Accelerated Insulation Aging Due to Thermal and Electrical Stresses in Future Power Grids

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Contents

• Future Trends and Repetitive transients
• Experimental investigations
• Modeling repetitive transients
• Conclusions
Future Trends

- Reliability on renewable sources
- HVDC Transmission
- Smart Grids
Necessity of a model in a smart grid environment

 Courtesy of www.smartgrids.eu
DC-AC Conversion using power electronics

- DC generated voltages need to be converted to AC using power electronic inverters e.g. wind farms

- The repetition frequency is in the range of 0.5 kHz to 10 kHz with slew rates around 1 kV/μs, depending on the technique used to convert DC to AC
The effects on HV Insulation

Main parameters:
- Repetition frequency
- Fast rise times
- Relatively high magnitude to the carrier waveform

Causes:
- Dielectric heating
- PD generated at transient rise
- Localized heating
Paper-oil samples preparation

- Paper with impregnated mineral oil
- 24 hours impregnation in vacuum @60 °C
- 0.06mm thickness
- PDIV at 2.4kV
- Breakdown Voltage 3.1kV

- Electrode: round flat contact surface with Rogowski profile edges
Experimental waveforms

- **Square**
  - PDIV
  - V bd

- **Superimposed transient**
  - Time to breakdown
  - Tan δ
Square wave aging

Test set-up:

- Measured using an antenna
- Varied rise time
- Increased amplitude until breakdown
Square wave aging - Results
Superimposed transients

Design Parameters:

- Variable repetition frequency 1kHz-10kHz
- Variable magnitude of transients (±1kV) and AC waveform (1kV-3kV)
- Manage high capacitance samples
- Safety!
Transients With the AC component

- Applied Waveform

5 kV ac component with 5 kHz pulses with a 1 µs rise times
Results – Time to Breakdown

- Two carrier waveforms were used: 2.22kV and 2.91kV
- Aging Times AC-only:
  - 2.91kV = 168 h
  - 2.22kV = 1400 h
Test set-up for elevated temperatures

- Heating element to warm up oil
- Applied Temp: 40, 60 and 80 °C
- Transient Freq.: 1, 5 and 10 kHz
- Carrier Waveform: 2.22 kV
- Application of parameters for 22 h
- Measured tan δ
Paper degradation above room temperature

![Graph showing Tan δ values for measuring voltage of 350 V](image)
The Fluctuation Model

- Energy is "injected" into the paper that breaks the polymeric chains
- $m$ measures the degree of connection between clusters of polymeric chains
- From $m$, the Weibull Beta parameter can be derived

<table>
<thead>
<tr>
<th>Transient Frequency</th>
<th>2.91 kV</th>
<th>2.22 kV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$m$</td>
<td>$\beta_{1/m}$</td>
</tr>
<tr>
<td>9 kHz</td>
<td>0.18</td>
<td>5.62</td>
</tr>
<tr>
<td>6 kHz</td>
<td>0.21</td>
<td>4.76</td>
</tr>
<tr>
<td>2 kHz</td>
<td>0.22</td>
<td>4.54</td>
</tr>
<tr>
<td>New</td>
<td>0.23</td>
<td>4.35</td>
</tr>
</tbody>
</table>
Power Law Aging Model

\[ \tau = aV^{-k} \]
Exponential Law Aging Model

\[ \tau = ae^{-bf} \]

- **Time to breakdown [h]**

- **Carrier Voltage:**
  - \( \eta \) for 2.91 kV
  - \( \eta \) for 2.22 kV

- **CC:**
  - 0.92 for 2.91 kV
  - 0.97 for 2.22 kV
The aging model

- Combination of two parts:
- Power Law – for aging caused by the carrier waveform
- Exponential law – for aging caused by repetitive transients

\[ t_{bd} = 10^6 \cdot V^{-9.565} \cdot e^{-0.15 \cdot f} \]
Model application

Aging of Paper-Oil Insulation under 1 kV Transient Conditions

Carrier voltage:
- 2.91 kV
- 2.22 kV
- 1.5 kV
- 1.2 kV
- 1 kV

Frequency [kHz] vs. Time to breakdown [hrs]

Frequency:
- 50
- 40
- 30
- 20
- 10
- 0

Time to breakdown:
- 1.0E-02
- 1.0E-01
- 1.0E+00
- 1.0E+01
- 1.0E+02
- 1.0E+03
- 1.0E+04
- 1.0E+05
- 1.0E+06

Approximate times:
- ~ 2.5 years
- ~ 50 years
Life time consumption (LC)

\[ LC = 1 - \frac{t_{bd_{tr}}}{t_{bd_{AC}}} \]

- Transient frequency:
  - 1 kHz
  - 3 kHz
  - 6 kHz
  - 9 kHz
Conclusions

• High repetition frequencies and rise times decrease the lifetime of insulation
• PDs are likely to be generated at high rise times
• Transients dissipate energy breaking the polymeric bonds within the paper
• An aging model comprises the aging effect of the carrier waveform and that of the transients

Recommendations

• Investigation of transformers in the field
• Relate transients to a measurable parameter such as DP
• Investigation on other network components/materials (XLPE, EPR)
Thank you for your attention!

Any questions?

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