OWTS® - a new method for diagnosis of installed medium voltage power cables

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An Introduction to cable testing and cable diagnosis

Medium voltage cables are of key importance in the power distribution network. The enormous lengths of cable now installed, together with the socio-economic costs of failure, have identified MV cable networks as a target for further attention.

Quality assured components have been assembled together in a medium voltage supply network which, if it fails, will cause repair costs, customer complaints and loss of revenue or even associated claims. In fact, many sections of the network are frequently very mature, consisting of earlier types of components such as oil paper cables and bitumen joints. Mixtures of component types, ages and workmanship standards result in a network whose reliability is difficult to predict. The modern trend is for asset managers in electrical utility companies to instigate predictive maintenance programs in an attempt to repair potentially faulty network components before problems occur. Of course, such a program must show a cost benefit.

What is ideally required is a compact solution using a non-destructive method which can diagnose cable network performance under operating conditions and locate potential faults.

Figure 1

An engineer in the field making tests on 770 metre long paper / oil cables which were originally installed in 1964

The most effective solution for diagnosis of installed MV cables

Partial discharge detection and location is internationally accepted [1] and demanded for non-destructive factory testing of medium voltage power cables. This method can run into practical difficulties when applied to field testing of installed cables. The main problem is that the power required to energise a few kilometres of cable at power frequency usually demands a large system consisting of motor generator, HV transformer or resonant set, instrumentation for control, PD detection and fault location, coupling capacitor and HV connection cables. Transportation requires a large truck which is usually dedicated to the system and the total cost is considerable, although reasonable on a "value per kg" basis (see Table 1).

Alternative methods have concentrated on very low frequencies (VLF) such as 0.1Hz [2]. The 0.1HZ method is particularly widely used, having been commercially applied for a couple of decades, and recent developments aim to include dissipation factor measurement and partial discharge measurement / location within this method, which is fundamentally a voltage withstand test e.g. $3U_o$ for 60 minutes [4].

System criteria	Energising with 50 Hz	Energising with 0.1Hz	OWTS
description	truck containing 50 Hz HV series resonant system and PD analyser	van containing 0.1Hz HV series resonant system and PD analyser	two units: 65 kg + 32 kg containing fully automated HV supply and PD analyser
field experience	< 5 years	> 7 years	< 2 years
system components	several separate units	several separate units	integrated solution
manufacture	made to order	made to order	standard product
measurement of PD in pC or nC	according to IEC 60270 and automatic following calibration	after digital post-processing	according to IEC 60270 and automatic following calibration
transportability	dedicated truck	dedicated van	any service vehicle
knowledge of PD location needed	yes	yes	yes
processing and analysis of phase-resolved PD patterns	yes	no	yes

Table 1 Comparison of different methods for testing installed MV cable

There are concerns about the results of dielectric testing at frequencies other than those under operating conditions. It is recognised that partial discharge results resulting from low frequency measurements cannot be directly extrapolated to normal power frequency conditions [5]. The PD level is much higher at VLF than at 50 Hz (or 60Hz). Further, the increase in dielectric losses caused by partial discharges at a test voltage of 6 kV upwards ("tan δ tip-up") is almost absent at VLF. These findings do not come as a surprise to those with experience of DC PD testing, as electrical field distribution in the test object undergoes a transition from capacitive to resistive as the test voltage changes in character from true AC to DC [6] and the resulting partial discharge behaviour also changes.

Based upon the assumption that sensitive detection of critical PD sites can be best achieved by a method most similar to 50 Hz (or 60 Hz) operating conditions, a new solution has been introduced based upon application of a medium voltage oscillating wave of several tens of cycles duration and frequency of between 50 Hz and 1000 Hz. This is known as the Oscillating Wave Test System OWTS® [7].

The OWTS® principle of operation

The use of oscillating voltages for testing of installed cables has been under investigation throughout the 1990's [8, 9]. Modern technological innovations have finally enabled a commercial realisation of the potential of this method by carefully considered integration of the latest digital instrumentation techniques, solid state high voltage switching and high Q HV components.

