An Overview of Diagnostic Testing of Medium Voltage Power Cables

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CIGRE WG 21:04 in 1994

- Purpose of diagnostic test is:

"To evaluate and locate degradation phenomena that will cause cable system (cable or accessory) failure."

We must consider the whole cable system

- Conductor (Al, Cu, solid, stranded)
- Shields (conductor, insulation)
- Insulation (PILC EPR XLPE, TRXLPE)
- Neutral/sheath (type, material)
- Jacket (type, material)
- Splices (type, material)
- Terminations/potheads (type, material)

What can go wrong with cables?

- Accessories.
- Interfacial problems in accessories ? PD, tracking.
- Connector problems in accessories ? overheating, etc.
- Extruded Insulation.
- Water trees ? electrical trees ? PD.
- PD in voids, delaminations ? electrical trees.
- Paper/oil Insulation.
- Oil leaks ? dry regions ? overheating, PD, etc.
- Water ingress ?increased loss ? overheating.

What can go wrong with cables? (cont'd)

- Extruded Shields.
- Increased resistivity ? reduced shielding ? PD.
- Hardening ? embrittlement ? cracking ? PD, etc.

5. Neutral/Sheath.

- Corrosion ? loss of continuity ?arcing, etc.
- Holes in sheath ? leaks ? loss of oil, etc.
- Jacket.
- Hardening ? cracking ? water ingress ? treeing, etc.

For good condition assessment need to know:

- What properties can be monitored for particular degradation, i.e., what tests?
- How degradation develops with time
- How degradation develops with service conditions
- Actual failure mechanism and how it develops with time

Types of diagnostics

- We looked at PD diagnostics at the last ICC. Now want to look at other techniques, e.g., to detect:
- Neutral corrosion,
- jacket or sheath integrity
- Insulation condition

Neutral corrosion

- Measure resistance
- TDR to detect breaks
- Measure changes in electric field
- Capacitance

Need to know if corrosion is localized or uniform

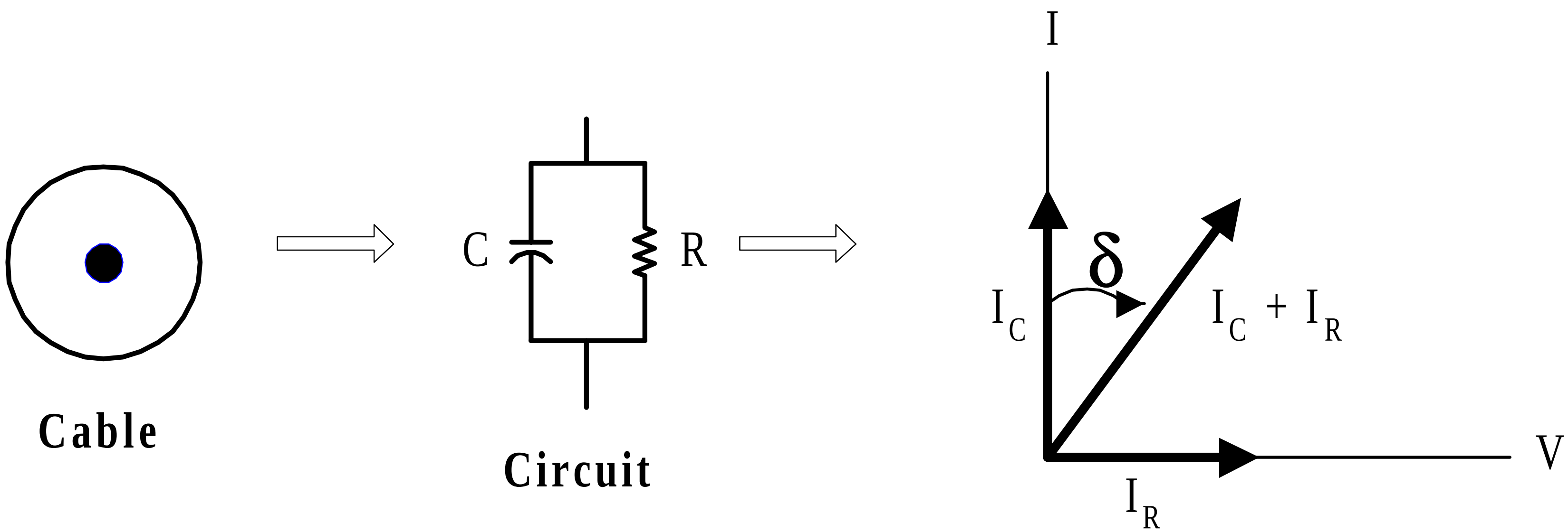
Neutral corrosion can affect insulation measurements

