Diagnostic techniques are generally used either to ensure the performance of newly installed equipment (commissioning tests) or to assess the state / health of older components or systems. Diagnostic programs contain four basic elements that can be summarized as:

**Selection** – Choose the cable circuits for testing. Typically this is based on age, failure rate, or other engineering judgment.

**Action** – What actions will be performed as the result of certain diagnostic outcomes or interpretations? The actions are in two groups (Act or Not Act) and may include replacement, defer action, rejuvenation, and/or repair.

**Generation** – Diagnostic tests generate data that are well fitted to the type of maintenance actions and prevalent failure mechanisms.

**Evaluation** – Are the methods employed for Selection, Action, and Generation, giving the expected results: lower rates of failure and increased times between failures? Can the diagnostic elements be improved?

The figure illustrates how the four components function together over time to produce (if implemented properly) a reduction in the anticipated failure rate. It is useful to note:

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**Additional Information**

**Principal Investigator**
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rick.hartlein@neetrac.gatech.edu

**NEETRAC**  
www.neetrac.gatech.edu

**Selection of diagnostics**

http://143.215.162.190/KBS_Servlet/

**Final Report on Cable Diagnostic Focused Initiative (CDFI) - DE-FC02-04CH11237**
available from Dept of Energy in late 2010

**Other Useful Documents**

7. R.N. Hampton, R. Harley, R. Hartlein & J.C. Hernandez; Practical Issues Regarding The Use Of Dielectric Measurements To Diagnose The Service Health Of MV Cables; International Conference on Insulated Power Cables; JICABLE07, Versailles France, June 2007

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Historical figures of merit (Monitored Withstand) derived within CDFI for US cable systems over a period of 2 years for more than 200 separate measurements.

Monitored Withstand Tests are conducted for 30 minutes as recommended by IEEE Std 400.2.

This time may be amended if the conditions listed in the Tables below are fulfilled:

### Condition Assessment of PE-based Insulations (i.e. PE, XLPE, WTRXLPE)

<table>
<thead>
<tr>
<th>Condition Assessment</th>
<th>Change in Tan Delta between 0 and 10 mins (E-3)</th>
<th>VLF-TD Stability (standard deviation) at Maintenance Level [10^{-3}]</th>
<th>Mean VLF-TD at Maintenance Level [10^{-3}]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduced to 15 Mins</td>
<td>-</td>
<td>&lt;0.3</td>
<td>&lt;15</td>
</tr>
<tr>
<td>Extended to 60 Mins</td>
<td>-</td>
<td>&gt;6</td>
<td>&gt;180</td>
</tr>
</tbody>
</table>

### Condition Assessment of Filled Insulations (i.e. EPR & Vulkene)

<table>
<thead>
<tr>
<th>Condition Assessment</th>
<th>Change in Tan Delta between 0 and 10 mins (E-3)</th>
<th>VLF-TD Stability (standard deviation) at Maintenance Level [10^{-3}]</th>
<th>Mean VLF-TD at Maintenance Level [10^{-3}]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduced to 15 Mins</td>
<td>-</td>
<td>&lt;0.3</td>
<td>&lt;15</td>
</tr>
<tr>
<td>Extended to 60 Mins</td>
<td>-</td>
<td>&gt;6</td>
<td>&gt;180</td>
</tr>
</tbody>
</table>

### Condition Assessment of Paper Insulations (i.e. PILC)

<table>
<thead>
<tr>
<th>Condition Assessment</th>
<th>Change in Tan Delta between 0 and 10 mins (E-3)</th>
<th>VLF-TD Stability (standard deviation) at Maintenance Level [10^{-3}]</th>
<th>Mean VLF-TD at Maintenance Level [10^{-3}]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduced to 15 Mins</td>
<td>&lt;1.3</td>
<td>&lt;0.7</td>
<td>&lt;75</td>
</tr>
<tr>
<td>Extended to 60 Mins</td>
<td>&gt;4</td>
<td>&gt;3.5</td>
<td>&gt;135</td>
</tr>
</tbody>
</table>

The maintenance test voltages for withstand testing in IEEE400.2 (see below) are used for Monitored Withstand Tests.

<table>
<thead>
<tr>
<th>CABLE SYSTEM VOLTAGE (kV)</th>
<th>15</th>
<th>20</th>
<th>25</th>
<th>35</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintenance Testing – rms (kV)</td>
<td>16</td>
<td>20</td>
<td>24</td>
<td>33</td>
</tr>
<tr>
<td>Maintenance Testing – peak (kV)</td>
<td>22</td>
<td>28</td>
<td>34</td>
<td>47</td>
</tr>
</tbody>
</table>

It is recommended that the test voltage is raised step wise to the test voltage in steps of 0.5Uo, 1Uo, 1.5Uo etc. This permits a “classic” Tan Delta diagnostic assessment to be completed prior to initiating the 30 minute Withstand.

