REVIEW OF THE ELECTRICAL AND THERMAL BEHAVIOUR OF ESTER-BASED DIELECTRIC LIQUIDS FOR EXTRA HIGH VOLTAGE APPLICATIONS

Mark Lashbrook, Dr Attila Gyore, Dr Russell Martin
Agenda

• Introduction to ester-based liquids
• Designing for esters
  • Permittivity
  • Dielectric Strength Considerations
  • Thermal Considerations
• Full Scale Synthetic Ester Test
• Case Studies
• Conclusions
What is an Ester?

- The term ‘ester’ comes from chemical linkage formed from the reaction of an alcohol & an acid
- Synthetic esters are manufactured from chemicals
  - Carefully selected acids and alcohol to give chosen properties
- Natural esters are derived from plant oils
  - Refined seed oils
  - Examples include Rapeseed, Soya, Sunflower

\[ RCOOR' \]

- \( O = \text{Oxygen} \)
- \( C = \text{Carbon} \)
- \( R \& R' = \text{Carbon Chain} \)
Transformer Liquid Structures

Synthetic Ester – MIDEL 7131

Natural Ester
MIDEL eN 1204, 1215

Mineral Oil
Key Benefits of Ester-based Liquids

- Increased Fire Safety
- Greater Environmental Protection
- Superior Moisture Tolerance
- Longer Paper Lifetime
- No Corrosive Sulphur
Design Considerations for Esters

• Permittivity of esters is higher than mineral oil
  • Changes the field distribution
  • Pushes stress into solid insulation

• Impulse Breakdown
  • Esters show lower impulse strength than mineral oil

• Field Divergence
  • Propagation of streamers is easier in esters, less strong in very divergent fields

• Thermal Considerations
  • Viscosity of esters is higher than mineral oil
Simple Permittivity Example

\[ Z = \frac{d_p}{\varepsilon_p} + \frac{d_f}{\varepsilon_f} \]

Electrical Stress kV/mm

\[ E_n = \frac{U}{\varepsilon_n \times Z} \]

<table>
<thead>
<tr>
<th></th>
<th>MIDEL 7131</th>
<th>Mineral Oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper Stress</td>
<td>10.7 kV/mm</td>
<td>8.8 kV/mm</td>
</tr>
<tr>
<td>Fluid Stress</td>
<td>15.7 kV/mm</td>
<td>17.6 kV/mm</td>
</tr>
</tbody>
</table>
Effect on Stress Distribution

Impulse Breakdown Sphere - Sphere

Effect of Changing Electrode Configuration

- Testing conducted with different types of electrodes
- Studied the influence of tip radius on the breakdown voltage in oil gaps

Results of Testing

- Difference between ester and mineral oil increases in more divergent fields

Thermal Considerations - Viscosity

<table>
<thead>
<tr>
<th></th>
<th>Min. Oil</th>
<th>Nat. Ester</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\theta_{\text{Oil_top}}$</td>
<td>59.9 K</td>
<td>64.4 K</td>
</tr>
<tr>
<td>$\theta_{\text{Oil_ax.}}$</td>
<td>27.4 K</td>
<td>37.8 K</td>
</tr>
<tr>
<td>$\theta_{\text{Oil_mean}}$</td>
<td>46.2 K</td>
<td>45.5 K</td>
</tr>
<tr>
<td>$\theta_{\text{Cu_oil}}$</td>
<td>17.2 K</td>
<td>17.6 K</td>
</tr>
<tr>
<td>$\theta_{\text{Cu_mean}}$</td>
<td>63.4 K</td>
<td>63.1 K</td>
</tr>
<tr>
<td>$\theta_{\text{hot_spot}}$</td>
<td>82.3 K</td>
<td>87.3 K</td>
</tr>
</tbody>
</table>
Full Scale 400kV Test with Synthetic Ester

- Joint project under UK OFGEM funding
  - National Grid, UK
  - Alstom UK (GE Grid, Stafford)
  - M&I Materials, UK
- Testing of a full scale 400kV coil winding
- Results of testing allowed design of 400kV synthetic ester transformers
- National Grid decision to extend use of esters to 400kV
National Grid UK 400kV – London Project

- Large scale project in a dense urban area
- Planning consent a major barrier
- Meet the needs of residents & planners
- Synthetic-ester design crucially delivered
  - Increased fire safety
  - Fire suppression benefits
  - Less complex containment system
- Heat recovery system using waste energy
  - Normal transformer operation
  - Supply heat to residents & school
- Lower overall project costs
  - Substation size (m²)
  - Civil construction
    - Containment & drainage
    - Fire barriers/walls
- NG see this system as a future strategy
  - Plan national rolled out
    - Urban
    - Space constrained developments.
- Reduce environmental impact & aids planning consent process

London Power Tunnels, Seven Sisters Road, public information leaflet, 2012
Vattenfall Letsi – 433kV GSU

- Four single phase Generator Step Up units for hydro plant
- Rated 433kV 122MVA
- Synthetic ester chosen for fire safety and environmental reasons
- Transformers in service 2016
Conclusions

• Use of ester-based liquids is increasing rapidly
• Interest in using them for transmission voltage levels
• Large amount of research has been conducted which finds some differences
• Design adjustments may be necessary to accommodate ester characteristics
• Despite this a number of projects at 400kV and above are using ester-based liquids
Thank you for your kind attention!

Websites:  www.midel.com
           www.midelamericas.com
Email:     AttilaGyore@mimaterials.com
Tel:       +44 161 864 5408