Insulation degradation

One of the main forms of deterioration is due to water treeing, treelike growths in the insulation that cause increased losses. Water trees can be detected by measuring:

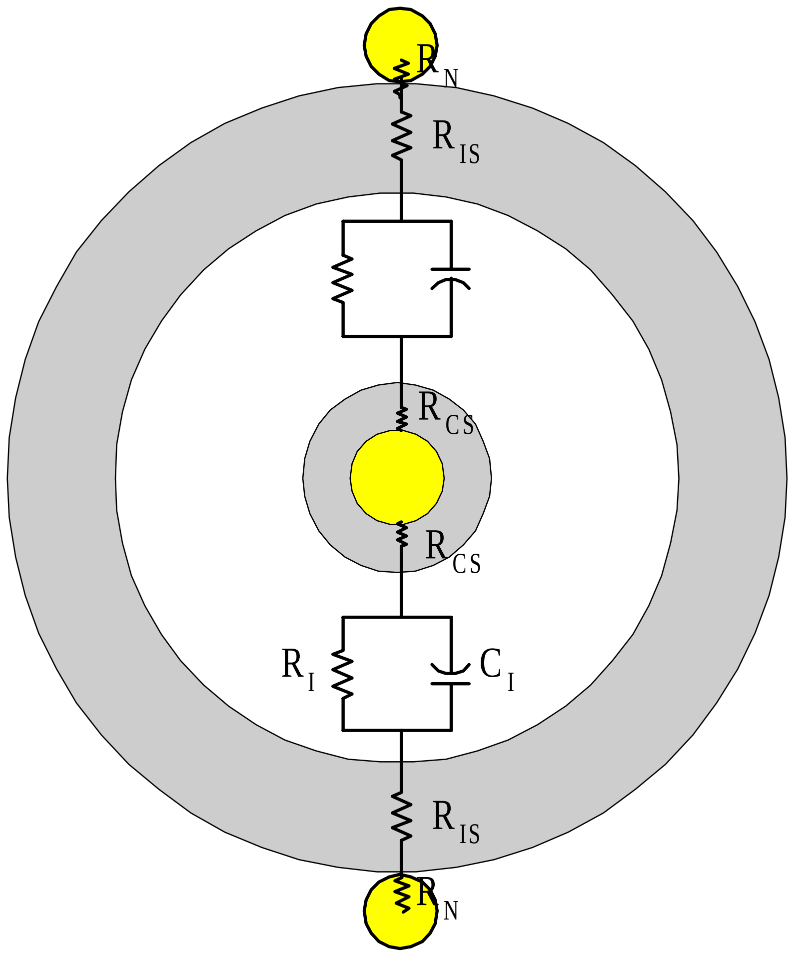
- Polarization/depolarization currents
- Recovery voltage
- Dissipation factor as function of Voltage and/or frequency

