



CHAPTER 14

Glossary

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14.0 GLOSSARY

The definitions below pertain to their use within this document. These definitions may differ slightly from those used by other sources.

ac: Alternating Current, usually with a constant amplitude
Acceptance Test: A field test made after cable system installation, including terminations and joints, but before the cable system is placed in normal service. The test is intended to detect installation damage and to show any gross defects or errors in installation of other system components.
Age Line: A probabilistic description of how a diagnostic classification changes with age of the cable system from all No Action Required when new to increasingly Action Required as the system ages.
Aging: Irreversible degradation of the capabilities of a cable system that is correlated with age
Amplitude or Range Resolution (TDR): The ability of a particular pulse setting (width and amplitude) to traverse the full cable system length <u>and</u> provide clear location information of accessories and other discontinuities.
Assessment Class: A classification of a diagnostic feature or features (bounded by limits based on population probability) that provides a convenient means to describe and rehabilitate a number of cable sections, segments, or circuits. The most common ones used in this project are: Action Required (AR) – poorest performing 5% for a diagnostic, No Action Required (NA) – best performing 80% for a diagnostic, Further Study (FS) – the 15% performance range for a diagnostic residing between 80th & 95 th percentiles.
Attenuation: The reduction in peak amplitude of a signal as it travels along a cable. Important concept in PD & TDR tests
Back to Service: A non-diagnostic test that is conducted after work but before placing the cable system back into service to ensure no very gross workmanship errors have occurred during the repair.
Bounce Diagram: A graphical method to interpret the traces resulting from PD and TDR tests
Box or Whisker Plot: A convenient way of graphically depicting the variation between groups of numerical data. The plots display variation in samples without making any assumptions of the underlying statistical distribution. These plots typically focus on the median and middle 50% of available data (interquartile range).
Breakdown: Permanent failure through insulation.
Cable Diagnostic Focused Initiative (CDFI): Large scale independent investigation conducted by NEETRAC to establish the best practice and use of cable system diagnostic technologies with

<p>the support of utilities, manufacturers, diagnostic providers, and US DOE.</p>
<p>Cable Injection or Rejuvenation: A means by which medium voltage cable systems can be remediated by the replacement of accessories, removal of water, and injection of a water reactive silicone fluid.</p>
<p>Cable System: Cable with installed accessories (terminations, elbows, and joints).</p>
<p>Calibration: In the context of Partial Discharge testing Calibration is the means by which the voltage response of the measurement system (data acquisition unit, sensors, and cable system) is related to the output of a pulse generator with known charge.</p>
<p>Capacitive Current: The portion of the current flowing in the cable system that is required to charge and discharge the capacitance of the cable system.</p>
<p>Characteristic Impedance (Z_0): The relationship between the series and shunt equivalent elements in a cable system that is modeled using signal transmission theory. Used to determine the tendency of a signal to reflect at different cable system components.</p>
<p>Cold Shrink: An elastomeric sleeve that has been factory expanded onto a supporting removable plastic core. The sleeve shrinks upon removal of the supporting core during the installation.</p>
<p>Combined Diagnostic Test: A test where two or more diagnostic tests are carried out simultaneously. Each diagnostic provides distinct information on a cable system.</p>
<p>Commissioning Test: A test conducted after the construction of a new cable system but before ownership transfers to a utility. The goal of the test is to minimize the likelihood of infant mortality failures and hopefully to reduce the long term failure rates by reducing the chance for defects to remain present in the cable system.</p>
<p>Confidence Intervals: Confidence intervals consist of a range of values (the interval) that act as good estimates of the uncertainty in the parameter of interest. When presented graphically, confidence intervals can be shown at several confidence levels, for example 90%, 95% and 99%. The percentage indicates the probability that the true answer is present within the band.</p>
<p>Conseil International des Grands Réseaux Électriques (CIGRE): A global electro-technical organization. It was founded in Paris, France in 1921. Its scope includes the technical and economic aspects of the electric grid, as well as the environmental and regulatory aspects.</p>
<p>Crosslinked Polyethylene (XLPE): A thermoset unfilled polymer used as electrical insulation in cables.</p>
<p>Cumulative Distribution: The distribution that describes the probability that a real-valued property will be found to have a value less than or equal to a chosen level x.</p>
<p>Damped AC (DAC) Test: A Partial Discharge detection test where the voltage source is formed by a dc supply, the cable capacitance, and an external inductance. The alternating frequency</p>

