In order to accommodate increasing urbanisation, and with it the growth in high-density housing, we will put more electricity supply underground in the future. This is a strategy used in Europe, where underground cable testing is increasingly relevant, particularly in regard to appropriate test equipment.

Cross-linked poly-ethylene (XLPE) has become the main type of extruded cable used in medium voltage (MV) distribution and different testing conditions apply to those used for laminated cables such as paper insulated cables. This article describes an important testing technique, monitored withstand testing (MWT), highly suitable to XLPE cables. The MWT technique uses a combination of very low frequency (VLF) voltage testing in combination with partial discharge (PD) measurement to indicate the health or otherwise of cables. The PD measurement involves the detection of high frequency discharges of tiny amounts of electric charge of the order of pico-coulombs. In other words, it is the direct measurement in the areas of breakdown in the insulation, not their inferred detection by means of ultra-sound. By making use of the propagation velocity as provided by the cable manufacturer, or the known length of the cable being tested, the precise location of discharges can be determined.

High voltage VLF testing of XLPE is a safe way compared to DC or power frequency testing. DC testing, in particular, is harmful as it can induce trapped space charges in the insulation material sometimes causing breakdown shortly after de-energising the cable. Power frequency testing is less hazardous but requires a higher rating power supply because of high capacitive current drawn by long cables. The advantage of a low frequency test, typically at 0.1Hz is the conductance of the insulation is not masked by capacitive current to nearly the same extent. The measurement of loss angle, the so called tan δ (tan delta) test can be performed and this is a very reliable indicator of the overall integrity of the insulation.

The tan δ test (note: ‘tan’ is the abbreviation of the trigonometric function, ‘tangent’) is the ratio of the conductive current to the capacitive current (see fig 1). The tan δ test is also called a ‘dissipation test’. The lower the conduction current, the lower tan δ becomes. As the diagram shows, δ is the phase angle of the current flowing through the insulation. The termination/s of a cable can have a big effect on the measurement, and problems there are also revealed by testing in combination with partial discharge. The tan δ test is more revealing than polarisation index, the latter being the ratio of the resistance reading at 10

**Figure 1:** Loss angle tan δ is equal to ig/ic. Ig is in phase with applied voltage V

**Figure 2:** Cross section of cable showing water tree (WT), build-up of voltage gradient, and development of electrical trees
minutes to the one after one minute after the application of a DC test voltage.

The behaviour of cable insulation with time is subject to initial strain imposed by bends and mechanical damage during the laying, degradation of the insulation material, heat effects (for example oil drying out in laminated, paper insulated cable) and water ingress. For XLPE and EPR (ethylene propylene rubber) the ingress of water is one of the remaining hazards. So-called water trees give rise to insulation breakdown in those regions. Mechanical strains can also give rise to the later development electrical trees, particularly the vented tree (see fig 2) stretching from conductor to neutral. In paper insulated cables the drying out of oil gives rise to carbonisation and subsequent breakdowns in insulation.

Partial discharge testing requires a source of high voltage and a capacitive coupler for the partial discharge detector. The schematic for the test is shown in fig 3. The coupling capacitor to the shunt impedance for the discharge measuring amplifier, is of a very low value. This means it is an extremely high impedance to the VLF voltage generator but has a low impedance to the very fast rise time discharge pulses.

In fig 4 the detail of a partial discharge is shown. The voltage $V_3$ is the applied voltage by the VLF generator. The capacitance $C_3$ represents the bulk capacitance of the cable. The capacitances $C_1$ and $C_2$ pertain to the fault region. $C_2$ is the capacitance of the fault – in the region phase to neutral, and $C_1$ is the capacitance from the phase to the fault region. Because of the capacitance divider effect, there is a reduced voltage across the fault. This is shown by the dashed sinusoidal voltage, $V_2$. Initially, the fault charges up but when the voltage reaches VInception discharge occurs, and continues until voltage has dropped to Vextinction. This charge-discharge action continues while $V_2$ exceeds VInception. Once the $V_2$ positive peak is passed, $C_2$ charges in the reverse direction, again until the negative value of VInception is reached. The sharp rise time pulses flow through the coupling capacitor of the test apparatus.

A complete test set up for VLF tan δ and partial discharge testing is shown in fig 5. The VLF generator is supplying one of the phases of a three-phase cable. In parallel with the cable is the high frequency capacitive coupler also housing the partial discharge detector. The latter is connected to the laptop that also supplies controlling signals to the VLF generator so that step increases of voltage can be made under a testing protocol specified by the operator. A sound cable will demonstrate its ability to retain the loss angle as voltage increases step by step, and furthermore through its ability to hold the loss angle value for a length of time. As ageing takes place, the loss angle can be expected to increase. Changes in the dielectric, not associated with electrical treeing, will change the displacement current flowing due to the changes in the polarisation of the insulating material. 

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**FIGURE 3:** Illustrating the principle of partial discharge measurement

**FIGURE 3:** Top diagram showing fault capacitance (area of partial discharge), $C_2$, and development of discharge pulses

**FIGURE 5:** Apparatus for simultaneously testing loss angle and partial discharge. Note: the graphs show a cable with ageing insulation in the blue and yellow (green) phase. The inset with emoticon shows the tan δ mean, and standard deviation of repeat measurements.