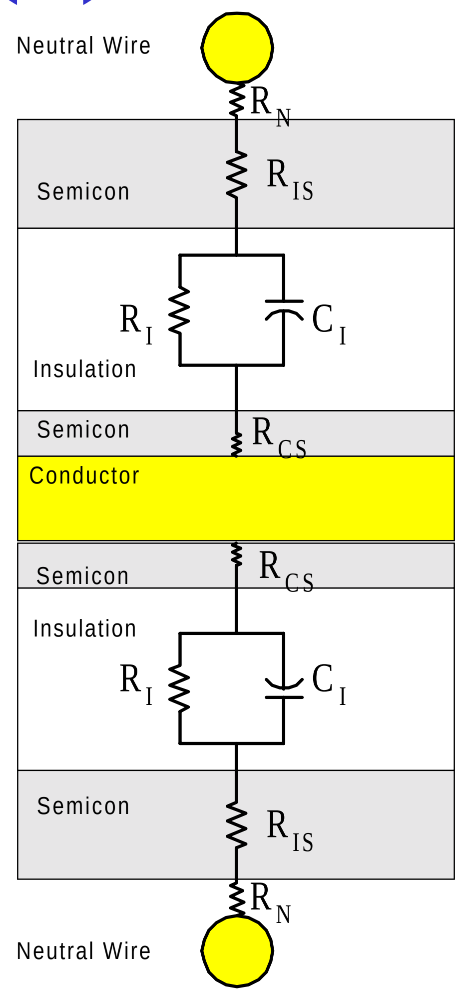
Tan delta for cable



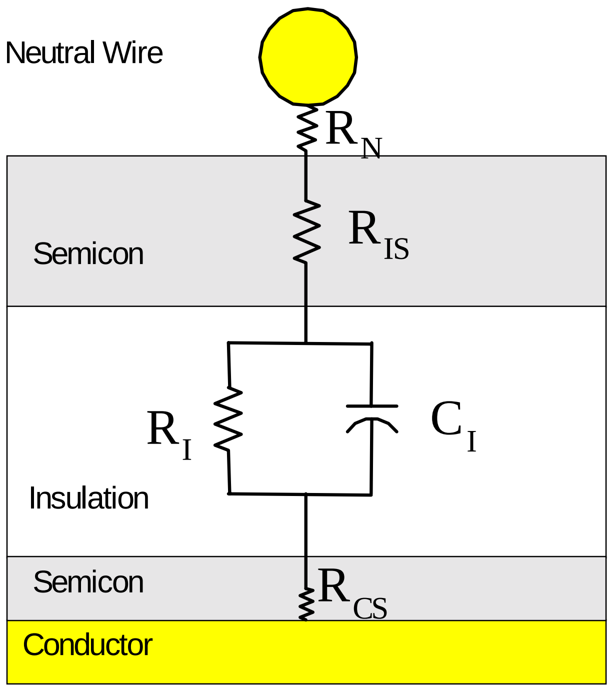
$$Tan\ Delta = \frac{I_R}{I_C} = \left(\frac{1}{2\pi fCR}\right)$$

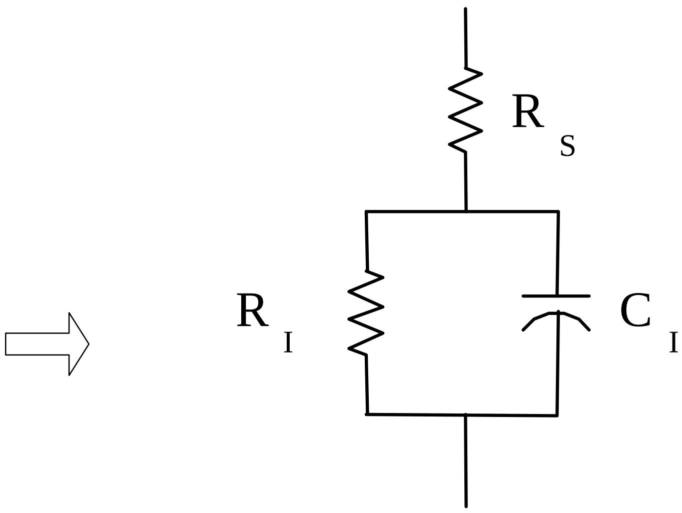
Cable model with shield/neutral resistance (1)





Cable model with shield/neutral resistance (2)





$$R_S = R_N + R_{CS} + R_{IS}$$

$$TanDelta = 2\pi f C_I R_S + \frac{1}{2\pi f C_I R_I} + \frac{R_S}{2\pi f C_I R_I^2} \approx 2\pi f C_I R_S + \frac{1}{2\pi f C_I R_I}$$

