer different types of equipment to deal with
Interchangeability and standardization

- Power transformers are required to interconnect the system voltages of 765, 400, 275 and 220kV step down from these voltages to 132 and 88kV to give supplies to distribution or other end users.

- Selecting these transformers generally involves deciding on the number of type of units i.e. MVA ratings, insulation, winding Connection, vector grouping and voltage ratio. Furthermore, impedance, type of tap-changer and tapping range plays a crucial role.
<table>
<thead>
<tr>
<th>Standard Number</th>
<th>Nominal Voltage (kV)</th>
<th>Ratings Main/Tertiary (MVA/MVA)</th>
<th>Impedance</th>
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<tbody>
<tr>
<td></td>
<td>HV</td>
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<td>132</td>
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<td>6.6</td>
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<tr>
<td>C1</td>
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</table>
Interchangeability and standardization

**Tapping Ranges**

+5% to -15% of HV voltage has been adopted as the standard for transformers based on the following:

- The electricity act states that supply voltages shall not vary by more than ±5% from the nominal.

- Thus sending end busbar voltages shall not exceed 105% while receiving end voltages shall not be less than 95%, assuming loads connected to both busbars.
Interchangeability and standardization

**Tapping Ranges cont....**

- Allowing for a 5% volt drop through the transformer at the receiving end and assuming that the voltage of the LV busbar associated with this transformer is required to be boosted to 105%, an 85% tap is required on the HV side together with an ability to withstand for at least a limited period of 10% over-fluxing condition.

- At light load a 5% voltage rise in the line due to the Ferranti effect with 100% sending voltage requires a maximum tap of 105% on the receiving end transformer.
Interchangeability and standardization

**Tapping Ranges cont....**

- 16 steps each of 1.25% is chosen as the standard to provide reasonably fine control without excessive operations due to minor fluctuations.

- For the 400kV system transformers the tapping range is reduced to 0% to -15%, firstly because $U_{\text{max}}$ for this system is only 105% and, secondly, because a 20% tapping range introduces problems with the insulation of the tapping winding.
Interchangeability and standardization

- **Insulation and connection**
- For economic reasons all auto-transformers and all star-connected windings of 132kV and above have graded insulation and must be solidly earthed.
- All transformers must be either auto-connected or Star/star so that there is no phase shift between primary and secondary voltages.
- Where voltage ratio(N) is 3:1 or less, economics dictate an auto-transformer
Weakness identified in the current Specification

Internal Faults : Failure Root Cause

• Insulation breakdown, collapse of the Tap windings as a result of an number of through faults and lightning strikes occurring in the network.
• Design reviews Conducted by an Independent Consultant revealed some shortcoming on the existing winding arrangement
• Over fluxing could be observed on the 400kV transformers with no plus tolerance due to the limitations on maximum system voltages
• These failures had exceeded the international limit of 2.5% per annum.
Severe failures transformers 12mmi

<table>
<thead>
<tr>
<th>Year</th>
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<th>2001</th>
<th>2002</th>
<th>2003</th>
<th>2004-April</th>
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<td>Value(s)</td>
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<td>4</td>
<td>6</td>
<td>6</td>
<td>8</td>
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<tr>
<td>Target</td>
<td>4</td>
<td>4</td>
<td>4</td>
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</tbody>
</table>

Number of severe failures transformers 12mmi from 2000 to 2004-April.
Existing winding arrangement

- Tertiary Winding
- Tapping Winding
- MV Winding
- HV Winding
Adoption of this arrangement

- This winding arrangement was originally adopted to ensure almost constant impedance throughout the tapping range in order to achieve the full rated power across the whole tapping range. Furthermore, it ensured maximum impedance occurring in the minimum tap-position, which is advantageous for LV fault MVA consideration. This is due to the fact that previously Eskom had a policy to supply the rural and farm communities from the tertiary terminals of the main autotransformer.
Adoption of this arrangement, Cont

• This policy has been abolished in the recent past due to the line faults failures experienced from the tertiary feeders which is a dangerous practice as a direct short-circuit fault on the tertiary winding can lead to very high forces on that winding, resulting in the destruction of the whole transformer.
Investigation findings on the windings
Investigation findings on the windings, cont

- The tap winding is located between the LV and MV both being more or less on ground potential.
- Tapping winding acts like a sharp electrode between the adjacent windings and is exposed to high axial short-circuit stresses (Voltage Knife condition).
- This condition requires a tap winding to be insulated from LV and MV windings.
- Disadvantages:
  - more paper insulation,
  - less mechanical stability,
- it becomes more spongy under through fault condition.
Investigation findings on the tap-changes
Protection against transients

