VLF Testing of Shielded Power Cables
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This article reviews the application of very low frequency (VLF) AC high voltage test sets for commissioning and maintenance of shielded medium voltage cables. The implication of DC Hipot testing in the premature failure of extruded solid dielectric cables led to the development of IEEE docuements - "IEEE Guide for Field Testing and Evaluation of the Insulation of Shielded Power Cable Systems" and IEEE 400.2 "Guide for Testing of Shielded Power Cable Systems using Very Low Frequency (VLF)". Additional information from HV Diagnostics Inc. regarding testing durations and test set selection form the basis of this article.

High voltage DC cable testing
Both DC Hipot testing and VLF testing can meet the needs of laminated paper cables such as PILC and newly installed solid dielectric cables such as XLPE. However with aging of the latter the insulation is no longer homogenous and defects accumulate. DC testing can result in space charge effects building at these defect points that can lead to discharge under normal AC service. These discharges rapidly grow into electrical trees in solid dielectric cables and can lead to a complete breakdown.
Unlike VLF instruments DC Hipots cannot initiate partial discharge at some existing defects. Since these will lead ultimately to failure DC testing can be quite misleading. The net outcome of DC testing is to weaken the cable while not detecting important defects.

Defect mechanism
Water trees are the main cause of failure in solid dielectric cables. These are tree-like structures that take years to mature in the cable's insulation forming minute water filled cavities. See Figure 1.

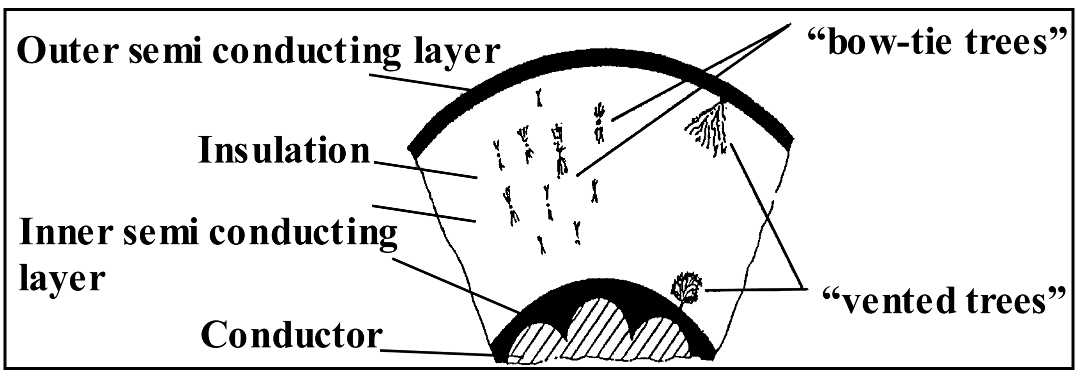

Figure 1: Cross Section of a Solid Dielectric Cable showing various possible Water Tree formations.