Effects of water trees on DF

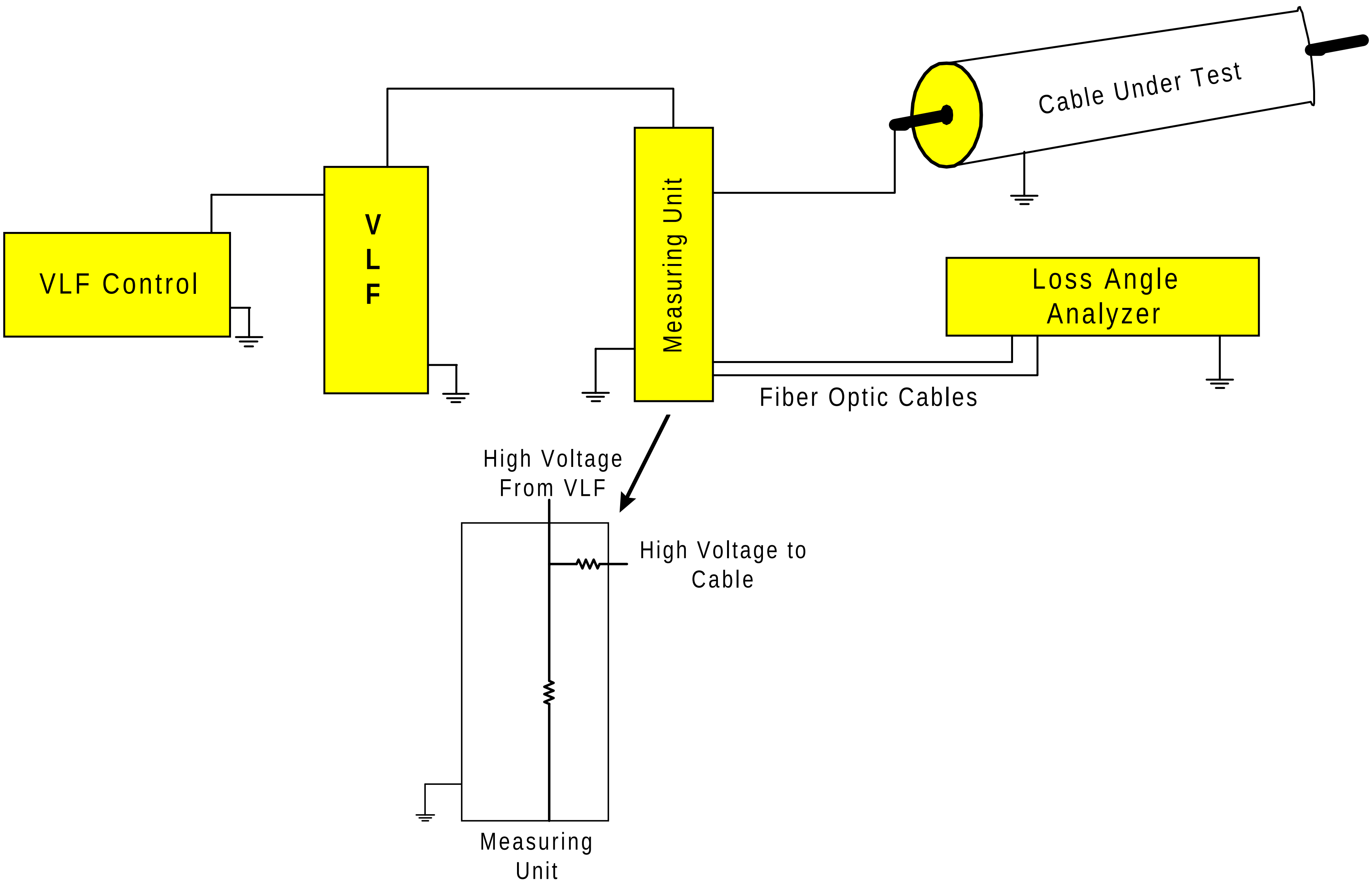
Water treed insulation:

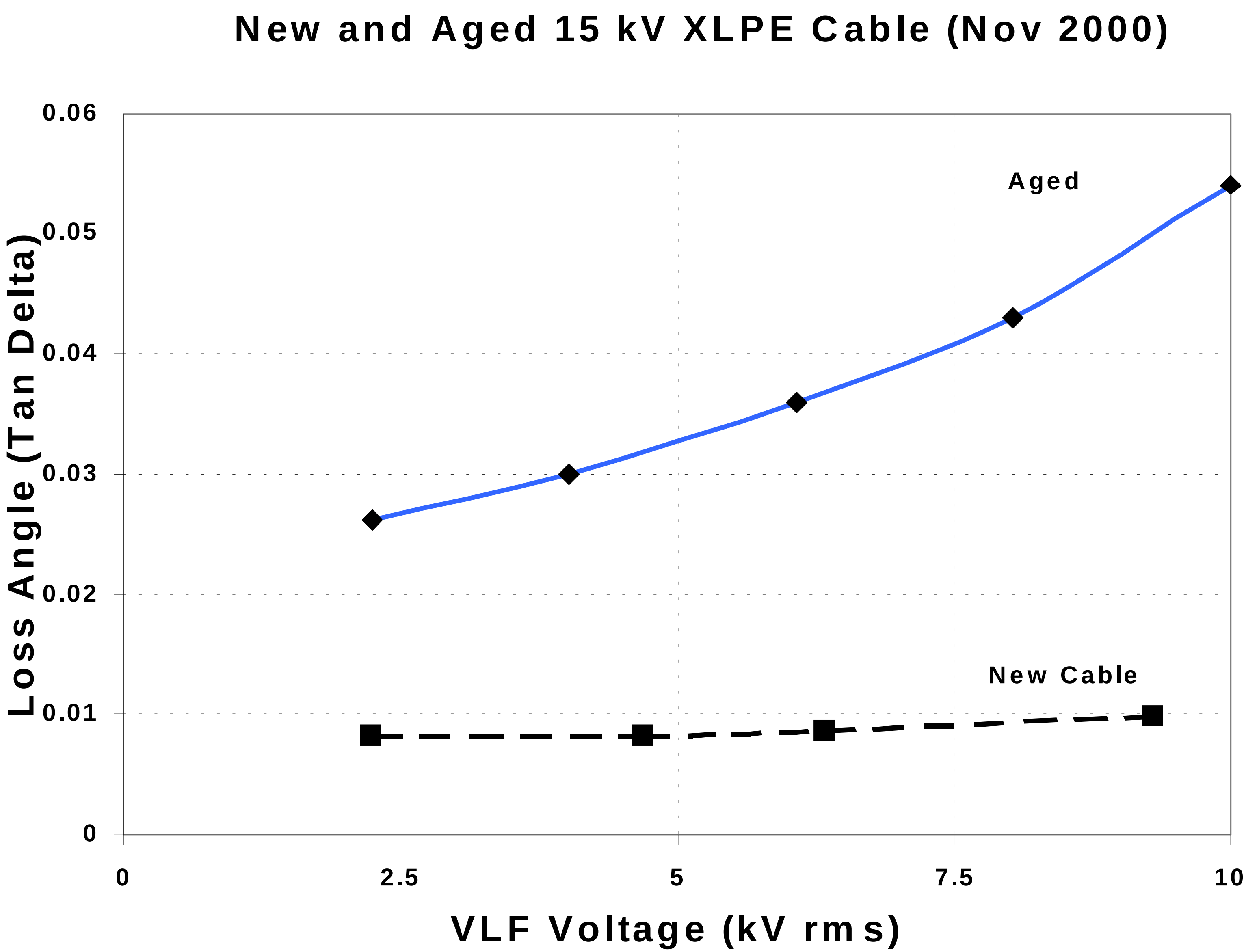
- Has higher DF than non treed insulation.
- DF increases with voltage, both rms and instantaneous values, i.e., shows non-linear behavior.
- After voltage interruption or change, DF takes some time to reach steady value.
- Care must be taken with accessories as some have materials with non-linear DF properties that could duplicate water treed insulation.
- Corroded neutrals can affect results.

