WESTERN POWER DISTRIBUTION

Serving the Midlands, South West and Wales
Gwasanaethu Canolbarth a De Orllewin Lloegr a Chymru

Company Directive

STANDARD TECHNIQUE: OS10C/4

Relating to Pressure Testing of High Voltage Apparatus

Policy Summary

The Electricity, Safety, Quality and Continuity Regulations 2002 and the Electricity at Work Regulations 1989, both require that High Voltage Apparatus shall be so constructed, installed, protected, used, maintained and tested so as to prevent Danger as far as is reasonably practicable.

Tests to the appropriate Standards are carried out on new Apparatus at the manufacturer's works and a test certificate is either issued or available for inspection. These tests satisfy the requirements of the regulations.

Author: **Richard Summers**

Implementation Date: **November 2017**

Approved by

Safety and Training Manager

Date: 22nd November 2017

IMPLEMENTATION PLAN

Introduction

The Electricity, Safety, Quality and Continuity Regulations 2002 and the Electricity at Work Regulations 1989, both require that High Voltage Apparatus shall be so constructed, installed, protected, used, maintained and tested so as to prevent Danger as far as is reasonably practicable.

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Main Changes

General Note 1 has been updated to address the limited number of situations where substation works or rejumpering/reconnection works take longer than the normally prescribed 24 hours time period between testing and energisation

Impact of Changes

This change adds a requirement for the SAP in charge of a project to provide a schedule of testing and enegisation to reduce risk where testing and energisation are not within 24 hours.

Implementation Actions

Team Managers responsible for staff who commission complex networks which may fall within this requirement shall bring this revised document to their attention.

Implementation Timetable

This reviewed ST shall be implemented immediately.

REVISION HISTORY

Document Revision & Review Table		
Date	**Comments**	**Author**
November 2017	General Note 1 updated to address the limited number of situations where energisation is delayed after pressure testing.	Richard Summers
July 2017	Update of test values for sheath testing in 3.5.2	Richard Summers
Nov 2016	Document reviewed Addition of page 2 Implementation Plan. Addition of 3.5.2.1 – Clarification of test details for Sheath Testing of Polymeric or Extruded Cables. This change has no impact on company policy	Peter White
01/07/2013	The changes that have been made to this document are the inclusion of the methods of applying test voltages to cables and plant that use the equipment interface as outer or inner cone separable connectors. The use of VLF testing on 66kV cable circuits. Rectification of known typographic errors.	Peter White

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OBJECTIVE

This document assumes that at all times the Distribution Safety Rules and any relevant Standard Techniques are being complied with at all times; this standard technique identifies the pressure tests that shall be carried out: -

(i) Before new HIGH VOLTAGE APPARATUS is connected to the system

(ii) Before HIGH VOLTAGE APPARATUS that has been disconnected from the SYSTEM for alteration or repair may be re-energised

It also states the voltage levels that shall be applied to: -

(a) Switchgear & Plant

(b) Underground Cables

(c) Overhead Lines

In addition it details when Tan Delta tests and Partial Discharge (PD) mapping shall be undertaken on a circuit. It should be noted that Tan Delta and PD mapping is only carried out on underground cable circuits.

This document also gives details of how to pressure test cable circuits and plant which are fitted with either outer cone or inner cone separable connectors

GENERAL NOTES

1. Pressure Tests shall normally be carried out immediately prior to energising HV APPARATUS. If a delay occurs after pressure testing, then a SENIOR AUTHORISED PERSON shall decide if a further pressure test is required.

   No HV APPARATUS shall be energised more than 24 hours after being pressure tested unless the APPARATUS is contained within a substation compound or works to rejumper/reconnect the network take more than 24 hours. Where a delay of more than 24 hours is unavoidable the SENIOR AUTHORISED PERSON responsible for the works shall create a schedule of testing and energisation to ensure the delay between testing and energisation is kept to a minimum to reduce the likelihood of subsequent damage or interference.

2. Pressure test methods may state that the secondary circuits are to be shorted and/or earthed during testing. These requirements may be ignored if there is a risk of injury from adjacent Live Apparatus or Connections. When secondary windings are not shorted / earthed, care shall be taken to discharge the Apparatus following the pressure testing in such a way that insulation is not damaged.

3. 132kV Apparatus with the exception of underground cables is not usually over-voltage tested. Insulation resistance tests should be conducted whenever reasonably practicable.

Note: -

Where this standard technique specifies a one minute 5kV insulation resistance test, it is intended that the test shall be applied to allow sufficient time for the instrument to charge the equipment under test.

This is indicated by a decreasing rate of rise and eventually a steady state or stable condition will be reached - which, depending on the capacitance of the item under test may be more or less than one minute.

All insulation resistance tests shall achieve this steady state or stable condition in order to provide repeatability and valid recording of deterioration rates.

1.0 INTRODUCTION

1.1 When Apparatus have been disconnected from the System for "on site" alterations or repair and insulating components have been disturbed or replaced, it shall be tested in accordance with Section 3 of this Standard Technique.

1.2 Apparatus that have been disconnected from the System and removed from site to a workshop for alteration or repair shall be subjected to the appropriate tests as specified in Section 4 of this Standard Technique before the Apparatus is again made available for duty. Additional "on site" tests as specified in Section 3 of this Standard Technique shall be applied before the Apparatus is re-energised.

1.3 There is a duty to check that any Apparatus which has been subjected to maintenance is in sound condition before it is re-energised, and this is considered to be reasonably met by adopting the following general practice. When HV Apparatus have been isolated or disconnected for routine on site electrical maintenance and such works do not require the dismantling of any insulating component(s) the Apparatus shall be tested with an insulation tester before it is returned to service, especially if reconnection involves the use of live line techniques.

1.4 Where such a test is not reasonably practicable the Apparatus shall be inspected by a Senior Authorised Person before it is returned to service. Where primary insulating components, (with the exception of insulating oil which has been separately tested, or SF6 Gas topped up) are disturbed or replaced then tests as specified in Section 3 shall be applied.

1.5 On occasions it will be necessary for a pressure test to be applied to a mixed or only polymeric cable circuit that is jointed into a cable box of a switch that is locked open with the busbars Live. The standard Very Low Frequency (VLF) test values selected ensure that the maximum peak voltage that can occur across the contacts of an open switch when the remote side is Live, does not exceed the peak to peak value of the switchgear routine one minute a.c. test.

1.6 On occasions it will be necessary for a pressure test to be applied to a paper insulated only cable circuit that is jointed into a cable box of a switch that is locked open with the busbars Live. The standard DC test values selected ensure that the maximum peak voltage that can occur across the contacts of an open switch when the remote side is Live, does not exceed the peak to peak value of the switchgear routine one minute a.c. test.

1.7 All Apparatus shall be discharged to Earth following the application of a test voltage, and prior to handling. In order to avoid damaging peak voltages during discharge, this shall be achieved where reasonably practicable, by the application of a proprietary resistor stick until the voltage has decreased to 5kV or less, whereupon a direct Earth may be applied.

2.0 VACUUM SWITCHGEAR - SPECIAL PRECAUTIONS

2.1 Whilst there is no detectable emission from vacuum interrupters at working voltage or from interrupters in the closed position at higher voltages there is concern that tests at higher voltages across open interrupters may promote the emission of x-rays. The possibility of this happening is considered to be remote but in the interests of safety the following precautions shall be taken;

- A warning label SHOPS No. 40033 bearing the ionising radiation symbol and the following legend shall be prominently sited on, or immediately adjacent to, each unit of vacuum switchgear. "KEEP 3 METRES AWAY DURING OVER-VOLTAGE TESTING".

- Wherever it is reasonably practicable, tests shall be made with the interrupter in the closed position. In this situation no emission hazard exists.

- When tests are made across an open vacuum interrupter, which is housed inside its switched unit, personnel should not approach within 3 metres of the interrupter during the tests.

- If an interrupter is to be tested when removed from its switch unit the 3 metre safety distance shall be maintained or a 1.5mm thick sheet steel screen must be positioned between all personnel and the interrupter under test. This screen shall be bonded to the substation Earth system as soon as reasonably practicable prior to the application of test voltages.

3.0 ON-SITE TESTING

In addition to any manufacturers tests, new Apparatus shall be subjected to "on site" tests before energisation.

No item of HV Apparatus as defined in the objective shall be energised until it has been subjected to a pressure test. Some of these tests may be combined by bonding two or more Conductors together e.g. by bonding the three phase cores of an HV cable together the phase to Earth tests for each core may be carried out at the same time.

Some VLF test sets, even when set to automatic frequency selection, will not be able to test three phase cores bonded together, as the VLF test set is dependant on the capacitance of the circuit. The maximum capacitance that an HV INC test set can cope with is 1.1μF, whereas the maximum capacitance the HVA test set can deal with is 0.5μF. If the length of the circuit under test causes this value to be exceeded then each phase shall be VLF tested separately. It should be noted that the preferred testing frequency is 0.1Hz.

Many VLF test sets have the facility to use tan delta, if tan delta is part of the test set then testing of all circuits with VLF and tan delta is the preferred method of testing. Tan Delta, also called Loss Angle or Dissipation Factor testing, is a diagnostic method of testing cables to determine the quality of their insulation. Details of the testing regime are given later in this document.

In addition some VLF test sets have Partial Discharge (PD) mapping facilities; PD mapping is an approved means of underground cable testing. The only approved equipment or method of PD mapping is the Baur or Capenhurst PD mapping systems, which are both similar in their respective mapping techniques.

Where one or more of the factors below apply to a given circuit then consideration to the use of PD mapping should be given: -

1) If the circuit contains underground cable which has been up-rated from 6.6kV to 11kV or;
2) If the NAFIR’s database shows a fault history or;
3) The tan delta test shows the circuit has a poor tan delta or loss angle result or;
4) If local knowledge points to the circuit rogue circuits or;
5) If the circuit is a ‘D’ circuit or;
6) If information from the Planning / Regulation Special Projects Team’s Condition Based Risk Management (CBRM) studies show that a particular circuit has a poor health index or;
7) The Asset Risk Management (ARM) Cable Condition reports which feed into the CBRM health indices’ that then highlight problems on a particular cable circuit.

Note: - All the above factors carry equal weighting.

The “Baur Cable Test Vans”, purchased against Engineering Equipment Specification EE: 92, are fitted with integral VLF test sets which are capable of undertaking Tan Delta and PD mapping measurements of the underground cable circuit whilst pressure testing the circuit. The raw data generated from these tests, (data that has not been worked on), gathered from both the Tan Delta and PD mapping shall be stored electronically, in a raw data folder so it can be kept for future reference and referral on the state of that particular circuit. If raw PD mapping data is not saved prior to working on it, that raw data is lost and can never be referred to and is no longer auditable.

A copy of the raw data shall therefore be copied to a new folder, before the copy is worked on.

3.1 Switchgear - On site

New switchgear shall normally be pressure tested to the requirements of the Regulations by the manufacturer at their works. An additional pressure test shall be applied to all switchgear after it has been erected on-site or subject to on-site alteration or repair. The "on-site" pressure test shall be either a one minute ac test applied before the switchgear is jointed, or a 15 minute dc test carried out with the all *paper* cable circuits connected, at the voltage levels set out in Tables 1 & 2 respectively. VLF testing can be used for all paper circuits, mixed cable circuits, or all polymeric cable circuits, the voltage levels to be applied shall be as detailed in Tables 9, 10, 11, 18, 19 and 20 depending on the voltage level of the switchgear. Before testing switchgear any associated voltage transformers shall be Isolated and tested separately under the provisions of 3.4, in order to avoid damage to their graded insulation.

Current transformer secondary windings shall be short circuited and Earthed unless the secondary circuits are complete. The test voltage shall be applied between phases, between all phases and Earth, and across the open switch contacts.

Table 1. AC Test before Switchgear is Jointed (unless Manufacturer specifies a Lower Voltage)

Rated Voltage	Test Voltage Level	Test Duration
6.6 kV	15.2 kV rms	}
11 kV	24 kV rms	} AC test
33 kV	60 kV rms	} for 1 minute

Table 2. DC Test with Paper Cable circuit Connected (unless Manufacturer specifies a Lower Voltage)

Rated Voltage	Test Voltage Level	Test Duration
6.6 kV	10.5 kV	}
11 kV	18 kV	} DC test for
33 kV	60 kV	} 15 minutes

With-drawable switchgear that has been maintained on site shall be tested using a 5kV insulation tester for one minute before it is returned to service, subject to the provisions of 1.3.

3.2 Transformers

6.6kV & 11kV Transformers

New transformers are tested by the manufacturer at works. An additional 5kV insulation test should be applied for 1 minute to the transformer after on site installation, alterations or repairs. If an additional pressure test is deemed necessary for ground mounted transformers after installation on-site or after on-site alterations or repair. The test voltage is specified in Table 3 below, and shall be applied between each HV winding and Earth, with all other windings, frame and core, Earthed. All connections to the winding under test shall be bonded together. The secondary winding of any current transformer shall be short circuited and Earthed unless the secondary circuits are complete. (LV transformer windings shall similarly be tested with a 1kV insulation tester before energising for one minute). See also General Note 2.

The HV windings of any additional or replacement pole mounted transformer shall be tested on-site with a 5kV insulation tester for one minute before it is erected on the pole (see 3.6). LV windings shall be tested with a 1kV insulation tester for one minute.

Table 3. DC Test after Installation

Winding Voltage	Test Voltage Level Winding to Earth	Test Duration
6.6 kV	10.5 kV	} DC test
11 kV	18.0 kV	} for 15 minutes

33kV, 66kV & 132kV Transformers

New transformers are tested by the manufacturer at works. An additional 5kV insulation test should be applied for 1 minute to the transformer after on site installation, alterations or repairs.

(**Note: –** A DC pressure test is likely to damage the transformer winding).