<p>portion of the applied voltage waveform is in the range 30 Hz to 300 Hz.</p>
<p>Damped ac (DAC): Decaying oscillation of a resonant circuit. Used and likely effective for PD testing. No evidence of effectiveness found for commissioning or dielectric loss testing. Virtually no use in North America</p>
<p>DC Hipot: A withstand or Proof test that is conducted using a direct current voltage. The test is defined in terms of voltage magnitude and time.</p>
<p>dc: Direct Current</p>
<p>Diagnostic Program Stages – Selection, Action, Generation, and Evaluation (SAGE): Suggested stages/steps of a planned diagnostic program.</p>
<p>Diagnostic Rank: The relative position of a cable system based on the outcome of a diagnostic test. The outcome may be defined in terms of the directly measured property (partial discharge magnitude) or a derived property such as a Health Index (Tan Delta, etc.).</p>
<p>Diagnostic Test: A field test made during the operating life of a cable system. It is intended to determine the presence, likelihood of future failure and, for some tests, locate degraded regions that may cause future cable and accessory failure.</p>
<p>Diagnostic Time Horizon: The period of time that the result of a diagnostic test may be projected forward in time and still be considered accurate. This will vary for each diagnostic and interpretation method and is not well defined. It may be thought of as the point at which a diagnostic result would change from one classification to a more severe one.</p>
<p>Dielectric Loss: An assessment of the electric energy lost per voltage cycle. A poorly performing cable system tends to lose more energy per ac cycle. Measurements can be made for selected voltages or over a period of time at a fixed voltage. The stability of the loss, the variation with voltage and absolute loss are used to estimate the condition. Data can be derived from time based (if sufficient time is taken) or frequency-based test methods.</p>
<p>Dielectric Puncture: see Dielectric Breakdown</p>
<p>Dielectric Spectroscopy: Measures of the dielectric property at different frequencies. The absolute loss and the variation with frequency are used to estimate the condition. Data can be derived from time-based (if sufficient time is taken) or frequency-based test methods.</p>
<p>Differential Tan δ or Tip Up (TU): Difference between the Tan δ (TD1) at voltage 1 and Tan δ (TD2) at voltage 2, a higher voltage. Very commonly used in VLF Tan δ testing with measurements at $0.5U_0$ and $1.5U_0$</p>
<p>Dispersion: The spreading (spatially) of a signal as different frequency components of the signal travel at different velocities along a cable. Important concept in PD and TDR tests.</p>
<p>Electrical Trees: Permanent dendritic growths, consisting of non-solid or carbonized micro-</p>

<p>channels, that can occur at stress enhancements such as protrusions, contaminants, voids or water trees subjected to electrical stress. The insulation is damaged irreversibly at the site of an electrical tree.</p>
<p>Ethylene Propylene Rubber (EPR): A type of thermoset-filled polymer used as electrical insulation in cables and accessories. There are several different formulations of EPR and they have different characteristics. The term also encompasses ethylene propylene diene monomer rubber (EPDM).</p>
<p>Extra High Voltage (EHV): Cable systems within the voltage range 161 kV to 500 kV, though more often between 220 kV and 345 kV. Also referred to as Transmission Class, though usually having a higher design stress levels than HV.</p>
<p>Extruded Dielectrics: Insulation such as EPR, HMWPE, PE, WTRXLPE, XLPE, etc. applied using an extrusion process.</p>
<p>Failure in Service (FIS): A failure that occurs under the voltage and thermal stresses of normal operation.</p>
<p>Failure Mechanisms: The different mechanisms by which the ultimate failure of a cable system occurs, different from the degradation mechanism.</p>
<p>Failure on Test (FOT): A failure that occurs under the voltage and thermal stresses of a diagnostic test.</p>
<p>Failure Rate: The number of failures of a defined type (on test or outage) as a fraction or percentage of a selected population, usually either initial population or remaining population.</p>
<p>Filled Insulation: Extruded insulations where a filler (Carbon Black or Clay) has been incorporated to modify the inherent properties of the base polymer. This class includes all types of EPR, Vulkene etc.</p>
<p>“Ghost” Reflection: A reflected signal in a PD or TDR test that continues to travel and reflect multiple times within the cable system length; thereby appearing as extra components.</p>
<p>“Health” Index: A method to combine different diagnostic features into a single meaningful number using a clear methodology – analogous to Consumer Price Index, Air Quality Index etc.</p>
<p>Heat Shrink: An open ended crosslinked elastomeric sleeve that has been factory expanded under the action of heat and then quenched below its crystalline melting point. The sleeve shrinks to the original unexpanded size upon the application of heat during the installation.</p>
<p>High Frequency Current Transformer (HFCT): A sensor commonly used in field tests using PD methods. Generates a voltage signal that is proportional to the current signal that passes through the sensor.</p>
<p>High Voltage (HV): Cable systems within the voltage range 46 kV to 161 kV, though more often</p>

