SAGE

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:

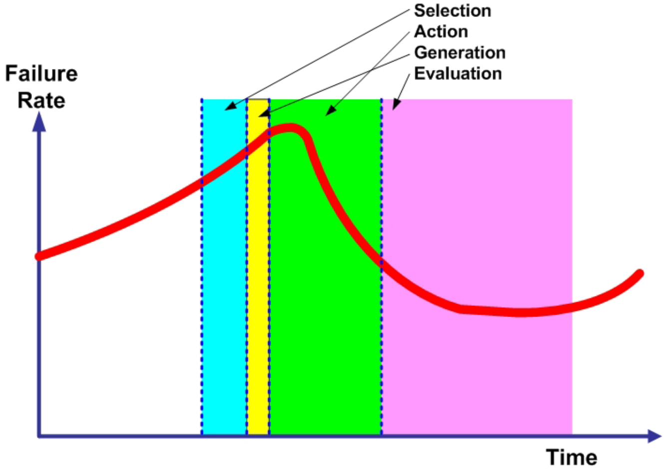
Selection – Choose the cable circuits for testing. Typically this is based on age, failure rate, or other engineering judgment.

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:



Effect of SAGE on the Failure Rate of a Target Population

FURTHER HELP

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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

1. Hampton, R.N..Perkel. J., Hernandez, J.C., Begovic, M., Hans, J., Riley, R., Tyschenko, P., Doherty, F., Murray, G., Hong, L., Pearman, M.G., Fletcher, C.L., and Linte, G.C., "Experience of Withstand Testing of Cable Systems in the USA"; *CIGRE 2010*, Paper No. B1-303
2. IEEE Guide for Field Testing and Evaluation of the Insulation of Shielded Power Cable Systems, *IEEE Standard 400-2001*, Apr. 2002.
3. IEEE P400.2/D8; Guide for Field Testing of Shielded Power Cable Systems Using Very Low Frequency (VLF) *IEEE Standard 400.2* - 2003,.
4. J. Densley, "Aging Mechanisms and Diagnostics for Power Cables-An Overview," *IEEE Electrical Insulation Magazine*, vol. 17, no. 1, pp. 14-22, Jan. /Feb. 2001.
5. L.A. Dissado, and J.C. Fothergill, "Electrical degradation and breakdown in polymers," *IEE Materials and Devices* series 9, Peter Peregrinus Ltd., London, 1992.
6. M. Begovic, RN. Hampton*, R. Hartlein, J.C. Hernandez-Mejia, and J Perkel; Validation of the accuracy of practical diagnostic tests for power equipment; *CIGRE 2008* Paris Study Committee D1 Paper 205
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

CDFI

Monitored Withstand Tan Delta

DOE Award No. DE-FC02-04CH11237

National Electric Energy Testing, Research & Applications Center
NEETRAC
A Research Center in the School of Electrical and Computer Engineering at the Georgia Institute of Technology

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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)

Condition Assessment	Change in Tan Delta between 0 and 10 mins (E-3)		VLF-TD Stability (standard deviation) at Maintenance Level [10^{-3}]		Mean VLF-TD at Maintenance Level [10^{-3}]
Reduced to 15 Mins	<0.25	and	<0.25	and	<5
Extended to 60 Mins	>17	or	>6	or	>45

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

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

Condition Assessment	Change in Tan Delta between 0 and 10 mins (E-3)		VLF-TD Stability (standard deviation) at Maintenance Level [10^{-3}]		Mean VLF-TD at Maintenance Level [10^{-3}]
Reduced to 15 Mins	-	and	<0.3	and	<15
Extended to 60 Mins	-	or	>6	or	>180

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

Condition Assessment	Change in Tan Delta between 0 and 10 mins (E-3)		VLF-TD Stability (standard deviation) at Maintenance Level [10^{-3}]		Mean VLF-TD at Maintenance Level [10^{-3}]
Reduced to 15 Mins	<1.3	and	<0.7	and	<75
Extended to 60 Mins	>4	or	>3.5	or	>135

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

CABLE SYSTEM VOLTAGE (kV)	**15**	**20**	**25**	**35**
Maintenance Testing – rms (kV)	16	20	24	33
Maintenance Testing – peak (kV)	22	28	34	47

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

The information contained herein is to our knowledge accurate and reliable at the date of publication.