3.3 Current Transformers

CT primary windings are to be tested after installation, as per switchgear. The secondary windings shall be short circuited and Earthed unless the secondary circuits are complete.

3.4 Voltage Transformers

A one-minute test with a 5kV insulation tester shall be applied to the HV winding with the low voltage and tertiary windings Earthed The neutral Earth link of an Earthed - star HV winding will need to be disconnected for this test. A voltage transformer with a permanent HV neutral Earth connection may be commissioned without being pressure tested. (Low voltage and tertiary windings should be tested for one minute with a 1kV insulation tester before energising).

3.5 Underground Cables - General

All LV underground cables regardless of length shall have their insulation resistance tested with a 1kV insulation resistance tester **prior to** jointing to ensure that the insulation has not deteriorated due to damage or the ingress of moisture. All 6.6 / 11kV and above underground cables regardless of length shall have their insulation resistance tested with a 5kV insulation resistance tester **prior to** jointing to ensure that the insulation has not deteriorated due to damage or the ingress of moisture. A one minute test with an insulation tester shall be applied between cores and each core to Earth to every length of cable. Care shall be taken to discharge the cable to Earth after testing and prior to handling or jointing the cores.

It should be noted that all paper insulated cables at 33kV and above are screened cables; therefore only phase to earth testing is required. In majority of WPD 11kV and LV paper insulated cables have the belted cable design, this type of cable requires additional testing as detailed in the 11kV cable section. All polymeric cables from 11kV upwards are a screened design of cable.

It is not mandatory to apply the phase to phase test to a short length (less than 10m), of cable jointed to a transformer which is not fitted with isolating links.

Circuits to be tested with VLF test sets that have the Tan Delta facility shall be tested using this facility. Tan Delta tests provide an indication as to the average loss angle (or tan delta) of the cable circuit under test and can be used to indicate whether the circuit needs PD mapping done to determine which section of the circuit is reducing the tan delta measurement.

It should be noted that if an underground cable circuit is protected by surge diverters then the surge diverters shall be disconnected from the system **prior to** any testing being carried out. This is due to the fact that surge diverters have changed from silicon carbide to metal oxide surge diverters. When metal oxide surge diverters are selected to protect the respective voltage levels i.e. 11kV, 33kV, 66kV etc. then one of the criteria used to select the surge diverter is the maximum continuous operating voltage (M_{cov}), this is the voltage the surge diverter can continuously withstand, all metal oxide surge diverters are capable of withstanding an over voltage for a short period, this period of over voltage withstand is not long enough to enable site commissioning tests on underground cables to be completed and the M_{cov} voltage level is to low to consider it as a satisfactory test voltage level for the underground circuit. In addition to this removing the surge diverters from the underground cable circuit prevents poor tan delta, PD Mapping and ordinary VLF results due to leakage currents that flow across the surface of the surge diverter, this will give incorrect readings for the circuit under test. In addition the leakage currents across the surge diverter could be excessive, thus preventing the test set from operating.

3.5.1 Paper Insulated Underground Cables whose voltage level exceeds 6kV

The definition of a paper insulated underground cable is a cable that falls into one of the following categories: - a fluid filled cable, also known as an oil filled cable, a gas compression cable or pipeline cable, an impregnated pressure gas cable or IP cable, a rosin oil or PILC cable, or an MIND cable which could be an H or HSL, or PICAS or PISAS. A DC pressure test shall be carried out on every length of paper insulated HV cable, which has been disconnected from the system for alteration or repair, within 24hours before it is re-energised.

Note: - The DC pressure test only applies to cable circuits which contain paper insulated cable ONLY. The DC pressure test is NOT to be used on a mixed cable circuit or a solely polymeric cable circuit. The definition of a mixed circuit is a circuit which contains both paper cable and polymeric cable. The definition of polymeric cable is any underground cable made from extruded insulation, for example XLPE, PE or EPR insulation.

When carrying out a DC phase to Earth test, the test supply should be arranged so that the phase cores are negative with respect to the sheath.

When a paper cable is connected to a pole termination(s) and a test is required during inclement weather, the test set may have insufficient capacity to supply the leakage current. Where this proves to be the case, and it is impracticable to postpone the test, the circuit can be tested using a 5kV insulation tester.

Where it is not reasonably practicable to disconnect a 132kV, 66kV or 33kV transformer windings from a length of cable, the route of the cable **shall** be inspected for open excavations or signs of recent damage and the cable plus windings **shall** be tested with a 5kV insulation tester.

(**Note: –** A DC pressure test on a 132kV, 66kV or 33kV transformer is likely to damage the winding).

DC pressure test values shall be selected from the following Tables 4, 5 or 6 on the basis of the oldest length of cable, within the section to be tested.

Table 4. DC test voltage levels before energising on paper insulated underground cables varying in age from new to 15 year old cable.

System Voltage	Test Voltage Level		Test Duration
	Ø – Ø**	Ø - E	
6.6 kV	18.0 kV	-10.5 kV	}
11 kV	30.0 kV	-18.0 kV	} DC test
33 kV	-	-60.0 kV	} for 15
66kV	-	-170kV*	} minutes
132 kV	-	-305 kV*	}

Note: - * These values are for fluid filled cables. For **gas filled or gas pressure cables** operating at 66kV system voltage, cable test at -132kV; for operation at 132kV system voltage, cable test at -264kV.

** (Ø - Ø test supply with centre point EARTHED).

These test voltages are the highest voltages that may be applied to a cable connected to HV switchgear. When a fault location is to be carried out on lengths of cable that are not connected to HV switchgear the test voltages may be increased provided the DC test voltages specified in BS 6480 are not exceeded. (i.e. 15kV at 6.6kV; 25kV at 11kV and 75kV at 33kV).

Table 5. DC test voltage levels before energising on paper insulated underground cables varying in age from 16 to 29 year old cable.

System Voltage	Test Voltage Level		Test Duration
	Ø - Ø	**Ø - E**	
6.6 kV	14 kV	-8 kV	}
11 kV	23 kV	-14 kV	} DC test
33 kV	-	-40 kV	} for 15
66kV	-	-79kV	} minutes
132 kV	-	-153 kV	}

Table 6. DC test voltage levels before energising on paper insulated underground cables varying in age from 29 year old or older cable.

System Voltage	Test Voltage Level		Test Duration
	Ø - Ø	**Ø - E**	
6.6 kV	12 kV	-7 kV	}
11 kV	19 kV	-11 kV	} DC test
33 kV	-	-33 kV	} for 15
66kV	-	-67kV	} minutes
132 kV	-	-133 kV	}

3.5.2 **Polymeric or Extruded Insulation Underground Cables whose voltage level exceeds 6.6kV**

The DC voltage test, which has been used successfully for some decades on paper cables, has proved itself unsuitable for polymeric cables. On one hand, serious defects are seldom detected, and on the other hand the DC voltage test can lead to long term space charges in water tree damaged polymeric insulated cables, leading to the cables' early demise, therefore it shall not be used as a site testing regime.

The on-site commissioning of polymeric circuits, mixed circuits and paper circuits shall be Sinewave VLF 0.1Hz the use of Sinewave VLF allows for PD mapping and Tan Delta measurement if required.

Sheath Testing of Polymeric or Extruded Underground Cables

All cables having an insulated oversheath, shall be tested, as follows, to ensure that the oversheath has an adequate level of insulation resistance before and after installation:

a) Each drum length shall be tested before installation, e.g. if graphite coated on the cable drum.
b) Each new section of cable shall be tested after installation and blinding of the cable, prior to jointing to other new cable sections and/or being connected to the network.
c) Where the new cable circuit comprises one or more new cable sections, the new circuit shall additionally be tested after jointing of all the new cable sections but prior to being connected to the existing network. For single core cables, all cores shall be tested in turn.

The HV test equipment shall comprise a HV d.c. test set equipped to measure the leakage current using the test voltage and duration values specified in Table 7. The values of maximum leakage current are given in Table 8 and are applicable to new cable lengths. An insulation resistance tester may be utilised as an alternative means of testing.

Note: - Specially bonded cable circuits complying with requirements of ENA ER C55 may require further tests in addition to the oversheath tests described here.

A suitable example testing arrangement using a d.c. test set is shown in Figure 1.The site test procedure for polymeric cables shall now incorporate a DC voltage sheath test. This test is to check that the primary protection for the cable i.e. the oversheath has not been damaged during its installation.

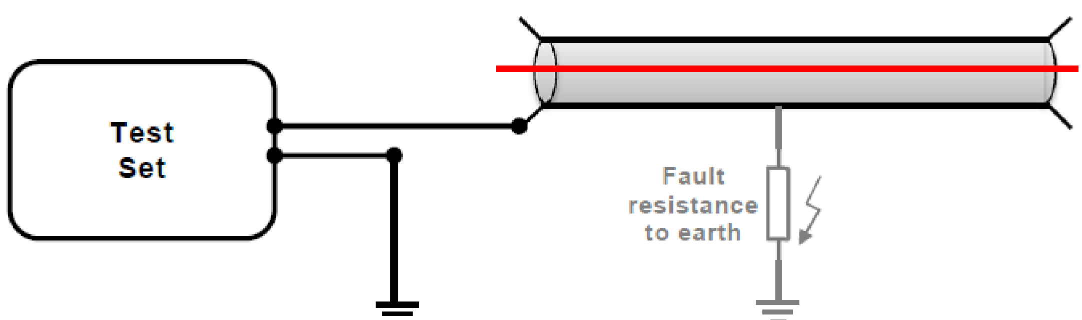


Figure 1 — Example testing arrangement

An alternative testing arrangement is shown diagrammatically in Figure 2. In this arrangement, the test set utilises a source of up to 10 kV d.c. with positive and negative polarity to facilitate the testing of cable sheaths. The bi-polar function ensures the elimination of external thermoelectric and galvanic influence. Additionally, with a suitably equipped test set and using the connections shown, combined sheath testing and pre-location of the earth fault can be carried out. following this procedure if there is a failure in the oversheath, the check for damage is restricted to a single drum length of cable, once the damage has been found a sheath repair may be carried out and the circuit re-checked.

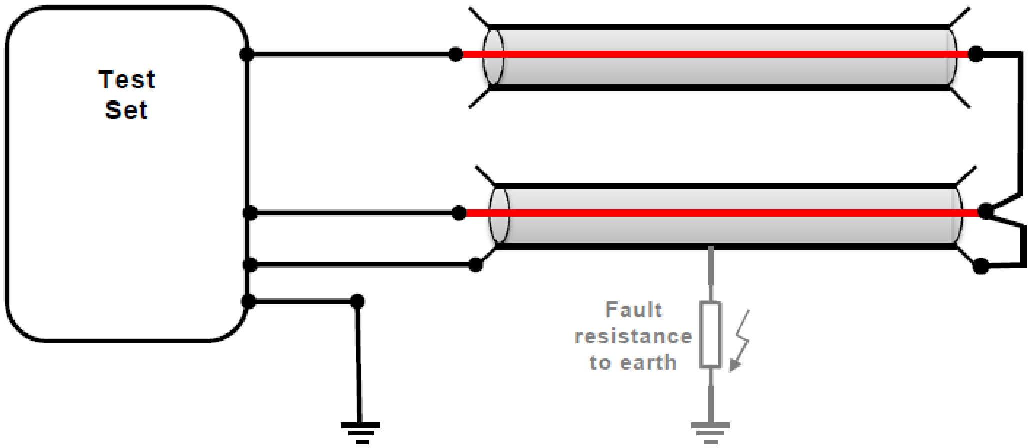


Figure 2 — Alternative testing arrangement

The following test method is applicable.

i. Using the test method 1 or test method 2, apply the test voltage and duration specified in Table 7.
ii. Record the maximum leakage current (or minimum insulation resistance, if using an insulation tester) during the test.
iii. If the section of cable does not carry the voltage specified for the required duration or fails to meet the leakage current criteria in Table 8 the oversheath test has failed.

Table 7 — Test voltages and durations for cable oversheath testing

Nominal phase voltage (kV)	Minimum d.c. test voltage (kV)	Test duration (min)[1)]
11	5	1
33	5	1
66	10	1
132	10	1

1) It is necessary to allow time for the cable charging. The timing begins when the set has reached the required voltage and for insulation resistance (IR) testers the time begins when the IR value has stabilised.

Table 8 — Acceptance criteria for cable oversheath testing

Cable length (m)	Acceptance Criteria			
	PVC sheathed cables		PE sheathed cables	
	Maximum Leakage Current (mA)	Minimum Insulation Resistance (MΩ) at 5kV	Maximum Leakage Current (mA)	Minimum Insulation Resistance (MΩ) at 5kV
50	0.04	1,250	0. 01	5,000
100	0.08	625	0.02	2,500
250	0.2	250	0.05	1,000
500	0.4	125	0.1	500
750	0.6	83	0.15	333
1000	0.8	63	0.2	250

In the event of a failed test at any stage of the installation, the oversheath fault(s) shall be located and repaired. The above test procedure shall be repeated. A new cable length or new cable shall not be accepted until a successful oversheath test result has is achieved.

3.5.3 66, 132 and 275kV POLYMERIC CIRCUITS

These circuits shall be ac tested using series resonance testing at or about 50Hz, using the voltage levels shown in Table 9. To ensure the circuits have been installed and jointed correctly the test shall include PD mapping. The PD mapping shall be done at four equally spaced points between 0V and the full site test voltage. The full site test voltage shall be 1.7 U_o (where U_o is the power frequency voltage between phase and earth for that particular circuit) the test shall be a single phase to earth test and shall last for 60 minutes. If there is a problem either with the cable or the installation work then by using four equally spaced pd mapping points, the inception voltage for the pd should be able to be found. This is important because, if the inception voltage is below U_o it implies that the PD would be active once the circuit is operating at service voltage and would ultimately lead to a failure.