• ZnO offer protection because as the voltage tries to rise above the threshold level, the resistance plummets and a large amount of current is passed. This action keeps the voltage between taps to below the threshold level as the power is shunted through the discs. They are made to operate only during very short time voltage transients due to lightning strikes and switching transients. These are types of transients which produce the highest internal voltage stresses in the transformer, as well as the highest possibility of exciting winding damaging resonances.
Studies for Transients stress suppression

1050 kV Full Wave at X
Voltage across RW

\[ \Delta V_{RW} \text{ (kV)} \]

- without
- with MOV's

\[ t \text{ (mys)} \]
Investigation for a new solution

- Because of such high failure rate of these Transmission transformers windings and tap changers on the Eskom Transmission National Grid. These failures reached an unprecedented high levels in the early 2000. These failures were the highest in such that they exceeded annual failure rate stipulated by international standards.
- The extent of failures has been quantified and was the major driving motivation behind the upgrading of the specification.
Changes and adoption of the new Specification

- Tertiary Winding
- MV Winding
- Tap Winding
- HV Winding

Diagram showing connections and components.
Challenges

• Tertiary impedance dropped due to the relocation of the tapping winding into the main field. Tertiary reactor was introduced to increase the impedance thereby dropping the fault level to < 20kA.

• Impedance slope differed due to the different winding arrangement.
Challenges – Tertiary Reactors
Challenges – Paralleling of units

500 MVA, 275 / 132 kV

Impedance characteristic

Impedance (%)

1 3 5 7 9 11 13 15 17

Tap position

old design
new design
The new Specification

SERVICE CONDITIONS

• The rated nominal frequency shall be 50Hz.

Temperature Rise.

• Temperature rises must be in accordance with IEC 60076 standards. It has to be considered that the annual average rated ambient temperature has been changed from 25°C to 30°C.

Winding Rise.

• The average winding rise above ambient at nameplate MVA rating shall not exceed 55°C for oil natural flow through the windings, and shall not exceed 60°C for oil forced directed flow through the winding.
• **Temperature Rise of Metallic Parts at Rated MVA.**

• The hot spot temperature rise above ambient of metallic parts in contact with cellulose material outside the winding block shall not exceed 68°C. The rise above ambient of other metallic parts in contact with oil including core and tank shall not exceed 75°C for the surface in contact with the oil.
The new Specification

Winding **Hottest Spot Temperature Rise.**

- The winding hot spot temperature rises above ambient at nameplate MVA rating has been changed from 73°C to 68°C.
- The top oil temperature rise above ambient has been changed from 55 to 50°C. If forced oil flow through the winding is applied (ODAF/ODWF) the oil flow through the core must also be forced so that the oil at top of the core does not exceed a 50°C temperature rise above ambient.
The new Specification

**Temperature Rise of Metallic Parts at Rated MVA.**

- The hot spot temperature rise above ambient of metallic parts in contact with cellulose material outside the winding block shall not exceed 68 °C. The rise above ambient of other metallic parts in contact with oil including core and tank shall not exceed 75 °C for the surface in contact with the oil.

- Flux density to be limited to 1.7 Tesla at 50Hz at rated voltage.
Changes and adoption of the new Specification

• 20% Insulation safety margin as per international standard as demonstrated by field plots.
• Increase the radial build of tap winding, reducing paper insulation within limits
• Fitting ZnO varistors across the tap winding to limit voltage transients that causes oscillation
• Using low chip epoxy to improve mech. strength of the tap Wdg’s.
Design reviews

• international Consultant is engaged
• Design Review is performed on every new design and the ff: is verified as per Cigre Guideline
• Focus area is on conformity and performance data with both ordering specification and IEC/IEEE Standards. Reliability aspects such as design safety margins crosschecks calculations, material quality, and quality assurance in terms of designs and manufacturing. Lifetime expectancy aspects such as thermal aspects focussing on hot spots in the windings and metal parts, Dissolved Gas Analysing limits, short circuit behaviour, overload condition behaviour as per IEC 60076-7 Loading guide.
Factors considered during the design reviews

**ELECTRICAL DESIGN**

Winding Arrangement

- Arrangement of windings.
- Describe type of windings to be used.
- Conductor configuration in each winding.
- Location and type of tap windings or tap sections to be used.
Factors considered during the design reviews

Insulation Clearances and Configuration of Insulation.

