Natural Ester Oil Power Transformer Solution for PPC Slurry Substation in Eskom’s North West Operation Unit

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Why?

- For this particular indoor substation, we decided to use natural ester oil in a 20MVA 88/6.6kV power transformer of the 1\textsuperscript{st} time due to positive implications on:
  a) environmental,
  b) safety and,
  c) cost

- Looking ahead.....implications for localization and industrialization of SA – job creation.
PPC Slurry Indoor Substation
SS Design Constraints

- Due to space constraints, an outdoor extension of the station was not viable.

- Part T of the South African Building Regulations has a major impact on indoor substations - The regulations are stringent with regards to fire safety when using oil filled equipment.

- Environmentally sensitive area – Underground spring
Transformer Oil

• The oil is a key component in the transformers makeup - acts as insulant, coolant and provides an opportunity to perform diagnostics on the transformer.

• Must have good insulation and dielectric properties and, good anti-ageing properties.

• This is why mineral oil has been used for decades
Mineral Oil

• Produced from Crude:
The 2 major drawbacks apply to the Slurry SS project.
Natural Ester Filled Transformer

- Readily biodegradable
- Longer life expectancy
- Higher fire point
Impact of Fire Point on Clearances

• SA Building Regulations Part T, IEC 61936-1 and CIGRE Guide 537
Challenges for NE Power Transformer Design

Kinematic Viscosity Challenge:

- NE have a higher viscosity—effect on their flow through ducts and channels designed for cooling in the transformer??
- How to adjust the cooling?

<table>
<thead>
<tr>
<th>Oil Type</th>
<th>Coefficient</th>
<th>40 °C Viscosity</th>
<th>100 °C Viscosity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mineral oil</td>
<td>0.1</td>
<td>9</td>
<td>2.5</td>
</tr>
<tr>
<td>Ester oil</td>
<td>0.17</td>
<td>35</td>
<td>8</td>
</tr>
</tbody>
</table>

Thermal conductivity:

\[ \rho C_p \frac{dT}{dt} - \nabla \cdot (k \nabla T) = q - \rho C_p v \cdot \nabla T \]
Heat Models
Kinematic Viscosity

Solution:

• Increase duct sizes to allow for acceptable flow of the higher viscosity natural ester oil through the winding.

• Adjust the heat transfer factor in thermal calculations from the winding through to the oil.

• The hydraulic resistance for the entire ONAN (Oil natural, air natural) system must be adjusted for natural esters.
Oil Impregnation of Solid Insulation Challenge

- Natural ester oil has a density and viscosity that is different to mineral oil.

- The permittivity of NE is higher than MO and closer to that of the paper. The electrical stresses are therefore more present in the paper as opposed to mineral oil where the stresses are in the oil.

- This is supported by the following FEMM simulations.
Solution: Increase oil impregnation times for NE oils. The temperature of the oil during filling should be increased to facilitate oil impregnation.
Material Compatibility

Compatibility of Materials with Natural Ester Oil

Challenge

• Some materials that are commonly used in transformers such as nitrile rubber are known to age prematurely in natural ester oil. There is also uncertainty over the reaction of the resin used in continuously transposed copper (CTC) windings with natural ester oils.

Solution

• Reputable manufacturers of natural ester oils have performed compatibility test to ensure that suitable alternatives to all non-compatible materials are accessible. This database is readily available for transformer manufacturers to verify the bill of materials against. Electrical designs can be modified to use paper covered conductor instead of CTC.
Fast Transient Response in Natural Ester Oils

Challenge:
• Fast streamers develop more easily in natural ester oils than in mineral oils and are therefore able to bridge longer gaps.

Solution
• Electrical designs must be modified such there are larger distances between live and grounded elements. A higher voltage class of tapchanger may be used to accommodate for the fast streamer response in natural ester. Vacuum tapchanger may be used to prevent switching from taking place in the ester oil.
Oxygen Stability

Oxidation Stability

Challenge

• Natural ester oils have lower oxidation stability than mineral oils and age considerably faster in the presence of oxygen.

Solution

• Fit a preservation bag to the conservator to limit exposure to the atmosphere and prevent oxidation of the natural ester oil.
## Cost Implications of NE Transformer

<table>
<thead>
<tr>
<th></th>
<th>Savings</th>
<th>Additional Costs</th>
<th>Reasons</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R406,080.00</td>
<td>R406,080.00</td>
<td>12690 liters of oil at R55 per liter Natural Esters versus R23 per liter Mineral Oil.</td>
</tr>
<tr>
<td></td>
<td>R300,000.00</td>
<td></td>
<td>Reduced oil holding dam and piping.</td>
</tr>
<tr>
<td></td>
<td>R5,000,000.00</td>
<td></td>
<td>Savings from not requiring active fire protection.</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>R5,300,000.00</td>
<td>R406,000.00</td>
</tr>
<tr>
<td></td>
<td>NET SAVINGS</td>
<td></td>
<td>R4,893,920.00</td>
</tr>
</tbody>
</table>
Conclusion

- The unique requirements of the additional transformer bay required at Slurry PPC 88kV Substation provided an interesting challenge to Eskom’s engineers.
- The sensitive environmental conditions, space constraints and the fire risks associated with an indoor station made the natural ester oil an obvious choice for the insulating fluid in the transformers.
- The use of natural ester oil allowed for a compact station and considerable savings were made by avoiding costs associated with active fire protection and oil containment facilities, in spite of the higher cost of the natural ester oil in comparison with mineral oil.
- The difference in electrical and thermal performance of the natural ester oils to mineral oil necessitated changes from the typical mineral oil transformer design.
Conclusion

• Extensive research was conducted into manufacturing transformers with natural ester oils and the subsequent electrical design met all criteria specified in currently available compliance documents.

• The transformer has been manufactured completed and passed all HV electrical tests as per IEC 60076 on the 19th of October.

• The natural ester oil filled transformer provided an innovative, safe and cost effective solution for a challenging project.

• The North West Operating should give serious consideration to replacing all the mineral oil filled transformers in operation at PPC Slurry substation with natural ester filled equivalents to address the fire and environmental risks at the station.
The authors would like to acknowledge the contribution of Annalie Lombaard (Eskom), Willibald Felber (Felber Engineering), the North West Operating Unit, TAP, Powertech Transformers and UKZN for their efforts in realizing this project.