For 66kV circuits it is acceptable to use VLF testing as a means of commissioning or proving of the cable circuit, the voltage and test time shall be as given in Table 9 for the 66kV below. If Tan Delta is available it shall be used the diagnostic sequences for the tan delta should be programmed in to the unit it shall be four steps, these steps would be $0.5U_o$, U_o, $1.35U_o$ and $1.7U_o$

Table 9. AC Series Resonance Test Voltage levels for 66, 132 and 275kV Polymeric circuits

Circuit operating voltage	Circuit U_o	Site test voltage level (Ø to E)	Test Duration
66kV	38.1kV	64.8kV	}
132kV	76.2kV	129.5kV	} 60 minutes
275kV	158.8kV	270kV	}

Note: - The test voltages given in Table 8 are **RMS** values.

3.5.4 33kV POLYMERIC CABLE CIRCUITS and MIXED CABLE CIRCUITS

Basic VLF Testing

After polymeric or mixed cable circuit has been jointed and is ready for final commissioning, the circuit shall be site tested using VLF AC test methods, a portable VLF set capable of testing 33kV cables or the "Baur Cable Test van" which has the VLF test set fitted shall be used. The 'plain' VLF method provides a "go" or "no go" appraisal of the cable circuit under test. It should be noted that VLF can test all polymeric cable circuits, mixed paper and polymeric cable circuits and just plain paper cable circuits. The voltage levels to be applied to the circuits under test are given in Tables 10, 11 and 12 below. It should be noted that these test voltage levels vary, with the age of the oldest piece of cable in the circuit determining the test voltage level. (The test voltages values given in the following Tables 10 up to and including 18 are **RMS** voltage levels).

Table 10. VLF Test Voltage levels for 33kV Polymeric circuits, 33kV mixed circuits varying in age from new to 15 year old cable.

Circuit	Voltage Level Ø to E		Test Duration
Each Phase (polymeric)	2.5 U_o	47.5kV	30 minutes
Each Phase (mixed)	2.5 U_o	47.5kV	30 minutes
Each Phase (paper)	2.5 U_o	47.5kV	30 minutes

Where U_o = the power frequency voltage between phase and earth.

Table 11. VLF Test Voltage levels for 33kV Polymeric circuits, 33kV mixed circuits varying in age from 16 year old to 29 year old cable.

Circuit	Voltage Level Ø to E		Test Duration
Each Phase (polymeric)	2.1 U_o	39.9kV	30 minutes
Each Phase (mixed)	2.1 U_o	39.9kV	30 minutes
Each Phase (paper)	2.1 U_o	39.9kV	30 minutes

Where U_o = the power frequency voltage between phase and earth.

Table 12. VLF Test Voltage levels for 33kV Polymeric circuits, 33kV mixed circuit varying in age from 29 year old or older cable.

Circuit	Voltage Level Ø to E		Test Duration
Each Phase (polymeric)	1.7 U_o	32.3kV	30 minutes
Each phase (mixed)	1.7U_o	32.3kV	30 minutes
Each Phase (paper)	1.7 U_o	32.3kV	30 minutes

Where U_o = the power frequency voltage between phase and earth.

3.5.5 **33kV cable VLF with Tan Delta Testing**

A VLF test set complete with the tan delta is required for this test. Diagnosis of the cable circuit using tan delta measurement provides differentiated information on the ageing of the cables within that circuit. It should be noted that the tan delta value given is the average value for the circuit.

In ideal terms the diagnostic sequences for the tan delta should be programmed in to the unit it shall be four steps, these steps would be $0.5U_o$, U_o, $1.5U_o$ and $2U_o$. For ease, Tables 13, 14 and 15 have been produced which take into account the age of the cables in the circuit. The phase to earth voltage to be applied has been called Test Voltage.

Tests on any underground cable circuit shall therefore be at the voltage levels that are given in the following Tables 13, 14 and 15. At each voltage level the tan delta test unit shall be programmed to take eight measurements, once the eight measurements have been taken the unit will move to the next test voltage level, the various readings will recorded and evaluated by the unit and then put into the report or file. After the test has been completed a differentiation can be made between new, slightly aged and heavily aged cables.

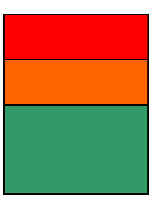
3.5.6 **Evaluation of Tan Delta Results**

Having completed the Tan Delta of the circuit under test, a quick comparison of the three phases to each other as they increase over the voltage range will show if there is an issue with one of the phases. These values should then be checked against the evaluation criteria given below.

3.5.7 **Evaluation criteria: -**

The evaluation criteria for cables that are different from XLPE need to be found and defined by comparing the first 40-50 test results. General criteria as per the PILC example over leaf have to be defined according to the local cable type. It should be noted that EPR cables are completely different from XLPE.

XLPE cables: -



tan delta (2 Uo) > 2,2 %
[tan delta (2 Uo) - tan delta (Uo)] > 1,0 %
tan delta (2 Uo) < 1,2 % and / or
[tan delta (2 Uo) - tan delta (Uo)] < 0,6 %

PILC Cables: -

- > 50 % cable highly degraded, cable overlay is recommended.
- 30 – 50% it is recommended to repeat the TD measurement after 6 – 12 months.
- 20 – 30 % Service aged but still O.K.
- < 10-20 % cable still O.K.
- 10 % cable is in good condition.

Tables13, 14 and 15 give the test voltage levels to be used when Tan Delta testing the various aged and types of 33kV cable, the oldest cable in the circuit will dictate the ruling test voltage level for the circuit.

Table 13. VLF Tan Delta Test Voltage levels for 33kV Polymeric circuits, 33kV mixed circuits varying in age from new to 15 year old cable.

Circuit Type	Voltage Level Ø to E	Test Voltage (V_t)	Test Duration
Each Phase (polymeric)	0.25*2.5U_o	11.8kV	}
Each Phase (mixed)	0.25*2.5U_o	11.8kV	}
Each Phase (paper)	0.25*2.5U_o	11.8kV	} The Tan Delta
Each Phase (polymeric)	0.5*2.5U_o	23.7kV	} Unit will
Each Phase (mixed)	0.5*2.5U_o	23.7kV	} automatically
Each Phase (paper)	0.5*2.5U_o	23.7kV	} take 8 shots at
Each Phase (polymeric)	0.75*2.5U_o	31.6kV	} each voltage level
Each Phase (mixed)	0.75*2.5U_o	31.6kV	} making this test
Each Phase (paper)	0.75*2.5U_o	31.6kV	} about 30 minutes
Each Phase (polymeric)	1*2.5U_o	47.5kV	} long.
Each Phase (mixed)	1*2.5U_o	47.5kV	}
Each Phase (paper)	1*2.5U_o	47.5kV	}

Where U_o = the power frequency voltage between phase and earth.

Table 14. VLF Tan Delta Test Voltage levels for 33kV Polymeric circuits, 33kV mixed circuits varying in age from 16 year old to 29 year old cable.

Circuit Type	Voltage Level Ø to E	Test Voltage (V_t)	Test Duration
Each Phase (polymeric)	0.25*2.2U_o	9.9kV	}
Each Phase (mixed)	0.25*2.2U_o	9.9kV	}
Each Phase (paper)	0.25*2.2U_o	9.9kV	} The Tan Delta
Each Phase (polymeric)	0.5*2.2U_o	19.9kV	} Unit will
Each Phase (mixed)	0.5*2.2U_o	19.9kV	} automatically
Each Phase (paper)	0.5*2.2U_o	19.9kV	} take 8 shots at
Each Phase (polymeric)	0.75*2.2U_o	29.9kV	} each voltage level
Each Phase (mixed)	0.75*2.2U_o	29.9kV	} making this test
Each Phase (paper)	0.75*2.2U_o	29.9kV	} about 30 minutes
Each Phase (polymeric)	1*2.2U_o	39.9kV	} long.
Each Phase (mixed)	1*2.2U_o	39.9kV	}
Each Phase (paper)	1*2.2U_o	39.9kV	}

Where U_o = the power frequency voltage between phase and earth.

Table 15. VLF Tan Delta Test Voltage levels for 33kV Polymeric circuits, 33kV mixed circuit varying in age from 29 year old or older cable.

Circuit Type	Voltage Level Ø to E	Test Voltage (V_t)	Test Duration
Each Phase (polymeric)	0.25*1.7U_o	8.2kV	}
Each Phase (mixed)	0.25*1.7U_o	8.2kV	}
Each Phase (paper)	0.25*1.7U_o	8.2kV	} The Tan Delta
Each Phase (polymeric)	0.5*1.7U_o	16.5kV	} Unit will
Each Phase (mixed)	0.5*1.7U_o	16.5kV	} automatically
Each Phase (paper)	0.5*1.7U_o	16.5kV	} take 8 shots at
Each Phase (polymeric)	0.75*1.7U_o	24.7kV	} each voltage level
Each Phase (mixed)	0.75*1.7U_o	24.7kV	} making this test
Each Phase (paper)	0.75*1.7U_o	24.7kV	} about 30 minutes
Each Phase (polymeric)	1*1.7U_o	32.3kV	} long.
Each Phase (mixed)	1*1.7U_o	32.3kV	}
Each Phase (paper)	1*1.7U_o	32.3kV	}

Where U_o = the power frequency voltage between phase and earth.

3.5.8 **33kV Cable VLF with Partial Discharge Mapping Testing**

This test requires the use of a VLF test set complete with partial discharge mapping (PD mapping) equipment, namely the 'Baur Test Van' purchased to EE 92. This is an off line system of PD measurement system and is designed to locate partial discharges in a cable when used in conjunction with a Baur VLF high voltage generator. Diagnosis of the cable circuit using PD mapping provides 'pin pointed' information on the discharges in the cables and accessories within that circuit, once the circuit has been mapped and the raw data saved, a copy of the raw data can then be manipulated to produce the typical pd map.

As with ordinary VLF testing and tan delta testing the maximum applied voltage to the circuit is dictated by the oldest section of cable in the circuit. Tables 16, 17 and 18 have been produced which take into account the age of the cables in the circuit and which indicate the maximum phase to earth test voltage (V_t) that should be applied to the various cable types.

It is important to ascertain the inception voltage which causes the discharge to occur. A discharge that initiates below U_o is cause for concern, as it will be present under normal service voltage. In ideal terms the voltage test levels for the PD mapping should be four equally spaced steps. For ease, these steps would be $0.5U_o$, U_o, $1.5U_o$ and $2U_o$, at each voltage step the PD mapping unit should be set to take '100 pictures' or events of partial discharge activity.

Tests on any underground cable circuit shall therefore be at the voltage levels that are given in the following Tables 16, 17 and 18. At each voltage level the pd mapping unit shall be programmed to take one hundred measurements, once the hundred measurements have been taken the unit will move to the next test voltage level, the various reading will recorded by the unit until the readings are saved, once saved a duplicated copy of the raw data results shall be evaluated, and put into the report or file.

After the test has been completed the operator can manipulate a copy of the data to produce a PD map of the circuit showing the various locations of the discharges. Most discharges are likely to occur at joint locations, so it is necessary to input all the circuit data required in order for the circuit data to be re-used for future tests on that particular circuit.

3.5.9 **Output from the PD Mapping**

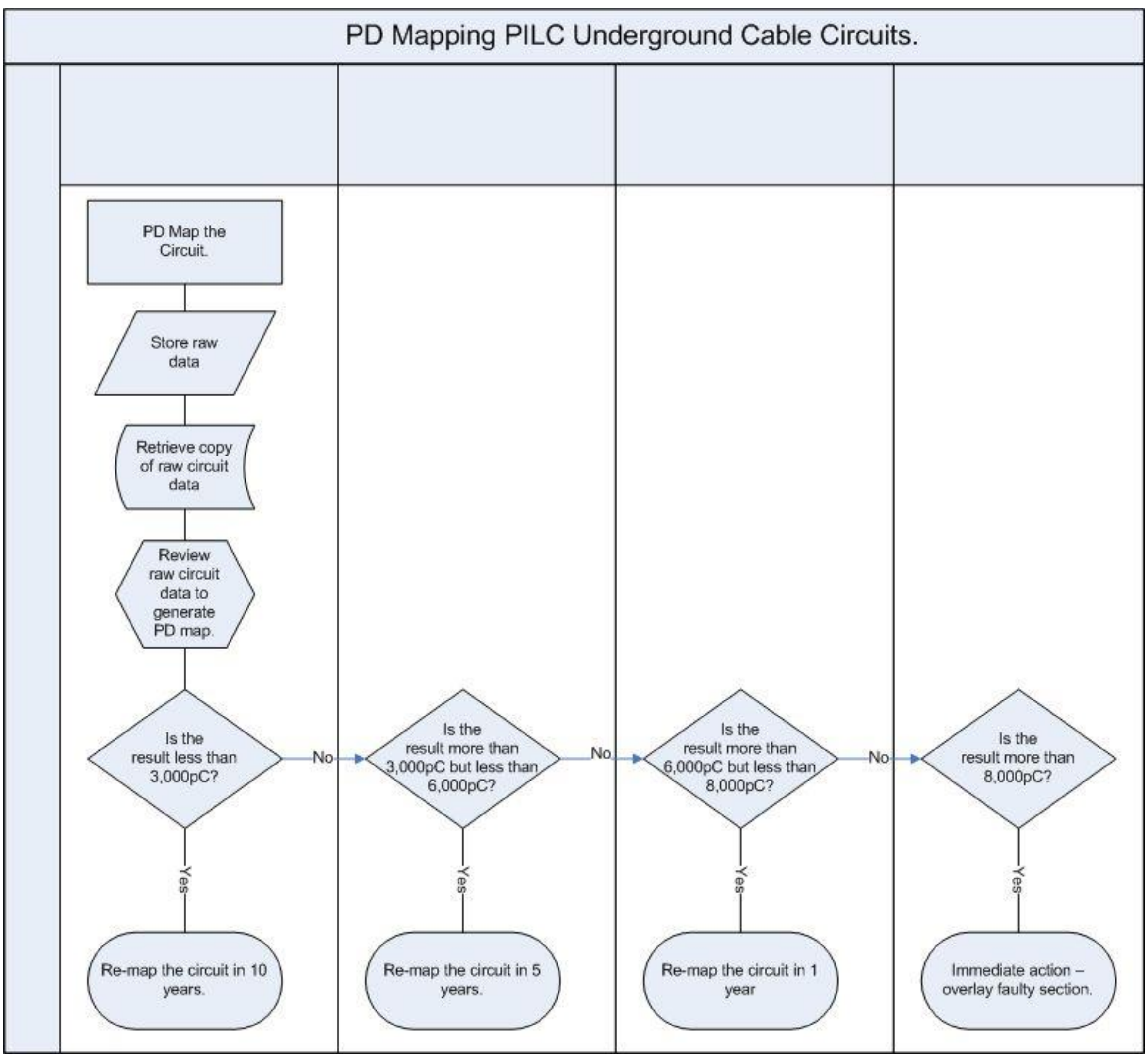
PD mapping technology is proven and has been used throughout the industry over a number of years. The wealth of experience gained over the years provides a high level of confidence in the interpretation of results and the associated conclusion and or recommendations that are given with each report. But the interpretation of the waveforms generated by the PD mapping strongly depends on the knowledge of PD mapping system, and this interpretation requires experience.