<p>between 66 kV and 138 kV. Also referred to as Transmission Class though usually has lower design stress levels than EHV.</p>
<p>“Hold” Phase: The constant voltage amplitude phase of a withstand test. The voltage exposure recipe of a withstand test is defined by the voltage/stress amplitude and the length of the hold phase. The outcome of a withstand test (the percentage of cable systems failing on test) is non-linearly dependent upon the length of the hold phase and the voltage magnitude.</p>
<p>Installation Test: A field test conducted after cable installation but before jointing (splicing), terminating, or energizing. The test is intended to detect shipping, storage, or installation damage. It should be noted that temporary terminations may need to be added to the cable to successfully complete this test.</p>
<p>Inter Quartile Range (IQR): The middle 50% of a data set that provides a measure of statistical dispersion. It is equal to the difference between the upper and lower quartiles, $IQR = Q_3 - Q_1$. The IQR is used to build box and whisker plots.</p>
<p>Isothermal Relaxation Current (IRC): A diagnostic test thought to be useful at the start of <i>Phase I</i> of <i>CDFI</i>, but its use and efficacy has not been verified; presumed not to be used in North America.</p>
<p>Jacket: An extruded outer polymeric covering for cables designed to protect the cable core and the metallic shielding (wires, tapes or foils).</p>
<p>Joint: A device to join two or more sections of power cable together. A joint includes a connector to secure the cable conductor and a stress controlling / insulating body to manage the electrical stress.</p>
<p>Laminated Dielectrics: Insulation formed in layers typically from tapes of either cellulose paper or polypropylene or a combination of the two. Examples are the PILC (paper insulated lead covered) and MIND (mass-impregnated non-draining) cable designs.</p>
<p>Leakage Current: The current component that flows in the resistive element of the insulation of a cable system. This current component corresponds to current that is in phase with the applied ac voltage and continues flowing once the cable capacitance has been charged under dc voltage conditions. Leakage currents are believed to increase as the system degrades.</p>
<p>Length Adjusted: The outcome of a withstand test depends upon the length of cable system tested (i.e. the number of likely weak links in a chain). Longer lengths have more weak links and experience more failures on test and thus apparently poorer reliability. The outcome of the withstand test is adjusted using the censoring concepts within Weibull Analysis or Dauser Shifts.</p>
<p>Level of Tan δ (TD): The magnitude of the dielectric loss – non dimensional. Commonly referred to as a number with is multiplier of 10^{-3} (i.e. $3 \cdot 10^{-3}$ is often referred to as a loss of 3).</p>
<p>Lower Quartile: The 25th percentile (splits off the lowest 25% of data from the highest 75%).</p>