- Insulation clearances between windings and between windings and ground.
- Electrostatic shielding around the core, at ends of windings, and adjacent to line coils or disks.
- Insulation spaces between disks. Calculated impulse voltages between disks.
- Conductor insulation on each winding. Calculated turn to turn voltage in each winding.
- Drawing of the insulation assembly between and around windings. Transient voltage distribution.
Factors considered during the design reviews

- Describe method used to calculate transient voltage distribution
- Calculated capacitances between windings. This must include induced voltages in adjacent windings. Acceptable voltages for the spaces across which the voltage appears.
- The voltages with and without the metal oxide varistors.
- Study of oil spaces and creepage stresses
Factors considered during the design reviews

Leakage Flux Heating in Cores and Mechanical Parts

- Calculation methods used to determine the field magnitudes.
- Determination of losses in the various elements.
- Cores and core supports.
- Frame and tank wall heating. Shielding used to reduce losses and prevent heating.
Factors considered during the design reviews

**MECHANICAL DESIGN**

**Tanks**

- Construction
- Joint design and welding to prevent leaks.
Factors considered during the design reviews

- **TEST PROGRAM**
  - Review requirements in the specifications and standards.
  - Review test plans for the transformer.
  - Accuracy of loss measurement methods.
  - Temperature tests including review of allowed gas in oil increases during temperature tests.
  - Impulse and partial discharge testing. Discuss acceptance criteria.
- Check points during testing.
Workshop Inspection - Individual windings
Workshop Inspection- Assembly line
Workshop Inspection-Top Lining up
Workshop Inspection - Winding inspection
Workshop Inspection- Winding assembly
Workshop Inspection - Active part before tanking
Quality control

Focus area is on

• **Tests to prove that the transformer has been built correctly:** This include ratio, polarity, resistance and taphange operation.

• **Tests to prove the guarantees:** These are the losses, impedance, and temperature rise and noise level.

• **Test to prove that the transformer will be satisfactory in service for at least 35 years.** The tests in this category are the most important and the most difficult to frame.

• **These tests are performed as per IEC 60076-3**
### Transformer testing

<table>
<thead>
<tr>
<th><strong>Main test required as per IEC:</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature rise test (only on the first unit)</td>
<td>Type</td>
</tr>
<tr>
<td>Short time duration heat run test</td>
<td>Routine, on subsequent units</td>
</tr>
<tr>
<td>Short circuit test</td>
<td>Calculation for the short circuit withstand capability should be submitted</td>
</tr>
<tr>
<td>Lightning impulse test</td>
<td>Routine</td>
</tr>
<tr>
<td>Switching impulse test</td>
<td>Routine</td>
</tr>
<tr>
<td>Induced over voltage test</td>
<td>Routine</td>
</tr>
<tr>
<td>Chopped impulse test</td>
<td>Routine</td>
</tr>
<tr>
<td>Acoustic noise level measurement</td>
<td>Type</td>
</tr>
<tr>
<td>Overload test</td>
<td>Type</td>
</tr>
<tr>
<td>Dielectric loss angle test and capacitance (Doble instrument)</td>
<td>Routine</td>
</tr>
<tr>
<td>Vibration test</td>
<td>Routine</td>
</tr>
<tr>
<td>SFRA – Fully assembled filled with oil. (Doble instrument)</td>
<td>Routine</td>
</tr>
<tr>
<td>SFRA – Fitted with test bushing and gas filled. (Doble instrument)</td>
<td>Routine</td>
</tr>
</tbody>
</table>
### Transformer testing

<table>
<thead>
<tr>
<th>Highest voltage for equipment $U_m$ (kV r.m.s.)</th>
<th>Rated switching impulse withstand voltage phase-to-earth (kV peak)</th>
<th>Rated lightning impulse withstand voltage (kV peak)</th>
<th>Rated short-duration induced or separate source AC withstand voltage (kV r.m.s.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>245</td>
<td>550</td>
<td>650</td>
<td>325</td>
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</tbody>
</table>

**NOTE 1** Dotted lines are not in line with IEC60071-1 but are current practice in some countries.

**NOTE 2** For uniformly insulated transformers with extremely low values of rated AC insulation levels, special measures may have to be taken to perform the short-duration AC induced test.

**NOTE 3** Note applicable, unless otherwise agreed.

**NOTE 4** For voltages given in the last column, higher test voltages may be required to prove that the required phase-to-phase withstand voltages are met. This is valid for the lower insulation levels assigned to the different $U_m$ in the table.
Thank You