The PD mapping technique allows the test voltage to be slowly increased and decreased. Inception and extinction voltages can be recorded which can provide further information with regards to the integrity of the cables installation. The availability to change the test voltage gives the test engineer the flexibility to test to working voltage and record the necessary data before deciding to increase the test voltage still further stressing the insulation and gathering further information.

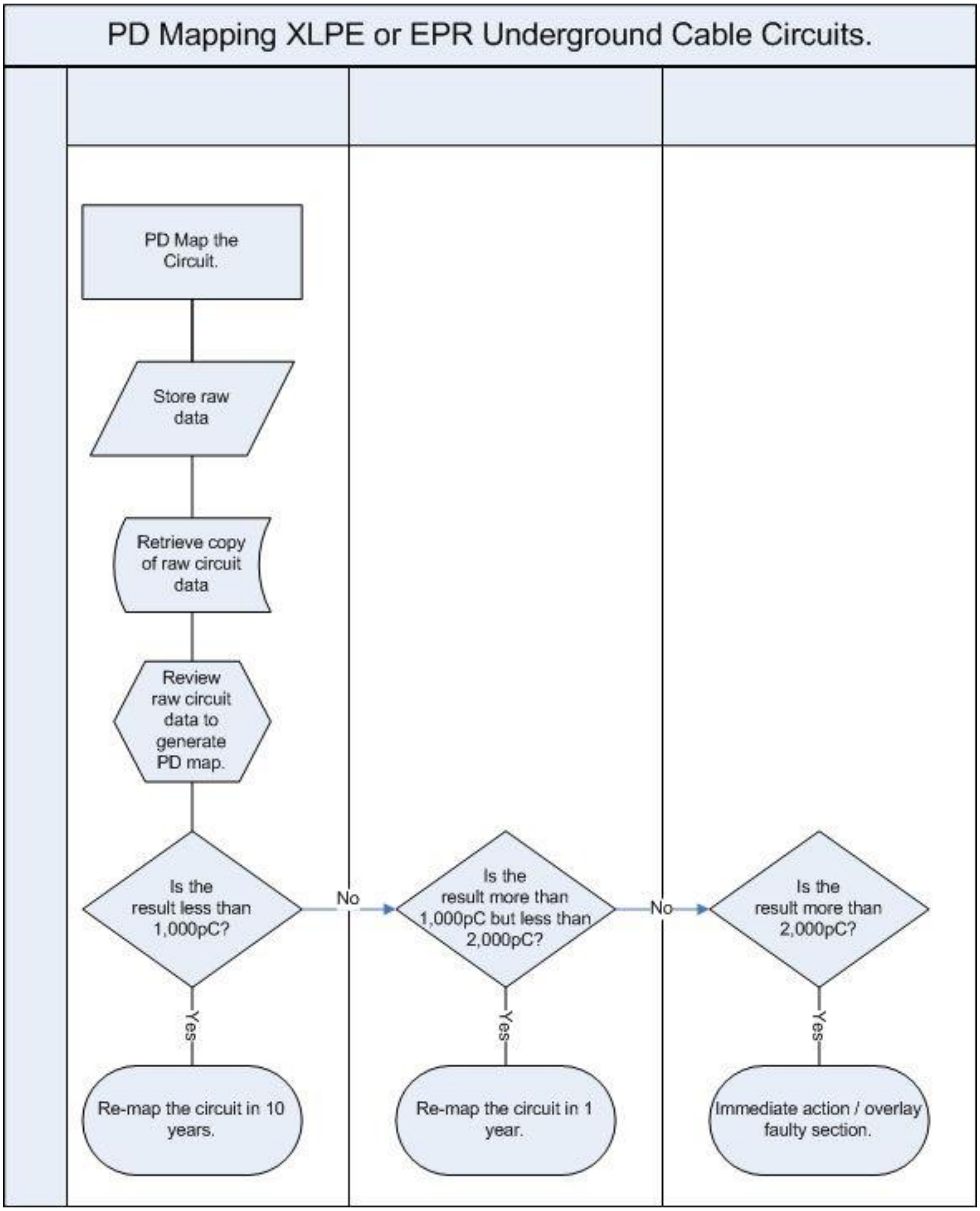
From anecdotal experience the levels of pico Coulombs developed during the testing of the cable circuits will determine the type of response required to prevent the circuits from causing CML’s and CI’s. The Table below gives these typical values: -

	PILC Cable Circuits.		**Clean EPR or XLPE Cable Circuits.**	
Baur PD Mapping	**<3,000pC**	Acceptable level of discharge	**<1,000pC**	Some concern, Monitor / Investigate possible source (normally accessory or termination)
	>3,000pC	Raised concern, Monitor	**>1,000pC**	Increased concern, plan retest in 12 months / repair
	>6,000pC	Increased concern, plan retest in 12 months / repair	**>2,000pC**	Immediate concern, urgent repair.
	>8,000pC	Immediate concern, urgent repair	Not applicable	

Flow diagram for PILC cables.



Flow diagram for EPR or XLPE cables.



See overleaf for the Tables: -

Table 16. PD Mapping VLF Test Voltage levels for 33kV Polymeric circuits, 33kV mixed circuits varying in age from new to 15 year old cable.

Circuit Type	Voltage Level Ø to E	Test Voltage (V_t)	Test Duration
Each Phase (polymeric)	0.25*2.5U_o	11.8kV	}
Each Phase (mixed)	0.25*2.5U_o	11.8kV	}
Each Phase (paper)	0.25*2.5U_o	11.8kV	} The PD mapping
Each Phase (polymeric)	0.5*2.5U_o	23.7kV	} Unit will
Each Phase (mixed)	0.5*2.5U_o	23.7kV	} automatically
Each Phase (paper)	0.5*2.5U_o	23.7kV	} take 100 shots at
Each Phase (polymeric)	0.75*2.5U_o	31.6kV	} each voltage level
Each Phase (mixed)	0.75*2.5U_o	31.6kV	} making this test
Each Phase (paper)	0.75*2.5U_o	31.6kV	} about 30 minutes
Each Phase (polymeric)	1*2.5U_o	47.5kV	} long.
Each Phase (mixed)	1*2.5U_o	47.5kV	}
Each Phase (paper)	1*2.5U_o	47.5kV	}

Where U_o = the power frequency voltage between phase and earth.

Table 17. PD Mapping VLF Test Voltage levels for 33kV Polymeric circuits, 33kV mixed circuits varying in age from 16 year old to 29 year old cable.

Circuit Type	Voltage Level Ø to E	Test Voltage (V_t)	Test Duration
Each Phase (polymeric)	0.25*2.2U_o	9.9kV	}
Each Phase (mixed)	0.25*2.2U_o	9.9kV	}
Each Phase (paper)	0.25*2.2U_o	9.9kV	} The PD mapping
Each Phase (polymeric)	0.5*2.2U_o	19.9kV	} Unit will
Each Phase (mixed)	0.5*2.2U_o	19.9kV	} automatically
Each Phase (paper)	0.5*2.2U_o	19.9kV	} take 100 shots at
Each Phase (polymeric)	0.75*2.2U_o	29.9kV	} each voltage level
Each Phase (mixed)	0.75*2.2U_o	29.9kV	} making this test
Each Phase (paper)	0.75*2.2U_o	29.9kV	} about 30 minutes
Each Phase (polymeric)	1*2.2U_o	39.9kV	} long.
Each Phase (mixed)	1*2.2U_o	39.9kV	}
Each Phase (paper)	1*2.2U_o	39.9kV	}

Where U_o = the power frequency voltage between phase and earth.

Table 18. PD Mapping VLF Test Voltage levels for 33kV Polymeric circuits, 33kV mixed circuit varying in age from 29 year old or older cable.

Circuit Type	Voltage Level Ø to E	Test Voltage (V_t)	Test Duration
Each Phase (polymeric)	$0.25*1.7U_o$	8.2kV	}
Each Phase (mixed)	$0.25*1.7U_o$	8.2kV	}
Each Phase (paper)	$0.25*1.7U_o$	8.2kV	} The PD mapping
Each Phase (polymeric)	$0.5*1.7U_o$	16.5kV	} Unit will
Each Phase (mixed)	$0.5*1.7U_o$	16.5kV	} automatically
Each Phase (paper)	$0.5*1.7U_o$	16.5kV	} take 100 shots at
Each Phase (polymeric)	$0.75*1.7U_o$	24.7kV	} each voltage level
Each Phase (mixed)	$0.75*1.7U_o$	24.7kV	} making this test
Each Phase (paper)	$0.75*1.7U_o$	24.7kV	} about 30 minutes
Each Phase (polymeric)	$1*1.7U_o$	32.3kV	} long.
Each Phase (mixed)	$1*1.7U_o$	32.3kV	}
Each Phase (paper)	$1*1.7U_o$	32.3kV	}

Where U_o = the power frequency voltage between phase and earth.

3.5.10 11kV POLYMERIC CABLE CIRCUITS and MIXED CABLE CIRCUITS

Basic VLF Testing

After the polymeric cable, or mixed cable, circuit has been jointed and is ready for final commissioning, the circuit shall be tested using VLF AC test methods. The portable VLF set capable of testing 11kV cables or the “Baur Cable Test van” which has the VLF test set fitted should be used. The ‘plain’ VLF method provides a "go" or "no go" appraisal of the cable circuit under test. It should be noted that a VLF test can be used on all polymeric cables, mixed paper and polymeric cables, and just plain paper cables.

The voltage levels to be applied to the circuits under test are given in Tables 19, 20 and 21. Test voltage levels vary, with the age of the oldest piece of cable in the circuit determining the maximum test voltage level that may be applied. As the majority of the existing paper cable circuits are of the belted design, the following procedure shall be used for testing all polymeric cable circuits, mixed cable circuits and paper cable circuits with the VLF test set: -

Phase 1 Under Test: - Phases 2 and 3 shorted together and connected to earth, with the relevant voltage applied to Phase 1 for 30 minutes.

Phase 2 Under Test: - Phases 1 and 3 shorted together and connected to earth, with the relevant voltage applied to Phase 2 for 30 minutes.

Phase 3 Under Test: - Phases 1 and 2 shorted together and connected to earth, with the relevant voltage applied to Phase 3 for 30 minutes.

The test voltages values given in the following Tables 19 up to and including 25 are **peak to peak** voltage levels.

Table 19. VLF Test Voltage levels for 11kV Polymeric circuits, 11kV mixed circuits varying in age from new to 15 year old cable.

Circuit	Voltage Level Ø to E		Test Duration
Each Phase (polymeric)	2.5 U_o	15.9kV	30 minutes
Each Phase (mixed)	2.5 U_o	15.9kV	30 minutes
Each Phase (paper)	2.5 U_o	15.9kV	30 minutes

Where U_o = the power frequency voltage between phase and earth.

Table 20. VLF Test Voltage levels for 11kV Polymeric circuits, 11kV mixed circuits varying in age from 16 year old to 29 year old cable.

Circuit	Voltage Level Ø to E		Test Duration
Each Phase (polymeric)	2.1 U_o	13.3kV	30 minutes
Each Phase (mixed)	2.1 U_o	13.3kV	30 minutes
Each Phase (paper)	2.1 U_o	13.3kV	30 minutes

Where U_o = the power frequency voltage between phase and earth.

Table 21. VLF Test Voltage levels for 11kV Polymeric circuits, 11kV mixed circuit varying in age from 29 year old or older cable.

Circuit	Voltage Level Ø to E		Test Duration
Each Phase (polymeric)	1.7 U_o	10.8kV	30 minutes
Each phase (mixed)	1.7U_o	10.8kV	30 minutes
Each Phase (paper)	1.7 U_o	10.8kV	30 minutes

Where U_o = the power frequency voltage between phase and earth.

3.5.11 **11kV cable VLF with Tan Delta Testing**

A VLF test set complete with the tan delta is required for this test. Diagnosis of the cable circuit using tan delta measurement provides differentiated information on the ageing of the cables within that circuit. See Figure 4 for typical tan delta measurements for a polymeric cable, on page 17 of this document. It should be noted that the tan delta value given is the average value for the circuit.

The diagnostic sequences for the tan delta can be programmed in to the unit, it shall be four steps, these steps would be $0.5U_o$, U_o, $1.5U_o$ and $2U_o$ at the respective testing levels, to make things easier Tables 21, 22 and 23 have been produced which take into account the age of the cables in the circuit for the test voltage to be applied. The phase to earth voltage to be applied has been called Test Voltage.