<p>Maintenance Test: A field test made during the operating life of a cable system. It is intended to detect deterioration and to check the serviceability of the system.</p>
<p>Mass Impregnated Non Draining Cable (MIND): A cable design using paper insulation impregnated with a thick compound such that the compound does not leak out should the lead sheath be breached.</p>
<p>Mean: Usually refers to the arithmetic mean which is the most common measure of the central tendency of a normal distribution.</p>
<p>Median: The number separating the higher half of a data set from the lower half. Otherwise known as the data point corresponding to the 50th percentile.</p>
<p>Medium Voltage (MV): Cable systems within the voltage range 6 kV to 46 kV, though more frequently between 15 kV and 35 kV. Also referred to as Distribution Class.</p>
<p>Monitored Withstand Test: A test in which a voltage of a predetermined magnitude is applied for a predetermined time. During the test, other properties of the test object are monitored and these are used, together with the breakdown (pass or fail) results, to determine the condition of the cable system.</p>
<p>Offline Test: A diagnostic where energizing and measurement equipment are temporarily coupled to the cable system, while the system is removed from operating voltage and not carrying load. The measurement equipment is removed after test and the system returned to normal voltage and load. Measurements are made at any voltage selected by the test equipment operator with all the load components removed from the cable system under test.</p>
<p>Online Monitoring Test: A diagnostic where measurement equipment may be permanently coupled to the cable system while the system is under voltage and carrying normal load, and monitored remotely at any desired occasion to determine the cable system health.</p>
<p>Online Test: A diagnostic test where measurement equipment is temporarily coupled to the cable system, while the system is under voltage and carrying load, and monitored remotely for a selected period of time to determine the cable system health. The measurement equipment is removed after test while the system is under voltage and carrying load.</p>
<p>Outage: A failure in service that results in at least one customer being without power for a period of time.</p>
<p>Outcome Line: A probabilistic description of what is likely to happen in service for each diagnostic class (i.e. No Action Required, Further Study, etc.) as the cable system continues to age.</p>
<p>Outlier: an observation that is distant from other observations. An outlier may be indicative of variability in the measurement or it may indicate experimental error; the latter are sometimes excluded.</p>

<p>Paper Insulated Lead Covered (PILC): A cable design using paper insulation impregnated with a fluid and encased in lead to prevent the fluid from leaking out of the insulation.</p>
<p>Paper Insulation: Paper tapes wrapped around a conductor (almost always copper), the interstices between the tape edges (butt gaps) are filled with either oil (PILC) or waxy compound (MIND).</p>
<p>Pareto Principle: A common heuristic (rule of thumb) in business; e.g., "80% of your sales come from 20% of your clients." Named after the Italian economist Vilfredo Pareto, who showed that approximately 80% of the land in Italy was owned by 20% of the population.</p>
<p>Partial Discharge (PD): A low voltage (mV or μV) signal resulting from the breakdown of gas enclosed in a dielectric cavity. The signal generated during the partial breakdown travels down the cable system and may be detected at the end by special sensors.</p>
<p>PCA Distance: Principal Component Analysis is the primary analytic tool used for Health Index estimation. The three to four Principal Components are combined into a single vector which is then compared to another reference vector. The difference between these two vectors is the PCA Distance. This is analogous to the Mahalanobis distance.</p>
<p>PD Sensors: Capacitive, inductive, or resistive devices through which currents correlated with Partial Discharges flow. The voltages that result are conditioned and displayed by suitable recording devices</p>
<p>PE-Based: Extruded insulations that do not have an incorporated filler (Carbon Black or Clay). This class includes all types of HMWPE, PE, WTRXLPE, XLPE, etc.</p>
<p>Percentile: A measure indicating the value below which a given percentage of observations in a group of observations fall (e.g. the 20th percentile is the value (or score) below which 20 percent of the observations may be found).</p>
<p>Performance Rank: Partial Discharge Magnitudes (mV), Tan Delta Tip Ups, PCA Distances all represent performance of the cable system. Furthermore the magnitudes have meaning – large numbers indicate poor performance, small numbers indicate good performance. Ordering the relevant metrics from smallest to largest results in a rank ordering that is correlated with the cable system performance. Thus understanding the rank position provides, with suitable random sampling, a definitive perspective of the true cable system performance in the field</p>
<p>Pico Coulomb (pC): Historical metric for the assessment of partial discharge when undertaking tests using the methods detailed in IEC 60270 for tests in high voltage laboratories. IEC 60270 assumptions are not fulfilled in field tests, thus the value and comparability of pC values are lower in field tests than in small laboratory loops.</p>
<p>Polyethylene (PE): A polymer used as electrical insulation in cables.</p>
<p>Power Frequency: A substantially sinusoidal waveform of constant amplitude with an</p>