Using the circuit shown in Figure 2, the cable under test is gently charged up to working voltage, over a period of a couple of seconds, using a DC source. At this point a solid state switch with fast closure time creates a series resonant circuit from the test object and an air-cored inductor. This circuit begins to oscillate at the frequency of $f = 1/(2\pi\sqrt{LC})$. The inductance of the air core is selected such that the resonant frequency (within the range 50 to 1000Hz) is similar to the power frequency of the service voltage.

Medium voltage cable insulation usually has a relatively low dissipation factor and this combines with the low loss factor of the air-core inductor to produce a high Q (30 to 100) resonant circuit. The result is an oscillating wave at the resonant frequency *f* with a decay time of 0.3 to 1 second. This produces a few tens of cycles to energise the test object and PD is initiated in a similar fashion to 50 (60)Hz inception conditions.

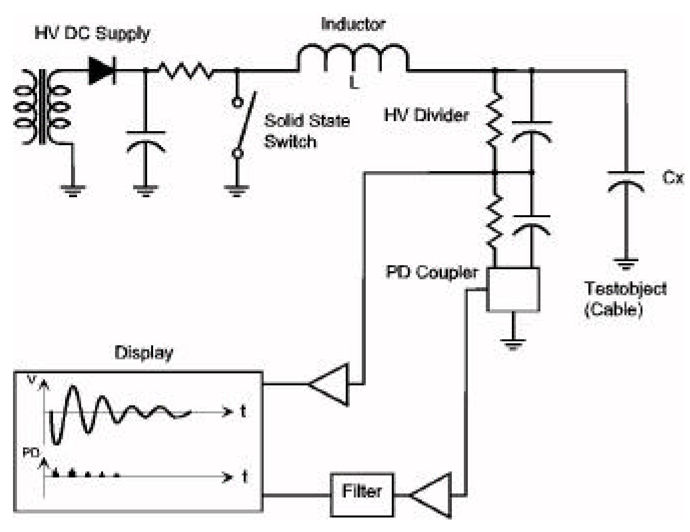

Figure 2

OWTS® test and measuring circuit for PD testing of capacitive components using oscillating waves

The specially developed measurement circuit detects all PD pulses that occur during the oscillating wave in accordance with IEC 60270 recommendations. Location of PD pulses is performed by the travelling wave method and a fault map of the cable can be produced.

In addition, values of capacitance C and tan δ can be calculated based upon the oscillating wave time and frequency characteristics.

Hardware implementation of the OWTS® system

The high voltage components are contained in a rugged plastic cylindrical housing with carrying handles and castors, total height 880 mm and weight 65 kg. This unit is placed next to the cable under test and consists of the HV air-cored inductor, HV divider, PD coupler and solid state switch. Recent advances in solid state power components have enabled the design of the high voltage switch for 50 to 100 Amps and 50kV. Mechanical wear, contact bounce and triggering uncertainty have been eliminated. The test object endures no extra stress and the stable switching allows exact and repeatable Q measurements for dissipation factor calculation. Two cables connect the cylinder to the control and detection instrumentation.

An aluminium field housing with vibration mounts contains the second part of the OWTS® system, which consists of the combined detector / fault locator / system control and a slimline HVDC power supply. This unit is 440 mm high and weighs 32 kg. The instrument is based upon an industrial PC, which has already been proven in numerous high voltage applications, and utilises the latest Pentium™ technology. A standard keyboard with touchpad mouse is located in a sliding tray below the instrument and, finally, the system cables are stored in the front cover of the housing (Figure 3).

Figure 3

OWTS® system consisting of a ruggedised control and measuring instrument and the HV cylinder which contains the air core inductor, solid state switch, divider and PD coupler.

System control and PD evaluation

The computer based instrument controls all aspects of the test once the cables have been connected by the operator. The first step is a low voltage calibration of the cable under test using a standard IEC 60270 compliant PD calibrator. This scales the readings in picocoulombs and, when the cable length is entered by the operator, calculates the propagation velocity of the cable which allows fault location in metres.

Charging of the test cable with the switched DC power supply generates disturbances so the system inhibits PD measurement during this part of the procedure. After a couple of seconds, when the pre-set voltage level has been reached, the solid state switch is closed (in less than 1 µs) which disconnects the DC supply and creates a series resonant circuit from the air-core inductor and cable under test. The resulting oscillating wave initiates PD activity from PD sites in the cable under test and the measurement / location begins.