3.5.12 Evaluation of Tan Delta Results

Having completed the Tan Delta of the circuit under test, a quick comparison of the three phases to each other as they increase over the voltage range will show if there is an issue with one of the phases. These values should then be checked against the evaluation criteria given below.

3.5.13 Evaluation criteria: -

The evaluation criteria for cables that are different from XLPE need to be found and defined by comparing the first 40-50 test results. General criteria as per the PILC example over leaf have to be defined according to the local cable type. It should be noted that EPR cables are completely different from XLPE.

XLPE cables: -

tan delta (2 Uo) > 2,2 %

[tan delta (2 Uo) - tan delta (Uo)] > 1,0 %

tan delta (2 Uo) < 1,2 % and / or

[tan delta (2 Uo) - tan delta (Uo)] < 0,6 %

PILC Cables: -

> 50 % cable highly degraded, cable overlay is recommended.

30 – 50% it is recommended to repeat the TD measurement after 6 – 12 months.

20 – 30 % Service aged but still O.K.

< 10-20 % cable still O.K.

10 % cable is in good condition.

Tests on any underground cable circuit shall therefore be at the voltage levels that are given in the following Tables 22, 23 and 24. At each voltage level the tan delta test unit shall be programmed to take eight measurements. Once the eight measurements have been taken the unit will move to the next test voltage level, the various reading will recorded by the unit and then they will be evaluated by the unit and put into the report or file. After the test has been completed a differentiation can be made between new, slightly aged and heavily aged cables.

Table 22. VLF Tan Delta Test Voltage levels for 11kV Polymeric circuits, 11kV mixed circuits varying in age from new to 15 year old cable.

Circuit Type	Voltage Level Ø to E	Test Voltage (V_t)	Test Duration
Each Phase (polymeric)	$0.25*2.5U_o$	3.9kV	}
Each Phase (mixed)	$0.25*2.5U_o$	3.9kV	}
Each Phase (paper)	$0.25*2.5U_o$	3.9kV	} The Tan Delta
Each Phase (polymeric)	$0.5*2.5U_o$	7.9kV	} Unit will
Each Phase (mixed)	$0.5*2.5U_o$	7.9kV	} automatically
Each Phase (paper)	$0.5*2.5U_o$	7.9kV	} take 8 shots at
Each Phase (polymeric)	$0.75*2.5U_o$	11.9kV	} each voltage level
Each Phase (mixed)	$0.75*2.5U_o$	11.9kV	} making this test
Each Phase (paper)	$0.75*2.5U_o$	11.9kV	} about 30 minutes
Each Phase (polymeric)	$1*2.5U_o$	15.9kV	} long.
Each Phase (mixed)	$1*2.5U_o$	15.9kV	}
Each Phase (paper)	$1*2.5U_o$	15.9kV	}

Where U_o = the power frequency voltage between phase and earth.

Table 23. VLF Tan Delta Test Voltage levels for 11kV Polymeric circuits, 11kV mixed circuits varying in age from 16 year old to 29 year old cable.

Circuit Type	Voltage Level Ø to E	Test Voltage (V_t)	Test Duration
Each Phase (polymeric)	$0.25*2.2U_o$	3.4kV	}
Each Phase (mixed)	$0.25*2.2U_o$	3.4kV	}
Each Phase (paper)	$0.25*2.2U_o$	3.4kV	} The Tan Delta
Each Phase (polymeric)	$0.5*2.2U_o$	6.7kV	} Unit will
Each Phase (mixed)	$0.5*2.2U_o$	6.7kV	} automatically
Each Phase (paper)	$0.5*2.2U_o$	6.7kV	} take 8 shots at
Each Phase (polymeric)	$0.75*2.2U_o$	10.1kV	} each voltage level
Each Phase (mixed)	$0.75*2.2U_o$	10.1kV	} making this test
Each Phase (paper)	$0.75*2.2U_o$	10.1kV	} about 30 minutes
Each Phase (polymeric)	$1*2.2U_o$	13.3kV	} long.
Each Phase (mixed)	$1*2.2U_o$	13.3kV	}
Each Phase (paper)	$1*2.2U_o$	13.3kV	}

Where U_o = the power frequency voltage between phase and earth.

Table 24. VLF Tan Delta Test Voltage levels for 11kV Polymeric circuits, 11kV mixed circuit varying in age from 29 year old or older cable.

Circuit Type	Voltage Level Ø to E	Test Voltage (V_t)	Test Duration
Each Phase (polymeric)	$0.25*1.7U_o$	2.7kV	}
Each Phase (mixed)	$0.25*1.7U_o$	2.7kV	}
Each Phase (paper)	$0.25*1.7U_o$	2.7kV	} The Tan Delta
Each Phase (polymeric)	$0.5*1.7U_o$	5.4kV	} Unit will
Each Phase (mixed)	$0.5*1.7U_o$	5.4kV	} automatically
Each Phase (paper)	$0.5*1.7U_o$	5.4kV	} take 8 shots at
Each Phase (polymeric)	$0.75*1.7U_o$	8.1kV	} each voltage level
Each Phase (mixed)	$0.75*1.7U_o$	8.1kV	} making this test
Each Phase (paper)	$0.75*1.7U_o$	8.1kV	} about 30 minutes
Each Phase (polymeric)	$1*1.7U_o$	10.8kV	} long.
Each Phase (mixed)	$1*1.7U_o$	10.8kV	}
Each Phase (paper)	$1*1.7U_o$	10.8kV	}

Where U_o = the power frequency voltage between phase and earth.

3.5.14 **11kV Cable VLF with Partial Discharge Mapping Testing**

This test requires the use of a VLF test set complete with PD mapping equipment, namely the 'Baur Test Van'. The PD measurement system is designed to locate partial discharges in a cable and to be used with a Baur VLF high voltage generator. Diagnosis of the cable circuit using PD mapping provides 'pin pointed' information on the discharges in the cables and accessories within that circuit.

As with ordinary VLF testing and tan delta testing the maximum applied voltage to the circuit is too dictated by the oldest section of cable in the circuit. Tables 25, 26 and 27 have been produced to indicate the maximum phase to Earth test voltage (V_t), to be applied to the various cable types. It is important to ascertain the inception voltage which causes the discharge to occur. A discharge that initiates below U_o is cause for concern, as it will be present under normal service voltage. In ideal terms the voltage test levels for the PD mapping should be four equally spaced steps, these steps would be $0.5U_o$, U_o, $1.5U_o$ and $2U_o$, at each voltage step the pd mapping unit should be set to take '100 pictures' or events of partial discharge activity.

Tests on any underground cable circuit shall therefore be at the voltage levels that are given in the following Tables 25, 26 and 27. At each voltage level the pd mapping unit shall be programmed to take 100 measurements, once the measurements have been taken the unit will move to the next test voltage level, the various readings will be recorded by the unit until the readings are saved, once saved a copy of the results will be evaluated, and put into the report or file. After the test has been completed the operator can copy the data and 'manipulate' it to produce a PD map of the circuit showing the various locations of the discharges.

3.5.15 **Output from the PD Mapping**

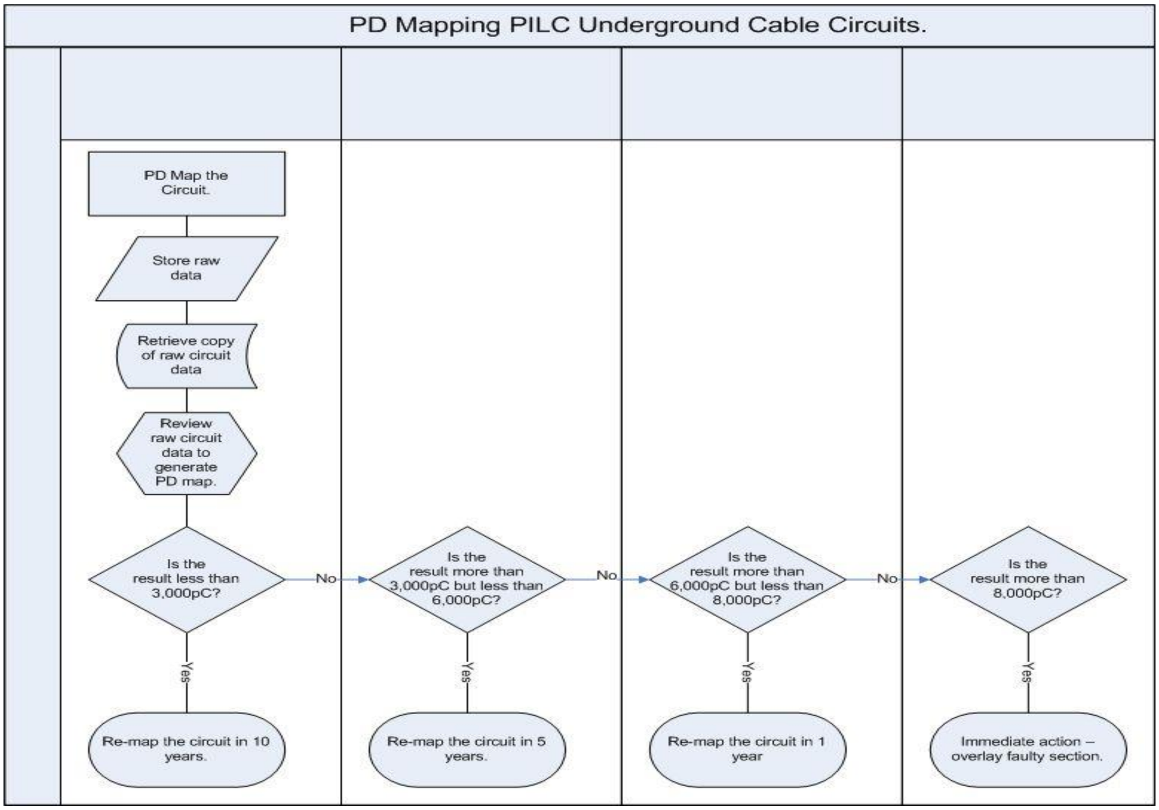
PD mapping technology is proven and has been used throughout the industry over a number of years. The wealth of experience gained over the years provides a high level of confidence in the interpretation of results and the associated conclusion and or recommendations that are given with each report. But the interpretation of the waveforms generated by the PD mapping strongly depends on the knowledge of PD mapping system, and this interpretation requires experience.

The PD mapping technique allows the test voltage to be slowly increased and decreased. Inception and extinction voltages can be recorded which can provide further information with regards to the integrity of the cables installation. The availability to change the test voltage gives the test engineer the flexibility to test to working voltage and record the necessary data before deciding to increase the test voltage still further stressing the insulation and gathering further information.

From anecdotal experience the levels of pico Coulombs developed during the testing of the cable circuits will determine the type of response required to prevent the circuits from causing CML's and CI's. The Table below gives these typical values: -

	PILC Cable Circuits.		**Clean EPR or XLPE Cable Circuits.**	
Baur PD Mapping	**<3,000pC**	Acceptable level of discharge	**<1,000pC**	Some concern, Monitor / Investigate possible source (normally accessory or termination)
	>3,000pC	Raised concern, Monitor	**>1,000pC**	Increased concern, plan retest in 12 months / repair
	>6,000pC	Increased concern, plan retest in 12 months / repair	**>2,000pC**	Immediate concern, urgent repair.
	>8,000pC	Immediate concern, urgent repair	Not applicable	

Flow diagram for PILC cables.



Flow diagram for XLPE or EPR cables.

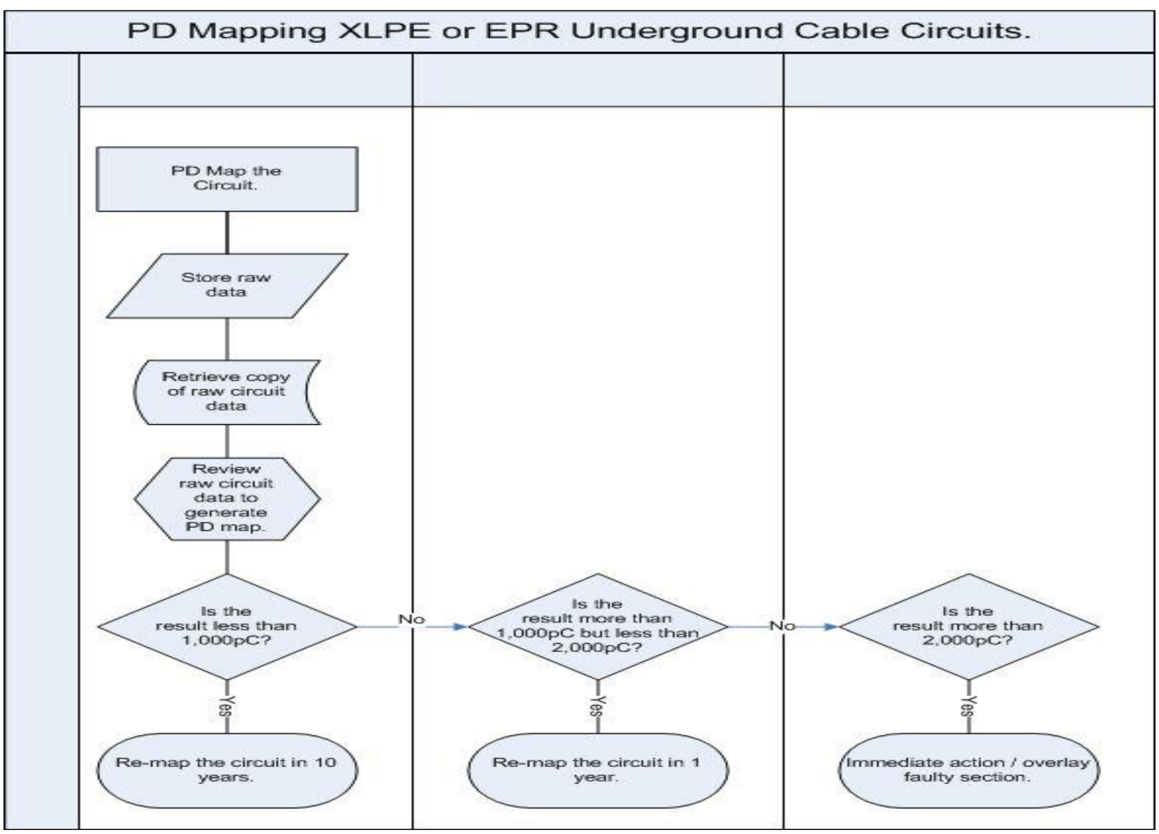


Table 25. PD Mapping VLF Test Voltage levels for 11kV Polymeric circuits, 11kV mixed circuits varying in age from new to 15 year old cable.