Anticipated Failure rate On Test (FOT) for the Withstand portion is:
- 15 Minutes 2.0% per 1000ft approx
- 30 Minutes 2.7% per 1000ft approx
- 60 Minutes 3.7% per 1000ft approx

**Disclaimer**

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Check latest CDFI Documentation for any updated values if used after July 2014.
**INTERPRETATION**

Actions following a Further Study diagnosis might include
- review data for a rogue measurement in the sequence – most common in the first acquisition
- check insulation type so that correct assessment table is used
- re-clean terminations & repeat measurements
- compare with previous tests or other results from other phases of this cable
- if filled insulations are tested check specific variety of material; if identified as discharge resistant or mineral filled XLPE consult CDFI / NEETRAC for guidance
- conduct IEEE400.2 Standard (30 mins) VLF Withstand whilst monitoring $\tan \delta$ – see Monitored Withstand Brochure for guidance
- place on “watch list”

**FURTHER HELP**

**Actions following an Action Required diagnosis might include**
- review data for a rogue measurement in the sequence – most common in the first acquisition
- check insulation type so that correct assessment table is used
- re-clean terminations & repeat measurements
- compare with previous tests or other results from other phases of this cable
- if filled insulations are tested check specific variety of material; if identified as mineral filled XLPE consult CDFI / NEETRAC for guidance
- conduct IEEE400.2 Standard (60 mins) VLF Withstand whilst monitoring $\tan \delta$ – see Monitored Withstand Brochure for guidance
- retest in near future
- place on “watch list” & consider remedial actions for the circuit

**Selection of diagnostics**


**Contact your CDFI representative**

**Final Report on Cable Diagnostic Focused Initiative (CDFI) - DE-FC02-04CH11237**
available from Dept of Energy in early 2011

**Other Useful Documents**

1. First practical utility implementation of monitored withstand diagnostics in the USA; CL Fletcher, J Perkel, RN Hampton, JC Hernandez, J Hesse, MG Pearman, CT Wall, W Zenger; *International Conference on Insulated Power Cables JICABLE11*, Versailles France, June 2011; Paper A.10.2
5. IEEE P400.2/D8; Guide for Field Testing of Shielded Power Cable Systems Using Very Low Frequency (VLF) IEEE Standard 400.2-2003,

The CDFI data have been incorporated in the most recent update of IEEE Std 400.2

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**CDFI**

**Tan Delta Diagnostics of Distribution & Network Cable Circuits using the CDFI MV Test Protocol**

**DOE Award No. DE-FC02-04CH11237**

CONSULT CDFI DOCUMENTATION IF USED AFTER JULY 2014

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Historical figures of merit within CDFI for US cable systems over a period of 6 yrs. Figures of Merit are based on more than 4000 separate field measurements at VLF.

<table>
<thead>
<tr>
<th>Condition Assessment [10^{-3}]</th>
<th>No Action Required</th>
<th>Further Study Advised</th>
<th>Action Required</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Assessment of PE-based Insulations</strong> (i.e. PE, XLPE, WTRXLPE)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stability for TD_{U0} (standard deviation)</td>
<td>&lt;0.05</td>
<td>0.05 to 0.5</td>
<td>&gt;0.5</td>
</tr>
<tr>
<td>&amp; or</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tip Up (TD_{1.5U_0} – TD_{0.5U_0})</td>
<td>&lt;5</td>
<td>5 to 80</td>
<td>&gt;80</td>
</tr>
<tr>
<td>&amp; or</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tip Up Tip Up ((TD_{1.5U_0} - TD_{0.5U_0}) - (TD_{U_0} - TD_{0.5U_0}))</td>
<td>&lt;2</td>
<td>2 to 52</td>
<td>&gt;52</td>
</tr>
<tr>
<td>&amp; or</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean TD at U0</td>
<td>&lt;4</td>
<td>4 to 50</td>
<td>&gt;50</td>
</tr>
</tbody>
</table>

A minimum of 6 measurements should be made at each voltage level; to determine the parameters detailed above.

In these tests (all materials) the “operational U_o” is used to determine test voltages.

The user may elect to add a measurement at 2U_0 of engineering information if this does not exceed the IEEE400.2 withstand voltages.

**A TDR Measurement is always “Good Practice“ in advance of a Tan \( \delta \) measurement as it serves to confirm Capacitance measurements and obtain a qualitative estimate of neutral condition.**

**CONSULT CDFI DOCUMENTATION IF USED AFTER JULY 2014**

An excel tool, which simultaneously assesses all features (Stability for TD_{U0} , Tip Up , Tip Up Tip Up & Mean TD) has been developed to enhance the analyses, especially in the region of Further Study (cable circuits ranked 5 to 15%) & “Action Required” (the lowest ranked 5% of cable circuits).

Contact your CDFI Representative to obtain a copy.

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