Dissipation Factor

- Measures average condition of whole insulation including accessories
- Is loss current/capacitive current
- Loss current consists of polarization and resistive currents
- As it measures average condition it is unlikely to detect small number of water trees

Setup for VLF tests




New and Aged 15 kV XLPE Cable (Nov 2000)
Loss Angle (Tan Delta)
0.06
0.05
0.04
0.03
0.02
0.01
0
Aged
New Cable
0
2.5
5
7.5
10
VLF Voltage (kV rms)

Comparison of techniques carried out in Norway

‘Condition Assessment of Water Tree Aged XLPE Cables – Comparison of Four Commercial Methods’

By S. Hvidsten and J.T. Benjaminsen

SINTEF Energy Report TR A5180

August 2000

Also published in 2000 CIGRE as

Paper 21-201

Compared 7 field aged cables

- 4 cables (1.2 km) had strippable shields, 2 (0.46 km) with semicon paint and tape and 1 (0.57 km) graphite.
- 6 manufactured between 1976 and 1980, the other in 1986.
- 12 kV (3.4 mm insul.) and 24 kV (5.5 mm).
- Cables with strippable shield had 5 failures.
- Diagnostic tests compared with AC step BD voltages and tree length and density counts carried out after tests.

Four commercial setups evaluated

- Depolarization current, 1 kV dc, 1 h/ph
- Recovery voltage, up to 2 Uo, 1 h/ph
- Dielectric spectroscopy, up to 1 Uo, <10 min/ph
- VLF (0,1 Hz), up to 2 Uo, ~ 10 min/ph

Retest Schedule of 4 Methods

Condition	Depol.	RVM	DS	VLF
(1) As new	No	No	5-10 years	2-5 years
(2) Some Damage	2 years	2-3 years	2-5 years	1 year
(3) Badly damaged	1 year	1-2 years	1-3 years	Replace 0.5 year
(4) Very badly damaged	Replace ASAP	Replace ASAP	Replace In 1 year	Replace Immed,

Results

- Degradation seen in all cables.
- All methods assessed correctly heavily treed cables (paint and tape shield). Equivalent to taped strand shield in North America?
- Differences in the results of the four methods seen for the cables with strippable shields having less severe treeing.

	A	B	C	D	Graph.
Length (%)	22-100	10 14	44-50	45-50	87-100
Density (N/cm^2)	0.2-0.3	0.1-0.2	0.4-0.6	0.2-0.4	1.9-2.4
BDV (Uo)	2-5	6-7	5-6	5-7	2-3
Depol.	2-3*	2-3	3-4	3	3
RVM	1*	3-4	2	1	1-4
DS	3*	1	1	1	4
VLF	2-4*	2	1-2	2-3	4

* Conditions as given previously

Conclusions

- The four methods gave different assessments for cables with strippable shields.
- The four methods gave similar results for heavily treed cables. Accurate for taped strand shield cables?
- How applicable are results to North American cables (materials, XLPE, constructions)?
- Results are encouraging but better to develop own data base and look for trends?

Conclusions (cont'd)

- These methods give measurement of whole insulation, including accessories (with non linear materials or surface leakage).
- Unlikely to see short length of treed insulation in long cable.
- Remember cable failures depend on system protection.
- Need to consider state of neutrals and types of accessories.

- ***Abstract:*** Distribution cable systems represent a large capital investment for electrical utilities. In today’s competitive environment, electrical utilities are being faced with decisions to maintain, repair, refurbish, or replace their cable systems. This requires an assessment of the condition of the cable system by understanding the aging mechanisms and also the development of diagnostic tests. According to a 1994 report of CIGRRE WG 21:04, the purpose of a diagnostic test is ‘*to evaluate and locate degradation phenomena that will cause cable or accessory failure’*. The presentation will describe the main aging and failure mechanisms of distribution cables and the advantages and limitations of diagnostic tests. Diagnostic tests usually measure or monitor one or more properties of the insulation system that are related to aging and/or failure. Some tests measure localised properties; for example, partial discharges at contaminants, voids or protrusions, while others measure an overall property, for example tan delta (loss, dissipation or power factor). These topics will be discussed in the presentation