Circuit Type	Voltage Level Ø to E	Test Voltage (V_t)	Test Duration
Each Phase (polymeric)	$0.25*2.5U_o$	3.9kV	}
Each Phase (mixed)	$0.25*2.5U_o$	3.9kV	}
Each Phase (paper)	$0.25*2.5U_o$	3.9kV	} The PD mapping
Each Phase (polymeric)	$0.5*2.5U_o$	7.9kV	} Unit will
Each Phase (mixed)	$0.5*2.5U_o$	7.9kV	} automatically
Each Phase (paper)	$0.5*2.5U_o$	7.9kV	} take 100 shots at
Each Phase (polymeric)	$0.75*2.5U_o$	11.9kV	} each voltage level
Each Phase (mixed)	$0.75*2.5U_o$	11.9kV	} making this test
Each Phase (paper)	$0.75*2.5U_o$	11.9kV	} about 30 minutes
Each Phase (polymeric)	$1*2.5U_o$	15.9kV	} long.
Each Phase (mixed)	$1*2.5U_o$	15.9kV	}
Each Phase (paper)	$1*2.5U_o$	15.9kV	}

Where U_o = the power frequency voltage between phase and earth.

Table 26. AC PD Mapping VLF Test Voltage levels for 11kV Polymeric circuits, 11kV mixed circuits varying in age from 16 year old to 29 year old cable.

Circuit Type	Voltage Level Ø to E	Test Voltage (V_t)	Test Duration
Each Phase (polymeric)	$0.25*2.2U_o$	3.4kV	}
Each Phase (mixed)	$0.25*2.2U_o$	3.4kV	}
Each Phase (paper)	$0.25*2.2U_o$	3.4kV	} The PD mapping
Each Phase (polymeric)	$0.5*2.2U_o$	6.7kV	} Unit will
Each Phase (mixed)	$0.5*2.2U_o$	6.7kV	} automatically
Each Phase (paper)	$0.5*2.2U_o$	6.7kV	} take 100 shots at
Each Phase (polymeric)	$0.75*2.2U_o$	10.1kV	} each voltage level
Each Phase (mixed)	$0.75*2.2U_o$	10.1kV	} making this test
Each Phase (paper)	$0.75*2.2U_o$	10.1kV	} about 30 minutes
Each Phase (polymeric)	$1*2.2U_o$	13.3kV	} long.
Each Phase (mixed)	$1*2.2U_o$	13.3kV	}
Each Phase (paper)	$1*2.2U_o$	13.3kV	}

Where U_o = the power frequency voltage between phase and earth.

Table 27. AC PD Mapping VLF Test Voltage levels for 11kV Polymeric circuits, 11kV mixed circuit varying in age from 29 year old or older cable.

Circuit Type	Voltage Level Ø to E	Test Voltage (V_t)	Test Duration
Each Phase (polymeric)	$0.25*1.7U_o$	2.7kV	}
Each Phase (mixed)	$0.25*1.7U_o$	2.7kV	}
Each Phase (paper)	$0.25*1.7U_o$	2.7kV	} The PD mapping
Each Phase (polymeric)	$0.5*1.7U_o$	5.4kV	} Unit will
Each Phase (mixed)	$0.5*1.7U_o$	5.4kV	} automatically
Each Phase (paper)	$0.5*1.7U_o$	5.4kV	} take 100 shots at
Each Phase (polymeric)	$0.75*1.7U_o$	8.1kV	} each voltage level
Each Phase (mixed)	$0.75*1.7U_o$	8.1kV	} making this test
Each Phase (paper)	$0.75*1.7U_o$	8.1kV	} about 30 minutes
Each Phase (polymeric)	$1*1.7U_o$	10.8kV	} long.
Each Phase (mixed)	$1*1.7U_o$	10.8kV	}
Each Phase (paper)	$1*1.7U_o$	10.8kV	}

Where U_o = the power frequency voltage between phase and earth.

If it is not reasonably practicable to use AC testing methods on the polymeric or mixed circuits, then a 5kV insulation resistance tester shall be used to determine whether or not gross errors have occurred during the jointing of the cables. The 5kV insulation resistance tester shall be used phase to Earth and phase to phase.

NOTE: - It should be noted that this dispensation for using the 5kV Megger is NOT a means of circumventing the AC testing methods of circuits, it has been written into policy to allow some form of testing to an underground cable circuit if AC testing physically cannot be undertaken on a particular circuit in question ONLY.

3.6 Testing of Cable and Plant fitted with Separable Connectors

Background

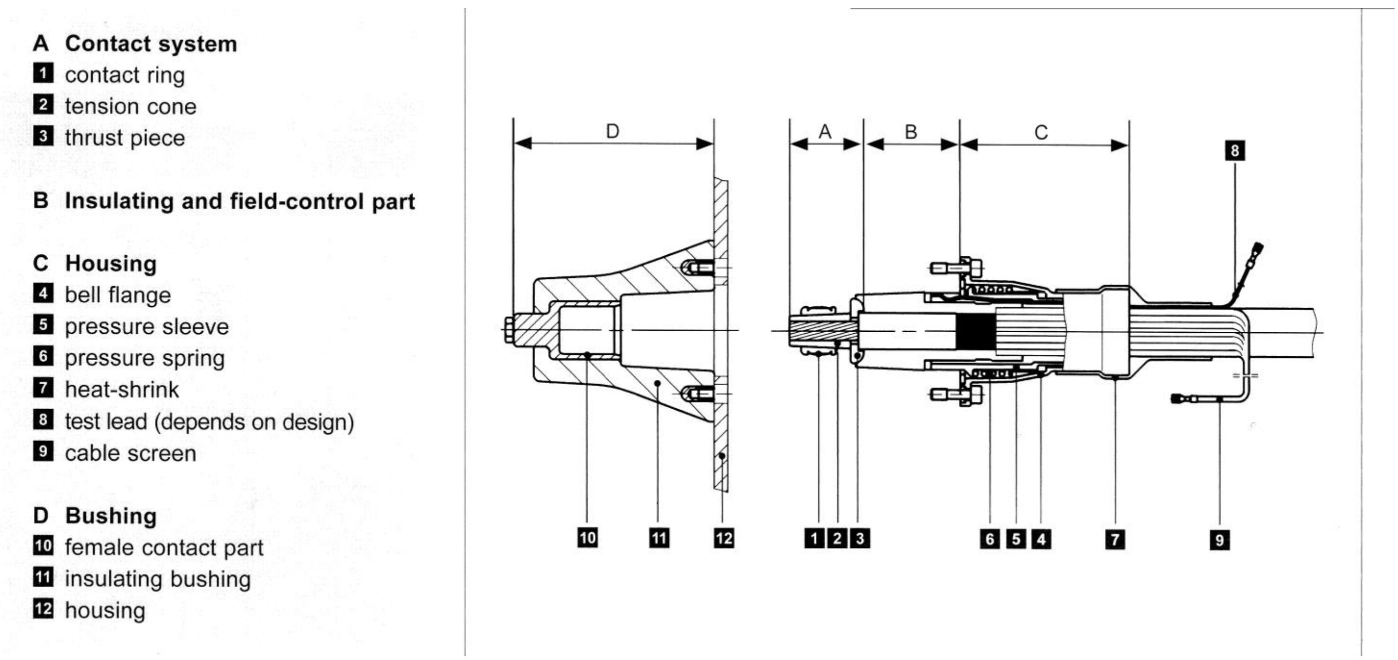
There are two types of separable connectors, both of which comply with EN 50180 and EN 50181; these separable connectors can be connected to cables and plant and can be sub-divided into ***inner cone*** separable connectors, in WPD these are usually, dead break, size 3, Pfisterer type connectors and are rated at 1250A at 33kV; or the ***outer cone,*** with outer cone there can be live break or dead break, separable connectors, in WPD these outer cone are usually the dead break, Euromold/Nexans separable connectors. The outer cones can then be further sub-divided into five differing types of outer cone, the one standardised on by WPD is the interface C. The interface C connector comes in two current ratings the 430 version which is rated at 630A and the 400/440 version which is 1250A.

The methods described in this document only cover the Pfisterer size 3 and Euromold interface C separable connectors, with the other Euromold interfaces the same principles that are applicable to interface C outer cone connectors would apply.

Note: - With both Pfisterer and Euromold products when installing any accessories the accessories SHALL be clean and ONLY grease supplied by the respective supplier shall be used to lubricate the accessories prior to insertion and re-assembly of the device after testing. Accessories when not in use shall be kept in a clean, dry & dust free environment.

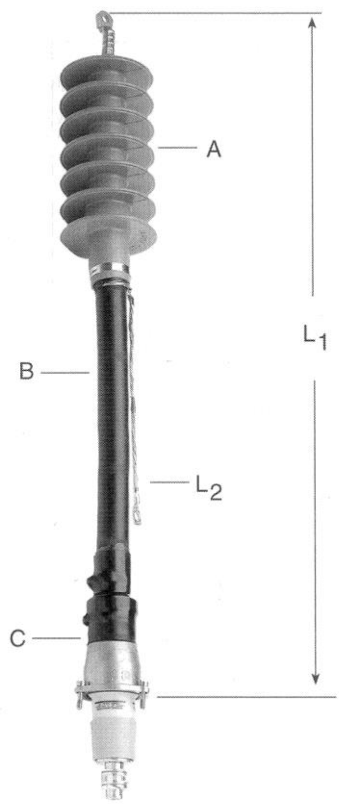
3.6.1 **Inner Cone Separable Connectors**

A sectioned view of the inner cone or Pfisterer connector is shown below: -



The section D on the above picture shows the inner cone prior to its attachment to the bushing mounted on the plant and is known as the equipment interface. When carrying out commissioning tests or fault location on the plant with no cables connected then size 3 dummy cable connectors shall be inserted into the equipment interface and torqued into place to prevent a flash over. See the picture below of the dummy cable connector.

Dummy Cable Connector.



When carrying out tests on the plant where there is no means of applying a test voltage to the plant then it is possible to connect to the equipment interface and torque into place a size 3 Connex test cable connector to the equipment interface, this allows voltage tests and partial discharge tests on transformers or gas insulated switchgear. See the picture of the Connex test cable connector.

Connex test cable connector

When testing or fault location on an underground cable circuit from the remote end of the circuit and there is no means of isolating the cable from the plant e.g. by opening a set of links or isolator on the plant thereby isolating the cable from the plant, then it will be necessary to disconnect the separable connector from the equipment interface. Once the cable has been disconnected from the equipment interface, it is necessary to then fit and torque into place a size 3 blind cap over the size 3 separable connector which is fitted to the cable. For clarity see the picture of the blind cap below.

Blind Cap.

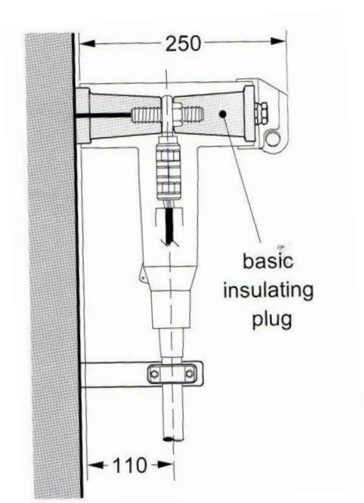
Cable testing socket.

When testing or fault locating on an underground cable circuit from the near end of the circuit and the remote end is isolatable, if there is no means of disconnecting the cable from the plant e.g. by opening a set of links or isolator on the plant thereby isolating the cable from the plant, then it will be necessary to disconnect the separable connector from the equipment interface. Once the cable has been disconnected from the equipment interface, then fit and torque into place a size 3 cable testing socket over the size 3 separable connector which is fitted to the cable.

It should be noted that cable test socket is NOT touch-proof. After testing, the test socket must be earthed and short circuited. The cable test socket is not suitable for partial discharge measurements.

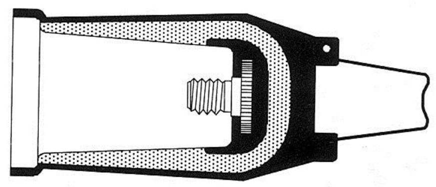
3.6.2 **Outer Cones Separable Connectors**

A sectioned view of the outer cone or Euromold 400/440 series connector is shown below: -



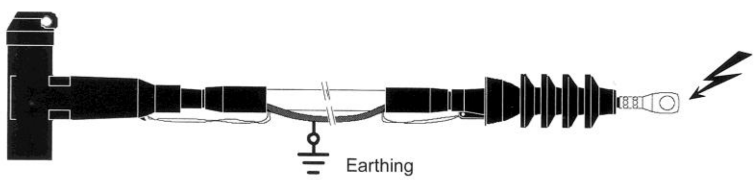
Sectional view of an interface C, 400 / 440 series connector.