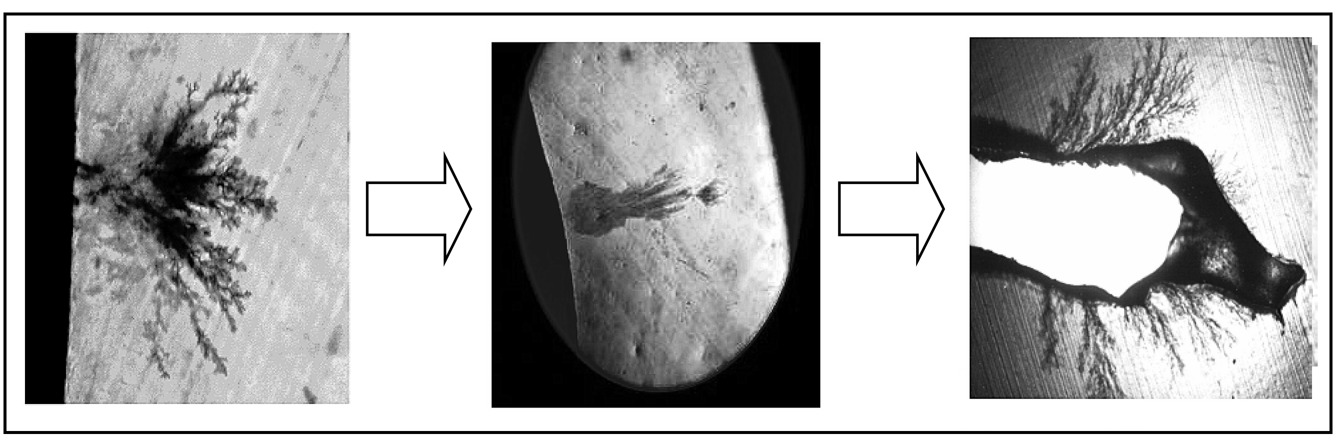

Figure 2: The progression of a water tree in a solid dielectric cable insulation to an electrical tree and then breakdown.

AC testing as an alternative to DC
The fundamental difference between AC and DC high voltage testing is the avoidance of space charge effects. AC is therefore recommended in most cable testing standards.

AC high voltage test equipment design
VLF operation reduces the power required to load cables which present a capacitive load. Test sets typically operate at 0.1Hz. The length of cable that can be tested at a given power increases by a factor of 5,000 compared to 50Hz with consequent weight and cost savings.
There are several VLF waveforms available and included within the IEEE 400 guidelines. Sinewave testing has some advantages. Research shows that the faster growth rate of any existing electrical tree with a sinewave waveform gives a higher probability of finding the defect.

The recently published IEEE 400.2 Guide for Field Testing Cables using VLF
Three types of test are listed.
· Installation test conducted before the installation of accessories such as splices and terminations.
· Acceptance test performed after the installation of the accessories before service energization.
· Subsequent maintenance tests to assess aging and /or serviceability of the cable system.
The IEEE 400.2 cable testing guide in table 1 below shows the recommended VLF voltage testing levels for various cable ratings.

Cable Rating phase to phase (RMS)	**Installation Test phase to ground**	**Acceptance Test phase to ground**	**Maintenance Test phase to ground**
kV RMS	kV RMS (or peak)	kV RMS (or peak)	kV RMS (or peak)
5	9 (13)	10 (14)	7 (10)
8	11 (16)	13 (18)	10 (14)
15	18 (25)	20 (28)	16 (22)
25	27 (38)	31 (44)	23 (33)
35	39 (55)	44 (62)	33 (47)

Table 1: IEEE 400.2 VLF Test Voltage Levels for Sinusoidal, Cosine-Rectangular. Voltage Peak values are shown in brackets for Cosine-Rectangular and Squarewave.

Test Duration.
The current IEEE recommendation for the duration of a VLF test is from 15 to 60 minutes. Industry experience justifies a minimum time of 30 minutes. The most common European recommendation is one hour.

Test Frequency
The industry default standard VLF test frequency is 0.1Hz. However high capacitive loads as encountered with very long cable runs may require a lower frequency for the correct operation of test sets. Lowering the VLF frequency needlessly is to be avoided given that it reduces the effectiveness of the test and can introduce some space charge effects.