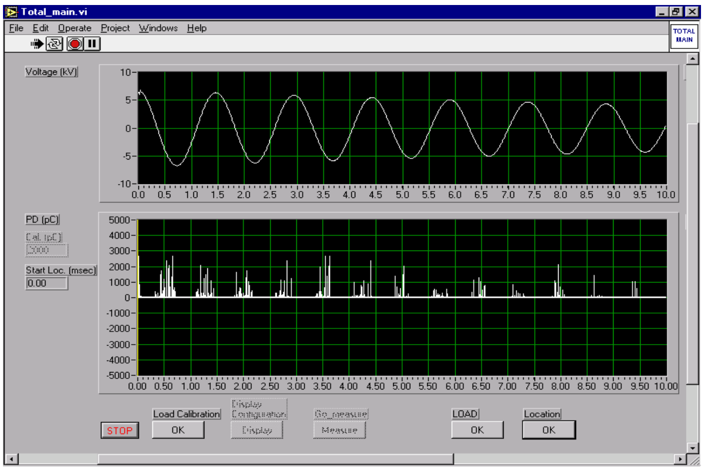

Figure 4

OWTS® display of oscillating wave and PD signals measured with a 12 kV XLPE cable showing internal discharges

OWTS® uses a dual input system, one with a bandwidth of 150 to 650 kHz for PD measurement according to IEC 60270 and one with a bandwidth of 150 kHz to 10 MHz for PD fault location. The oscillating voltage waveform and all PD pulses initiated during the test are measured, stored in memory and displayed on the screen (see Figure 4).

The operator can see the PD activity that corresponds to the oscillating wave cycles and select PD pulses for further investigation. Once selected, the PD waveform is viewed in detail and the fault can be located by positioning of the cursors on the incident and reflected waves. Each fault location can then be saved in the cable map, which may contain the results of several oscillating waves if desired (see Figure 5).

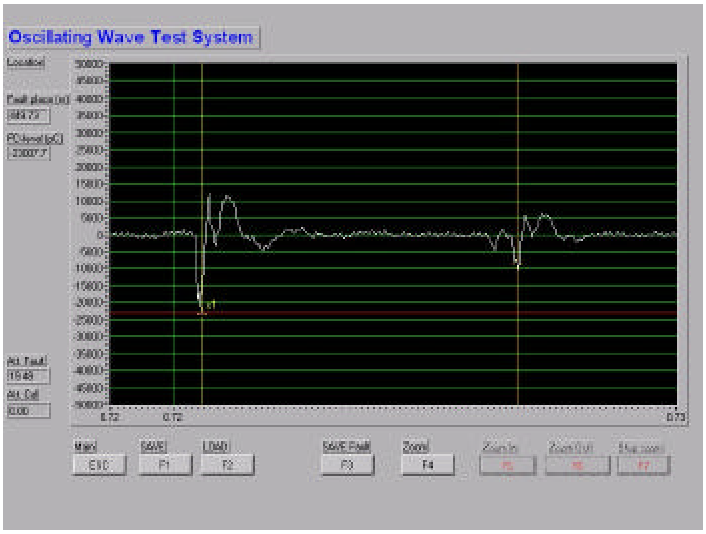

Figure 5

OWTS® location of a PD fault at 449 m on a 10 kV 840m paper / oil cable tested at 12 kV.

On-site testing with OWTSò

2 years' systematic laboratory and on-site application of this system [7] encouraged Energie Noord West in Alkmaar, Netherlands to launch a program of OWTS® testing for their medium voltage distribution cable network (see Figure 6). Allocation of a dedicated test engineer, together with the compactness of the OWTS® system, has set this electrical utility on the route to achieving a preventative maintenance program based upon diagnostic test results.

Figure 6

Energie Noord West in Alkmaar, Netherlands have instigated a review of their MV cable network using OWTS®

Having scheduled testing of a particular cable run, the OWTS® is transported to the site in a normal field test vehicle (typically a medium sized car). A single mains power connection is required for the OWTS® instrument and earth connections for the instrument and cylinder.

A typical test procedure for OWTS® is as follows.