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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 δ – see Monitored Withstand Brochure for guidance
- place on "watch list"

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 δ – see Monitored Withstand Brochure for guidance
- Retest in near future
- place on "watch list" & consider remedial actions for the circuit

FURTHER HELP

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NEETRAC
www.neetrac.gatech.edu

Diagnostic Tool
Contact your CDFI representative

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 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
2. Challenges associated with the interpretation of dielectric loss data from power cable system measurements; J. Perkel, J.C. Hernández, R. N. Hampton, J. F. Drapeau, J. Densley; *International Conference on Insulated Power Cables JICABLE11*, Versailles France, June 2011; C.4.5
3. Hampton, R.N..Perkel. J., Hernandez, J.C., Begovic, M., Hans, J., Riley, R., Tyschenko, P., Doherty, F., Murray, G., Hong, L., Pearman, M.G., Fletcher, C.L., and Linte, G.C., "Experience of Withstand Testing of Cable Systems in the USA"; *CIGRE 2010*, Paper No. B1-303
4. IEEE Guide for Field Testing and Evaluation of the Insulation of Shielded Power Cable Systems, *IEEE Standard 400-2001*, Apr. 2002.
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

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

NEETRAC
National Electric Energy Testing, Research & Applications Center
A Research Center in the School of Electrical and Computer Engineering at the Georgia Institute of Technology

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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.

Condition Assessment [10^{-3}]	No Action Required	Further Study Advised	Action Required
Assessment of PE-based Insulations (i.e. PE, XLPE, WTRXLPE)			
Stability for TD_{U_0} (standard deviation)	<0.05	0.05 to 0.5	>0.5
	&	or	
Tip Up ($TD_{1.5U_0} - TD_{0.5U_0}$)	<5	5 to 80	>80
	&	or	
Tip Up Tip Up $\{(TD_{1.5U_0}-TD_{U_0}) - (TD_{U_0}-TD_{0.5U_0})\}$	<2	2 to 52	>52
	&	or	
Mean TD at U_0	<4	4 to 50	>50

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 Uo" is used to determine test voltages.

The user <u>may</u> elect to add a measurement at 2Uo of engineering information if this does not exceed the IEEE400.2 withstand voltages.

Condition Assessment [10^{-3}]	No Action Required	Further Study Advised	Action Required
Assessment of Unidentified Filled Insulations (i.e. EPR, Kerite & Vulkene) *			
Stability for TD_{U_0} (standard deviation)	<0.1	0.1 to 1.3	>1.3
	&	or	
Tip Up ($TD_{1.5U_0} - TD_{0.5U_0}$)	<5	5 to 100	>100
	&	or	
Tip Up Tip Up $\{(TD_{1.5U_0}-TD_{U_0}) - (TD_{U_0}-TD_{0.5U_0})\}$	<0.5	0.5 to 30	>30
	&	or	
Mean TD at U_0	<35	35 to 120	>120
Condition Assessment of Mineral Filled Insulations (i.e. EPR) *			
Stability for TD_{U_0} (standard deviation)	<0.1	0.1 to 1	>1
	&	or	
Tip Up ($TD_{1.5U_0} - TD_{0.5U_0}$)	<4	4 to 120	>120
	&	or	
Tip Up Tip Up $\{(TD_{1.5U_0}-TD_{U_0}) - (TD_{U_0}-TD_{0.5U_0})\}$	<0.65	0.65 to 40	>40
	&	or	
Mean TD at U_0	<20	20 to 100	>100

* Experience has shown that it is difficult to precisely identify the type of filled insulation of field-installed cable. The issues encountered include: incorrect /missing records, obliterated or obscured markings on the cable jacket, indistinct coloring etc. In these cases it is recommended to use the criteria for **Unidentified Filled** data.

Condition Assessment [10^{-3}]	No Action Required	Further Study Advised	Action Required
Assessment of Paper Insulations (i.e. PILC)			
Stability for TD_{U_0} (standard deviation)	<0.1	0.1 to 0.4	>0.4
	&	or	
Tip Up ($TD_{1.5U_0} - TD_{0.5U_0}$)	-35 to 10	-35 to -50 or 10 to 100	<-50 or >100
	&	or	
Tip Up Tip Up $\{(TD_{1.5U_0}-TD_{U_0}) - (TD_{U_0}-TD_{0.5U_0})\}$	<9	9 to 19	>19
	&	or	
Mean TD at U_0	<90	90 to 200	>200

A TDR Measurement is always "Good Practice" in advance of a Tan δ measurement as it serves to confirm Capacitance measurements and obtain a qualitative estimate of neutral condition.

<u>CONSULT CDFI DOCUMENTATION IF USED AFTER JULY 2014</u>

An excel tool, which simultaneously assesses all features (Stability for TD_{U_0} , 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.

Disclaimer

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Neither GTRC nor The Georgia Institute of Technology nor NEETRAC will be responsible for any injury to or death of persons or damage to or destruction of property or for any other loss, damage or injury of any kind whatsoever resulting from the use of the project results and/or data. GTRC, GIT and NEETRAC disclaim any and all warranties both express and implied with respect to analysis or research or results contained in this report. It is the user's responsibility to conduct the necessary assessments in order to satisfy themselves as to the suitability of the products or recommendations for the user's particular purpose. No statement herein shall be construed as an endorsement of any product or process or provider Any opinions, findings and 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