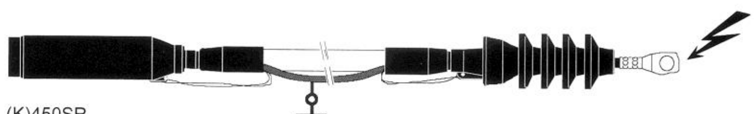
The sectional picture of an interface C 400 / 440 connector shows the outer cone separable connector attached to the bushing mounted on the plant and is known as the equipment interface. When carrying out commissioning tests or fault location on the plant with no cables connected then an interface C Dead-end receptacle connectors shall be inserted into the equipment interface and torqued into place to prevent a flash over. See the picture below of the dummy cable connector.



Interface C Dead-end receptacle.

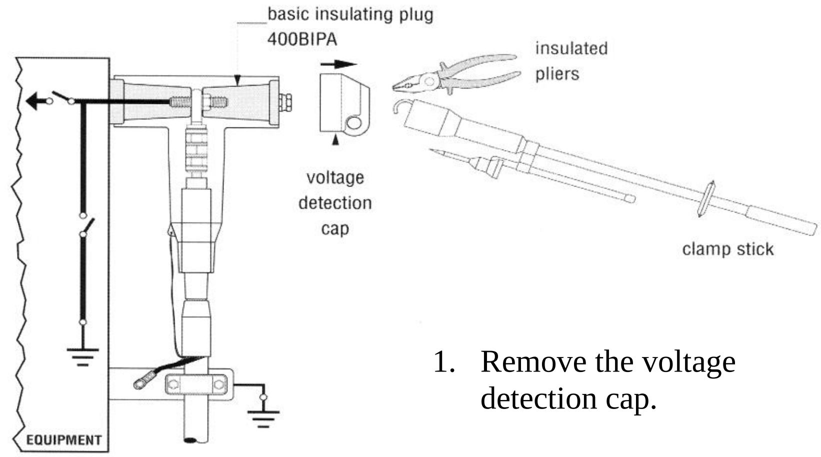
When carrying out tests on the plant where there is no means of applying a test voltage to the plant then it is possible to connect to the equipment interface and torque into place a size 3 Connex test cable connector to the equipment interface, this allows voltage tests and partial discharge tests on transformers or gas insulated switchgear. See the picture below of the Connex test cable connector.



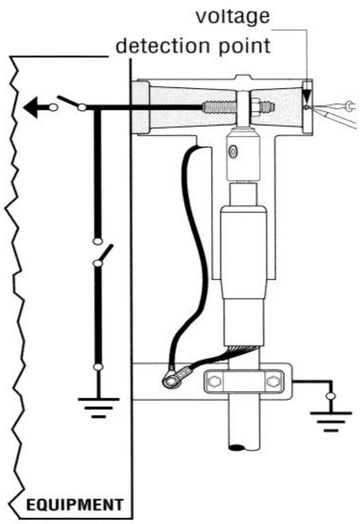


When testing or fault locating on an underground cable circuit from the near end of the circuit and the remote end is isolatable, if there is no means of disconnecting the cable from the plant e.g. by opening a set of links or isolator on the plant thereby isolating the cable from the plant, then it will be necessary to disconnect the separable connector from the equipment interface. Once the cable has been disconnected from the equipment interface, then fit and torque into place a 400TR test rod into the interface C separable connector which is fitted to the cable.

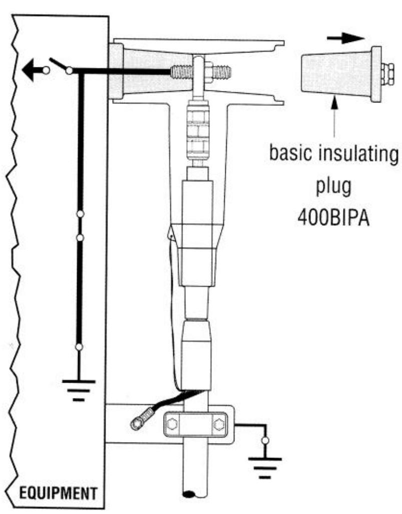
A. 400TB & 440TB connectors



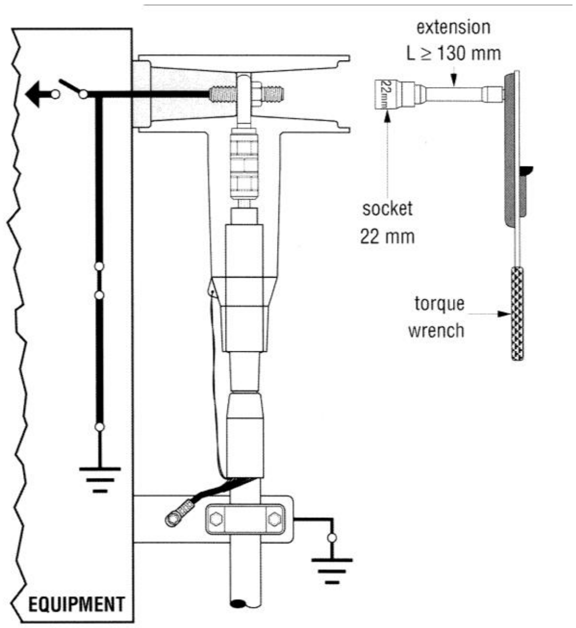
1. Remove the voltage detection cap.



2. Check there is no voltage present on the voltage detection point.

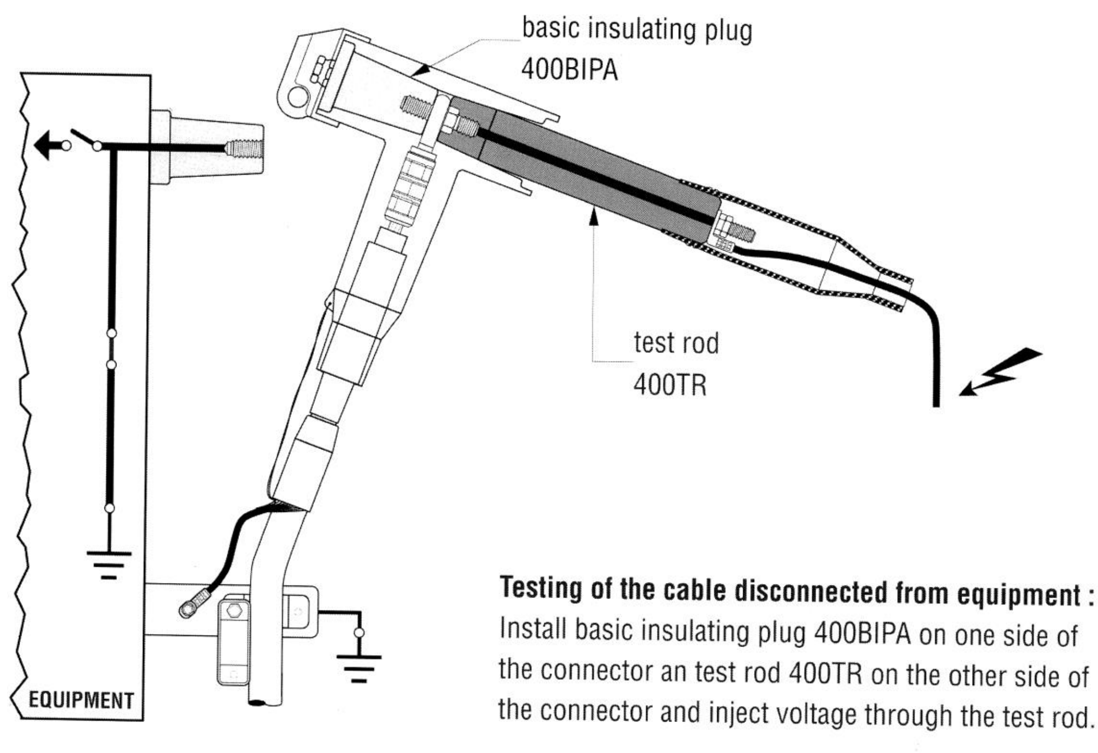


3. Remove the 400 BIPA basic insulation plug using a 22mm socket



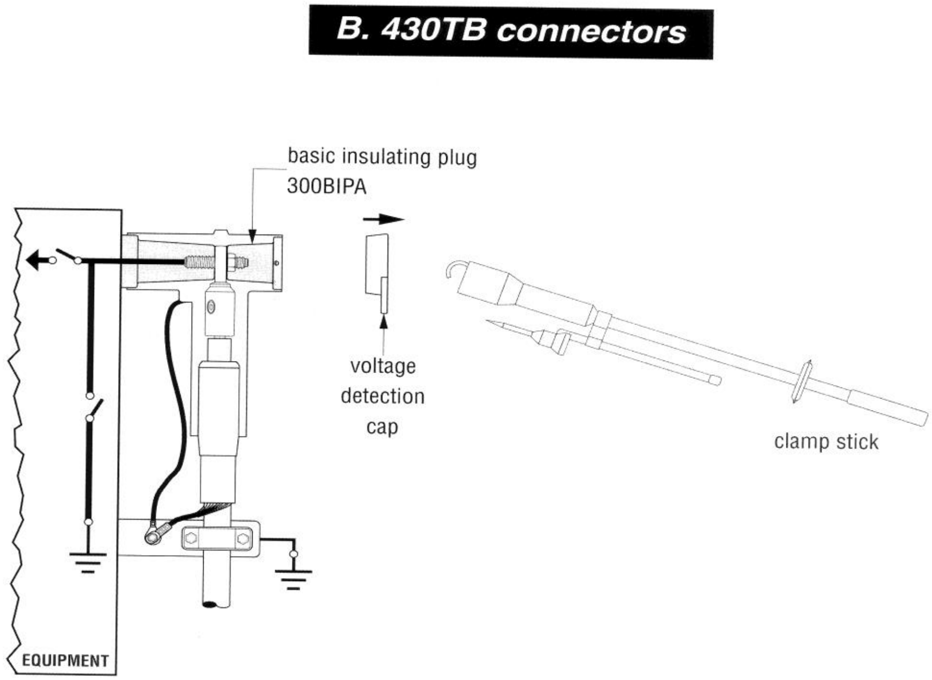
4. Remove the coupling screw

5. Remove the separable connector from the equipment interface and insert the 400BIPA into one side of the separable connector and the test rod 400TR on the other side of the connector and inject voltage through the test rod.

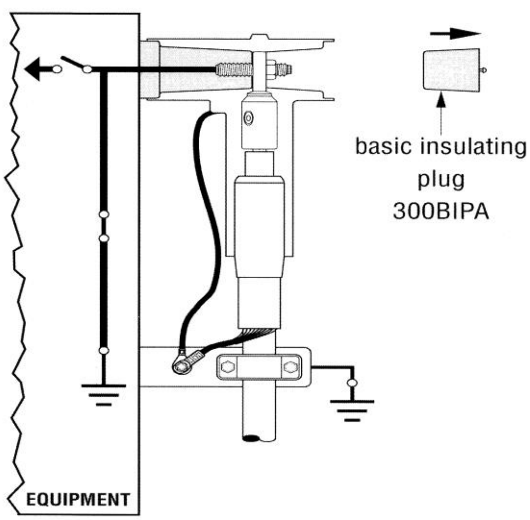


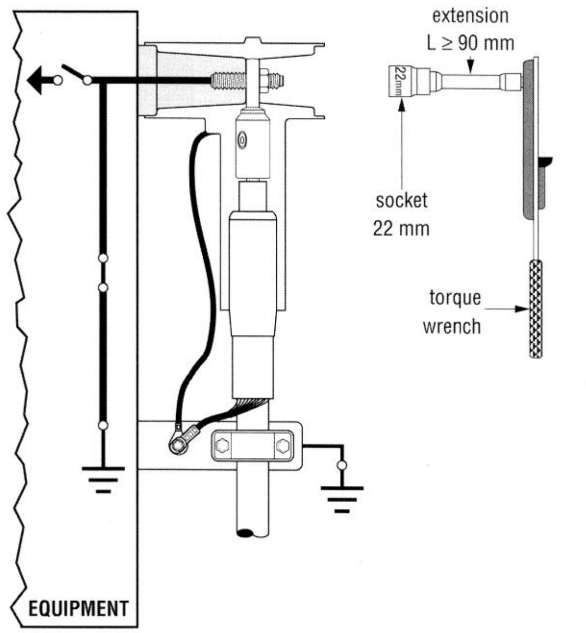
With the 430 TB connectors a slightly different approach has to be adopted.

1. Remove the voltage detection cap.



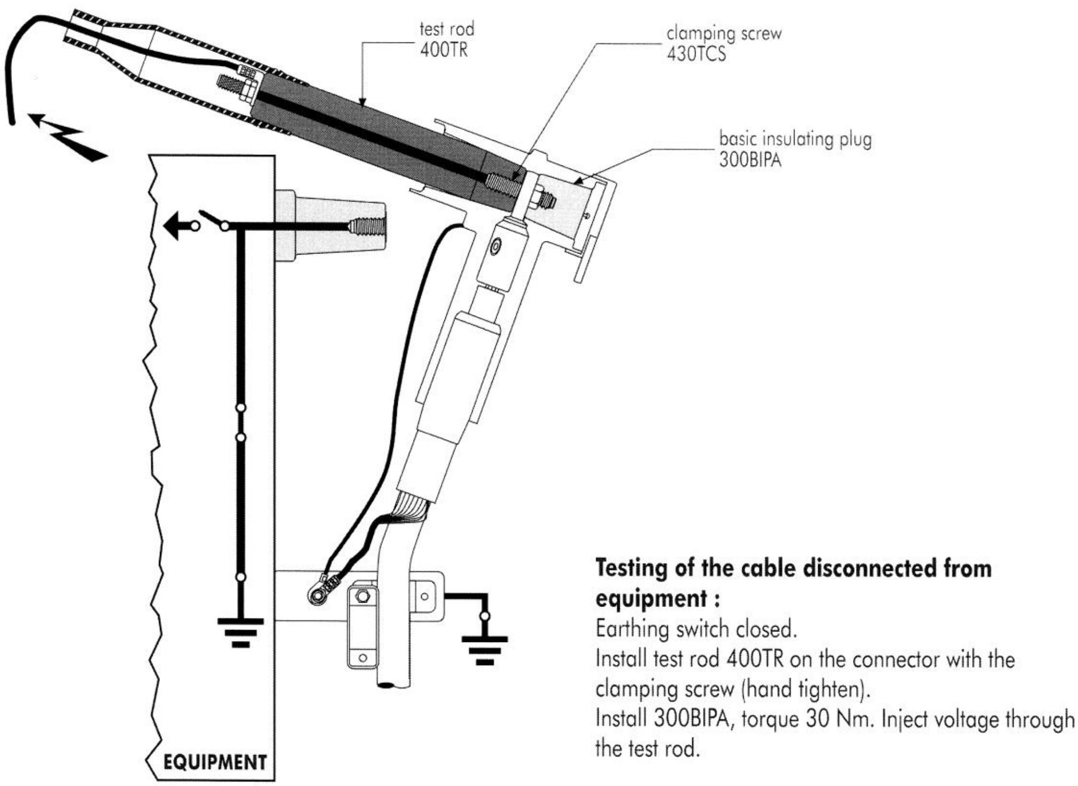
2. Check there is no voltage present on the voltage detection point.
3. Remove the 300 BIPA basic insulation plug using a 22mm socket.



