VLF Tests conducted by NEETRAC as part of the CDFI

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Acknowledgements

• Thanks to CDFI Participants and NETA for much of the data presented here.

• This material is based upon work supported by the Department of Energy under Award No DE-FC02-04CH1237 and CDFI.

• Any opinions, findings, conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the Department of Energy.
Issues

• Voltage levels for Tan δ
• Tan δ at failure
• Establishing Critical Levels for Tan δ
• Effect of test voltage level on VLF Withstand Tests
Tan δ Test Levels 1 - Withstand
Tan δ Test Levels 2 – Voltage Stability
Thoughts

- Should we be recommending test voltages for a Tan δ test (ie one that can be done to determine whether a stability test is done) in the revision of 400.2 that are above the ones used for a stability test
Tests carried out at Duke Energy
1980’s vintage jacketed XLPE URD cable
Operated at 25kV
Test location known to have reliability issues
– failure rate 3 to 4 time the US national average
Voltage Stability Test

Tan-delta vs Voltage

Tip Up
Tan $\delta$ Stability (Constant Voltage)

![Graph showing Tan $\delta$ vs Voltage and Time]

- Voltage [p.u.]
  - 0.5
  - 1.0
  - 1.5
  - 1.7

- Time [min]
  - 0
  - 1
  - 2
  - 3
  - 4
  - 5
  - 6
  - 7

- Tan-$\delta$ vs Voltage
- Tan-$\delta$ Stability
- Before Failure
- Failure

The graph illustrates the relationship between Tan $\delta$ and voltage over time, with distinct markers for different voltage levels. The graph shows the degradation of Tan $\delta$ as voltage levels increase, leading to a failure point.
Repeat Voltage Stability Test

![Graph showing voltage stability test results](image)

- **Voltage vs Time (min)**
- **Tan-delta vs Voltage**
- **Before Failure**
- **Failure**
- **After Elbow Failure**

- **Voltage [p.u.]:**
  - 0.5
  - 1.0
  - 1.5
  - 1.7
A Similar Story

Time [min]
Tan-delta \[1e-3\]

Failure

Before Failure

After Cable Repair - two slices and piece of cable

Tan-delta Stability

Voltage

Voltage [p.u.]
- 0.5
- 1.0
- 1.5
- 1.7

Before Failure

"Failure"
Thoughts

• Monitoring a property during the constant voltage phase does provide information
• Certainly give confidence to utilities
• Have found that it is easier to undertake the longer time tests when there is a monitoring phase
Establishing Critical Levels

• Seems to be general agreement that the present IEEE400 levels do not fully represent the situation
• How to set critical levels
• How to relate Tan $\delta$ and Tip Up
• We have started with
  – Approx 200 measurements
  – Measurements <2 Uo
Compiling Available Tan $\delta$ Data

![Graph showing compiled Tan $\delta$ data with different Uo values.](image-url)
Compiling Available Tan δ Data (Uo)
Empirically divide Tan δ and Tip Up
The division gives a “map”
Diagnostics map with presently data – PE based insulations

- Tan Delta at U₀ (E-3)
- Tip Up 1.5U₀ - 0.5U₀ (E-3)

- Required
- No Action

- Required Action
- Study
- Further
Overall Results For PE Based Insulations

- **Tip Up 1.5Uo - 0.5Uo (E-3)**
  - Tan Delta at Uo (E-3)
  - 1000.0
  - 100.0
  - 10.0
  - 1.0
  - 0.1
  - 0.01

- **No Action Required**
  - 70%

- **Action Required**
  - 6%

- **Further Study**
  - 25%
Filled and Unfilled Insulations

![Graph showing filled and unfilled insulations with Tan Delta (1e-3) on the x-axis and Percent on the y-axis. The graph compares filled and unfilled insulations with distinct markers for each category.]
Thoughts

• We propose a way to determine critical levels
• We see little difference between HMWPE, XLPE & WTR XLPE insulations
• Would expect the lower \( \tan \delta \) limit to be a little higher for Filled insulations (Vulkene & EPR); do not expect the Tip Up and upper \( \tan \delta \) limits to change
• Could be used as the basis for IEEE400.2 levels
• Work underway on the recommendations for “Further Study”
VLF Withstand Results

• At previous meetings we have presented a collation of the US experience of the VLF withstand tests
• Analysis showed that the time to failure in service is much higher if a 30 min rather than a 15 min test is used
• We have extended the analysis to look at the effect of test voltage on the failures that occur under test
Effect of Test Voltage

<table>
<thead>
<tr>
<th>Test Voltage (Uo)</th>
<th>Survivors on Test (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.0</td>
<td>30</td>
</tr>
<tr>
<td>3.5</td>
<td>40</td>
</tr>
<tr>
<td>3.0</td>
<td>50</td>
</tr>
<tr>
<td>2.5</td>
<td>60</td>
</tr>
<tr>
<td>2.0</td>
<td>70</td>
</tr>
</tbody>
</table>

- PILC
- Extruded
- Mixed (PILC and Extruded)
Times to 1st Failure: 15 & 30 Minutes

![Graph showing the relationship between time to first failure and percentage of tested cables failing for 15 and 30 minutes test durations.](image)
Thoughts

• Test voltage has a profound effect on the failures under test
• Test time has a profound effect on the failures after test
• Great care is needed if the IEEE400.2 voltage levels are exceeded