1. Connection of the OWTS® cylinder HV and ground terminals to the test circuit (see Figure 7).
2. Calibration of PD magnitude and PD pulse velocity* / cable length using the IEC 60270 PD calibrator.
3. Voltage application and PD measurement by selection of the voltage level, charging of the cable under test and storage of test data.
4. Evaluation of the PD level and inception voltage.
5. If PD result is abnormal in comparison with similar cable installations, then PD location* is performed.

* = knowledge of travelling wave principles is required at this point

Now the set-up can be changed to test the other cable phases.

Figure 7

Connection of the OWTS® HV cylinder to a 500m paper oil cable which was originally installed in 1977.

Summary

OWTS® is a practical and convenient solution for on-site PD diagnosis of medium voltage cables and is of assistance to network operators in planning of predictive maintenance programs. The main advantages of the system are that it is compact and performs non-destructive testing under AC conditions.

OWTS® FAQ

The most frequently asked questions (FAQ) about this method, which have not been answered by the above text, are covered below.

Q OWTS® claims to be energising the test object under AC conditions. What about the initially charging of the cable under test with HV DC? Isn't DC dangerous for some types of cable?
A The oscillating wave itself is an AC waveform of between 50 and 1000 Hz, depending upon the L and C of the resonant circuit (300 Hz is a typical value). The initial charging of the cable under test takes a couple of seconds and never reaches a steady state of DC. This is comparable to just one quarter cycle of VLF (compared to 360 cycles in a typical 60 minute 0.1 Hz test). Long-lived space charges, which can cause problems in plastic cables, require much longer periods of DC loading.

Q OWTS® disables the PD measurement during the DC charging. Is this because of over voltage transients caused by the HV switch which could be damaging to the test cable?
A The PD measurement is disabled during the DC charging as the DC power supply is switch mode and generates noise, not impulses. The electrical characteristics and circuit position of the solid state HV switch prevent any potentially damaging impulse subsequent to the closure of the switch and commencement of the oscillating wave.

Q PD behaviour at VLF has been shown to be quite different to that at 50 Hz. What about the differences between 50Hz and higher frequencies, such as those generated by OWTS®?
A The type of PD test results produced by OWTS® in comparison with other test methods, especially 50 Hz, is an area of intensive research by our academic research partner, TU Delft in the Netherlands [7, 10, 11, 12, 13]. Papers presented at ISH '99 in London (see Table 2) contain research evidence that the PD level, inception voltage and phase resolved patterns obtained at 50 Hz and by OWTS® show no significant differences.

	Energising with 50 Hz AC		1066 Hz OWTS	
Defect	U inc (kV)	PD (pC)	U inc (kV)	PD (pC)
Bad contact between semicon and stress cone	2.6	25	3	30
Bad adjustments of the stress cone	15	20	13	40

Table 2 Comparison of inception voltage U_{inc} and PD magnitude in pC for the same internal defects in cable accessories with charging voltages of 50 Hz AC and 1066 Hz oscillating voltage [11].

Q Are a few tens of cycles of oscillating voltage sufficient for PD measurement and location, when other tests usually last up to an hour?
A A few tens of cycles is all OWTS® needs to generate and measure PD. It must be remembered that OWTS® is not a voltage withstand test, but a diagnostic method. And, in any case, 50 Hz fault location usually only looks at part of one cycle at a time.

Q Can OWTS® test the same levels of PD as in a cable factory test e.g. < 5 pC?
A Yes, if OWTS® was placed in a cable factory test environment then it could see such low levels. But this is not applicable to field testing. The reason is that factory rules are thrown away in the field because bad cable joints (the most common source of problems) produce discharges of hundreds or thousands of pC.

Q OWTS® claims a shorter testing time than other methods, but the results are still open to interpretation, aren't they?
A Recognising PD pulses, discriminating interference and making recommendations for maintenance actions are a task for personnel familiar with travelling wave principles and with knowledge of the cables systems under test . The shorter test time of OWTS® is thanks to the simplified operation of the system and short duration of the test voltage, even if several oscillating waves are generated. The operator does require knowledge and training to operate the system for maximum benefit. This is the same with any method of on-site cable diagnosis. For this reason we provide an OWTS® Technical School at TU Delft in the Netherlands and run OWTS® seminars at different locations world-wide.

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