alternating frequency in the range 49 Hz to 61 Hz.
Principal Component Analysis (PCA): A statistical procedure that converts a set of observations of possibly correlated variables into a set of variables called principal components . The number of principal components is less than or equal to the number of original variables. It is useful to reduce the complexity of analysis when there are many types of observations.
Principal Component: The outcome of PCA Analysis. The first principal component accounts for as much of the variability in the data as possible, and each succeeding component in turn accounts for the next largest amount of variability.
Probability Plot: A graphical technique for comparing two data sets
“Ramp-up” Phase: The voltage ramp that precedes the constant voltage amplitude phase of a withstand test. The voltage exposure recipe of a withstand test is defined by the voltage/stress amplitude and the length of the hold phase. The Ramp Up phase does not contribute to the voltage exposure recipe.
Reflection Coefficient (ρ): Ratio of the difference in characteristic impedances of difference cables and accessories. This relationship determines the portion of a signal that is reflected back to its source and the portion that is transmitted to the next component.
Resonant ac: The voltage waveform commonly used in a commissioning test. The voltage exposure recipe is defined by a voltage/stress amplitude and the length/duration of the hold phase. DAC tests do not meet this definition as the amplitude is not constant and a recipe cannot be defined.
Scaled Charge (pC): When the IEC 60270 assumptions are not fulfilled the value and comparability of charge values are much lower than in small laboratory loops. When it is appropriate to consider charge (usually the integration of the measured current over time), the term Scaled Charge is used so as not to increase confusion with the “pC” used to refer to charge in small laboratory loops (IEC 60270).
Shielded Cable: A cable in which an insulated conductor is encapsulated in a conducting ‘cylinder’ that is connected to ground. The voltage at the exterior of such a cable is by definition at ground potential.
Simple Withstand Test (SW): A test in which a voltage of a predetermined magnitude is applied for a predetermined time. If the test object survives the test it is deemed to have passed the test.
Space Charge: Quasi-permanent injected charge that is trapped within the insulation of a cable system. This charge is sufficient to modify the applied ac and Impulse voltage stresses.
Splice: A joint.
Survivor Curve: A survivor curve plots the number of survivors within a system as a percentage of the initial population against time or cycles or any suitable variable that describes “exposure”.

<p>The curve starts in the top left at 100 and decays towards zero in the bottom left. The shape of the curve relates to the failure rate and ultimately the hazard plot.</p>
<p>Tan δ (TD): The tangent of the phase angle between the voltage waveform and the resulting current waveform. Can alternatively be described as the ratio of the loss current to the charging current.</p>
<p>Tan δ Non-linear Voltage Dependence or Tip Up of the Tip Up (TuTu): The differential Tan δ is the difference between the Tan δ (TD1) at voltage 1 and Tan δ (TD2) at voltage 2, a higher voltage. This is the first feature for Tan δ analysis and assumes that the voltage dependence is linear. However experience has shown that there are cases where this is not linear and these cases are quite concerning. Thus the difference of the differential Tan δ is a useful feature. This is calculated from the TD 1.5 (i.e. a voltage midway between 1 and 2).</p>
<p>Tan δ Speed: In the monitored withstand mode of testing one of the features is how the Tan δ changes with time. The magnitude is conveniently labeled as Tan δ Speed. Obviously high speeds are concerning as they tend to be well correlated with problems in service.</p>
<p>Tan δ Stability (STD): In standard Tan δ and monitored withstand tests, a series (6 and 180, respectively) of measurements are made sequentially at different times. The amount of variation in Tan δ over the constant voltage period is conveniently described by the standard deviation of the 6 – 180 data points. High standard deviations are concerning as they tend to be well correlated with problems in service.</p>
<p>Tan δ Trend: In the monitored withstand mode of testing one of the features is how the Tan δ changes with time. The direction of the change (increasing or decreasing) is conveniently labeled as Tan δ Trend. Obviously high positive speed trends are concerning as they tend to be well correlated with problems in service, whereas high negative speed trends are merely confusing.</p>
<p>Termination: A device that manages the electric stress at the end of a cable circuit, while sealing the cable from the external environment and providing a means to access the cable conductor. Devices referred to as Elbows or Potheads are types of terminations.</p>
<p>Time Domain Reflectometry (TDR): A technique to determine cable system lengths and positions of joints using reflections from a rapid rise time low voltage pulse.</p>
<p>Time Domain Spectroscopy (TDS): A diagnostic technique that examines a response as a function of measurement frequency. Dielectric loss measurements can be made at different frequencies and thereby plotted. Another way of doing this is to measure the dielectric function as a function of time and then perform a mathematical transform to derive the spectra. Spectra derived in this manner are termed Time Domain Spectroscopy.</p>
<p>Time Frequency Map (TF-Map): The major problem with PD tests in the field is that the signal and noise are convoluted and that it is not possible to be certain that when filtering that only the noise is being filtered away. One way to reduce these concerns is to map the equivalent pulse length deviation (a time) and pulse frequency deviation (a frequency) for each received pulse; thence a Time-Frequency Map. Clusters of PD like and Noise like pulses can be separated and</p>