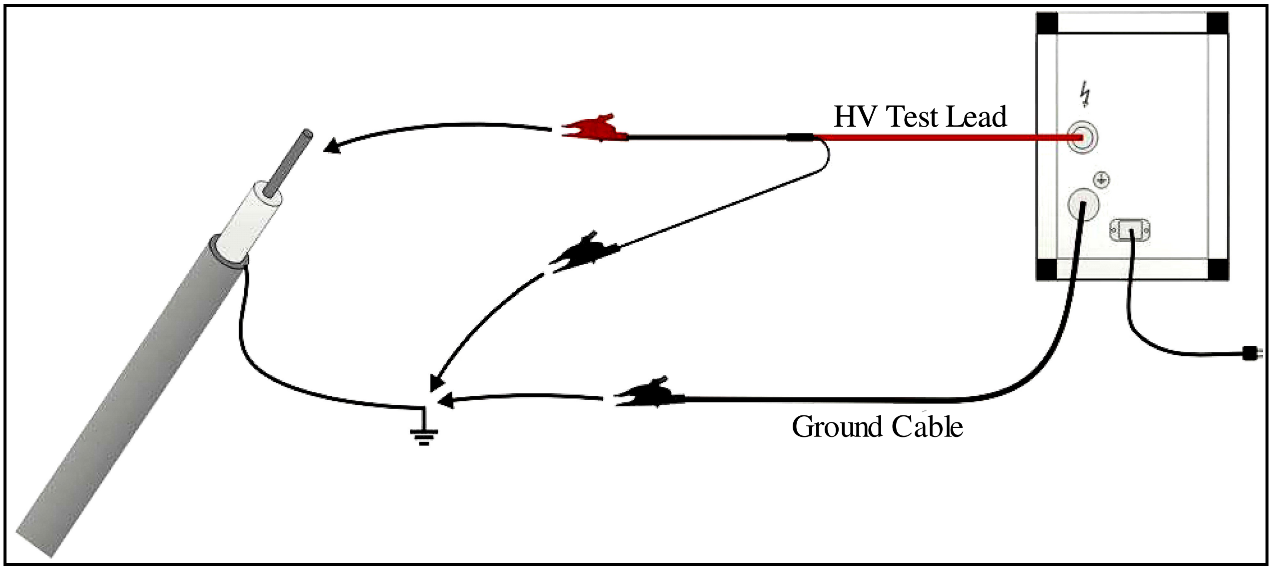

Figure 4: Connection Setup for a VLF Cable

Connecting a VLF Test Instrument to a Cable
Refer to IEEE 400.2 for safety guidelines.
The VLF test instrument should be solidly grounded before connecting up any cables. The HV test lead outside shield conductor is connected to the concentric neutral ground point of the cable under test. The main conductor of the HV test lead is then connected to the conductor of the cable under test. The other phases are grounded. It is possible to reduce the testing time by connecting all three phases together, except for a belted cable, or if the individual phases are unshielded. In such cases, each phase should be tested independently, grounding the other two phases so as to detect phase to phase faults.

The benefits of VLF maintenance testing
Regular routine maintenance testing of aged cables has been demonstrated to reduce the chance of unscheduled failure to approximately 10% of the failure rate that might be encountered without such testing. Approximately 12% of cables fail during the test and cable repair can then be done in a planned manner.
Alternative cable diagnostic techniques may be preferred however this may not be viable on circuits with combinations of different types of cable, very long cable runs, and network cables with multiple taps.

Fault Conditioning
Fault location usually involves the use of a DC thumper with considerable stress on what may be an aged cable. Preconditioning using a VLF tester can reduce the thumper voltage required by ionising carbonising the insulation at the fault location. It may also enable fault location with a low voltage TDR.

Figure 4: HV Diagnostics Inc. 60kV VLF AC and DC high voltage test instrument

VLF test equipment features and specifications

There are a number of factors to consider when selecting a test set for rental or purchase. (Rental may be useful for short term needs and pre-purchase evaluation).

Maximum cable length will be determined by the output load capacitance capability. Output voltages are determined from the IEEE 400.2 guide choosing RMS or peak depending on the output waveform.

A typical modern VLF test set has an output rating of 33kV peak sinewave (23kV RMS) and is capable of accommodating an output load of 0.5µF at 0.1Hz i.e. typically 1,500 metres. At 0.02Hz the range increases to 7,500 m. DC output is also included. This instrument is compact and portable weighing 20kg. A similar 62kV test set with a 1µF output capability is adequately portable.

Cable capacitance measurement is important with automatic frequency adjustment being desirable. Too large a cable load can cause misleading collapse or tripping of the output.

Sinewave test set accessories may be available enabling dissipation factor (tan delta) and /or partial discharge diagnostic capability.

Conclusion

A new set of well conceived testing standards has been developed in response to changes in cable technology in recent years. The choice of testing techniques and procedures for medium voltage cables is now well defined and enables the implementation of effective plans for the proving cable fitness for service.