any filtering more precisely performed.
Time Resolution (TDR): A pulse used in TDR testing that has a finite width in terms of time, and hence distance when coupled with the appropriate Velocity of Propagation. Thus the finite distance width leads to the uncertainty in distance measurement and thence resolution (i.e. the ability to clearly distinguish between two closely located features). This is analogous to Spatial Resolution and Rayleigh Criteria in optics. For reference, a 1 GHz frequency pulse has a pulse width of 20 cm in PE-based cable insulations.
Ultra Wide Band (UWB): The outcome of a PD diagnosis is influenced to a very high degree by the frequency range over which the measurements are made (i.e. the bandwidth of measurement). Ultra Wide Band (UWB) measurements are used to maximize the chances of capturing PD signals (known to be very high frequencies). However the simple PD metrics of Apparent IEC 60270 charge no longer hold as the signals essentially travel – hence field data / criteria cannot relate to the data collected in the field
Upper Quartile: The 75 th percentile (splits off the lowest 75% of data from the highest 25%)
Velocity of Propagation (VOP): The velocity by which an electromagnetic pulse (TDR signal, PD signal) propagates down a concentric dielectric. This is some fraction of the speed of light. However it is not constant and depends upon the impedance of the cable system in this case. A good selection of the VOP is required to undertake accurate distance estimation.
Very Low Frequency (VLF): AC waveform of constant magnitude with an alternating frequency in the range 0.01 Hz to 1.0 Hz.
VLF Cosine Rectangular: A VLF waveform that can be approximated by a rectangular waveform of 0.1 Hz, where the transitions have the shape of a cosine and a frequency determined by the capacitance of the device under test. The frequency of transition is not fixed (or known) and it is likely in the range 30 to 300 Hz.
VLF Sinusoidal: A VLF waveform that can be closely approximated to a sine wave. The most common embodiment has a frequency of 0.1 Hz, however the frequency may be lowered (manually or automatically) to accommodate longer or more lossy test lengths that require more power to energize.
Voltage Exposure: Withstand Tests are essentially Proof Tests (in the same way that all firearm barrels are subjected to overstressing). Clarity and reproducibility are important in Proof Tests. In cable system Withstand Tests clarity and reproducibility are ensured through a defined Voltage Exposure; which is a prescribed Voltage Level for a prescribed Time. This is often referred to as a Test Recipe. The voltage levels and times are non-linearly related and are chosen with great thought and care. Common examples of Proof Tests conducted on cable systems are $1.7U_0$ applied for 60 min, 20 impulse shots (10 positive, 10 negative) at 1,050 kV, etc.
Water Tree Retardant Crosslinked Polyethylene (WTRXLPE): A thermoset polymer used as electrical insulation in cables that is designed to retard water tree growth.

Water Trees: Dendritic pattern of electro-oxidation that can occur at stress enhancements such as protrusions, contaminants, or voids in polymeric materials subjected to electrical stress and moisture. Within the water tree the insulation is degraded due to chemical modification in the presence of moisture.