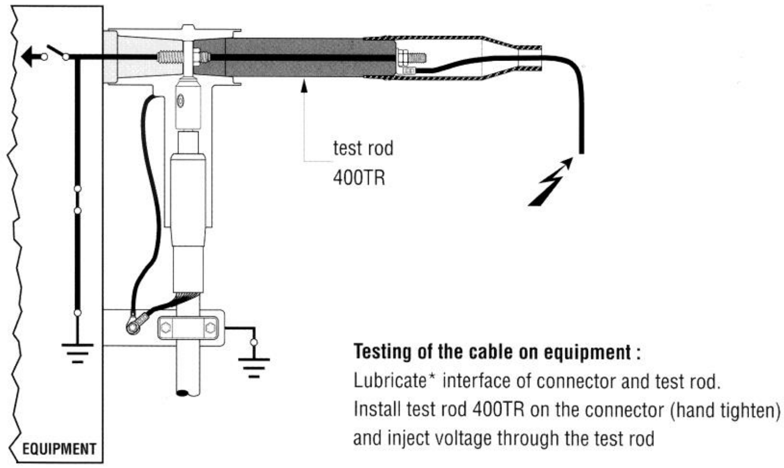


4. Remove the coupling screw.

4. Remove the separable connector from the equipment interface and insert the 300BIPA into the separable connector and torque to 30Nm, insert the test rod 400TR on the other side of the connector and hand tighten, inject voltage through the test rod.



When testing or fault location on an underground cable circuit from the remote end of the circuit and there is means of isolating the cable from the plant e.g. by opening a set of links or isolator on the plant thereby isolating the cable from the plant, then it will be necessary to disconnect the 300 or 400 BIPA and insert the 400TR into the back of separable connector.



3.7 Overhead Lines

Overhead lines are difficult to pressure test and the results obtained depend to a great extent on the weather conditions, the number of parallel paths to Earth, and the condition of the insulator surfaces. It is often possible to apply a 15 minute ac pressure test to a 33kV line, but this is rarely so in the case of lower voltage HV lines.

Any new length of HV line, or section of HV line which has been subject to alteration or repair, shall be inspected from the ground by a Senior Authorised Person shortly before commissioning. The details of the inspection shall be recorded together with the details of any electrical test applied. The HV Test Certificate (Remarks Section) shall be used for this purpose. Any new 33kV line shall also be subjected to a 15 minute ac pressure test, or, if this is not reasonably practicable, it shall be tested with a 5kV insulation tester for one minute between phases, and each phase to earth.

Table 28. AC Test before 33kV Line is connected

System Voltage	Test Voltage		Test Duration
	Ø - Ø	Ø - E	
33 kV	41.3 kV rms	23.9 kV rms	AC test for 15 minutes

All additional or replacement pole mounted plant shall be subjected to 5kV insulation tests on-site immediately before erection on the pole.

3.8 **Surge Diverters**

All additional or replacement surge diverters shall be subjected to 5kV insulation for 1 minute test on site immediately before erection.

Surge diverters shall not be subjected to test voltages specified for transformers, switchgear or underground cables. When it is necessary to apply HV tests to such plant any associated surge diverters shall first be disconnected.

4.0 WORKSHOP TESTING

Switchgear, transformers, or other associated items of Apparatus, which have been removed from service for maintenance, alteration or repair at another location (e.g. workshops), or for storage, shall be subject to the relevant ac test specified below before being released for further service.

The one minute test is preferred, but when the specified voltage cannot be obtained from the available test set, a lower voltage may be applied for a longer period, as specified below. (This may also be used for any ac test specified in paragraph 3.3). When suitable workshop test accommodation is not available, the relevant ac test shall be applied on site before the Plant is jointed or connected to the System.

Both prior to, and on completion of workshop testing, insulation tests should be carried out using an insulation tester. This will ensure that the pressure test has not had a seriously damaging effect on the insulation value.

4.1 **Switchgear**

Table 29 gives test voltage to be applied between phases with switch closed, phases to Earth, and across open switch contacts. Current transformer secondary windings should be short circuited and Earthed.

Table 29. Switchgear AC test voltage levels

	Switchgear Voltage Rating			**Period**
Rated Voltage	**6.6 kV**	**11 kV**	**33 kV**	**(minutes)**
A.C. Test Voltage (kV rms)	15.2	24.0	68.0	1
	12.7	20.0	56.8	2
	11.4	18.0	51.0	3
	10.6	16.8	47.6	4
	10.1	16.0	45.3	5
	9.1	14.4	40.8	10
	8.8	13.8	39.2	15

4.2 **Transformers**

Table 30 gives test voltage to be applied to each HV winding with all other windings, frame and core Earthed. Current transformer secondary windings should be short circuited and Earthed.

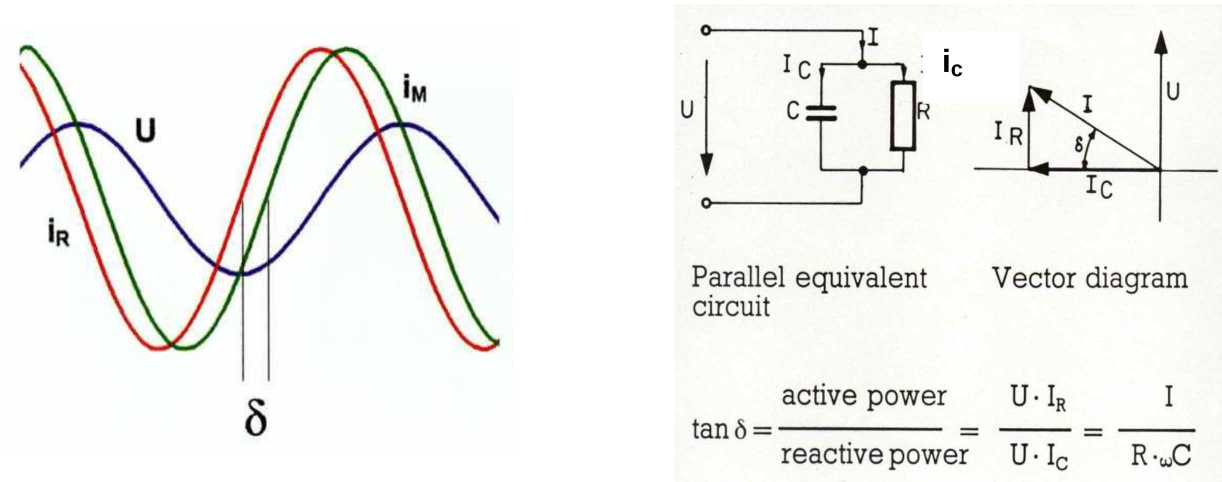
Table 30. Transformer AC test voltage levels

	Transformer Voltage Rating			Period
Rated Voltage	**6.6 kV**	**11 kV**	**33 kV**	**(minutes)**
A.C. Test Voltage (kV rms)	16.5	21.0	52.5	1
	15.4	19.6	49.0	2
	14.5	18.5	46.2	3
	13.6	17.4	43.4	4
	13.2	16.8	42.0	5
	11.9	15.1	37.8	10
	11.0	14.0	35.0	15

1 TAN DELTA or DISAPATION FACTOR

The dielectric of a cable performs like the insulation in a capacitor with the cable conducting elements acting as the electrodes. As no cable insulation is a prefect dielectric, a certain portion of the energy is lost, this energy ends up being dissipated as heat and causing a rise in temperature in the cable insulation.

Fig 1. Cable Representation for Tan Delta Measurements



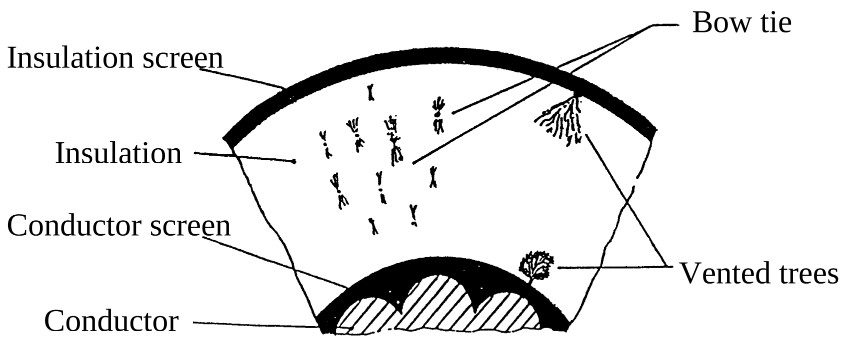
Tan δ will give you the average value for the whole circuit; therefore it is an indication of the state of the circuit. Tan Delta (Dissipation Factor) is derived by active power divided by reactive power (Ir / Ic). Good insulation has a low Power Factor or Tan Delta and very little increase in the Power Factor or Tan Delta is achieved as increased voltage is applied to the cable, the tan δ curve will tip-up.

In a new cable tan δ is reasonably constant up to a certain critical value of stress or voltage, beyond this level the curve bends upwards due to ionization which increases the dielectric loss. The ionization of a paper cable is often caused by moisture whereas a polymeric cable this would indicate the presence of voids, which would be of the form of bow tie trees or vented trees.

Water trees in the insulation both cause a high power factor or Tan Delta. But tan δ cannot distinguish between water trees and electrical trees. Nor can it locate the position of the water trees.

The conditions in which water trees develop in a polymeric cable are: -

- Service voltage,
- water,
- electric field disturbance (impurities)
- time.



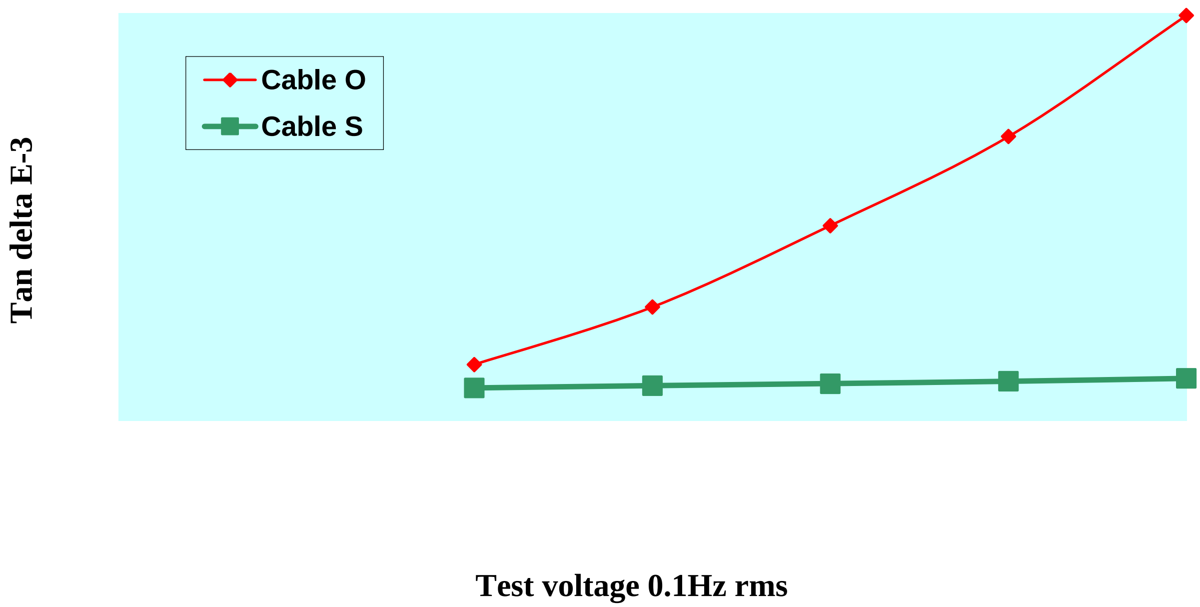
"Water treeing" in polymeric insulation (schematical layout)

2 COMPARISON OF ELECTRICAL TREEING and WATER TREEING

- Electrical Treeing: -
  - at high local field strength
  - accompanied by partial discharge
  - long channel structures (visible trees)
  - very fast tree growth in the EPR, PE, XLPE
  - initiation of an electrical pre-discharge

- Water Treeing: -
  - growing even at low field strength (e.g. < 1 kV / mm)
  - extremely slow tree growth (e.g. over 6 - 10 years)
  - no partial discharge recognizable
  - no visible channels
  - not visible without special colouring procedure

Tan delta of an 11kV 3 Core XLPE cable with a faulty joint



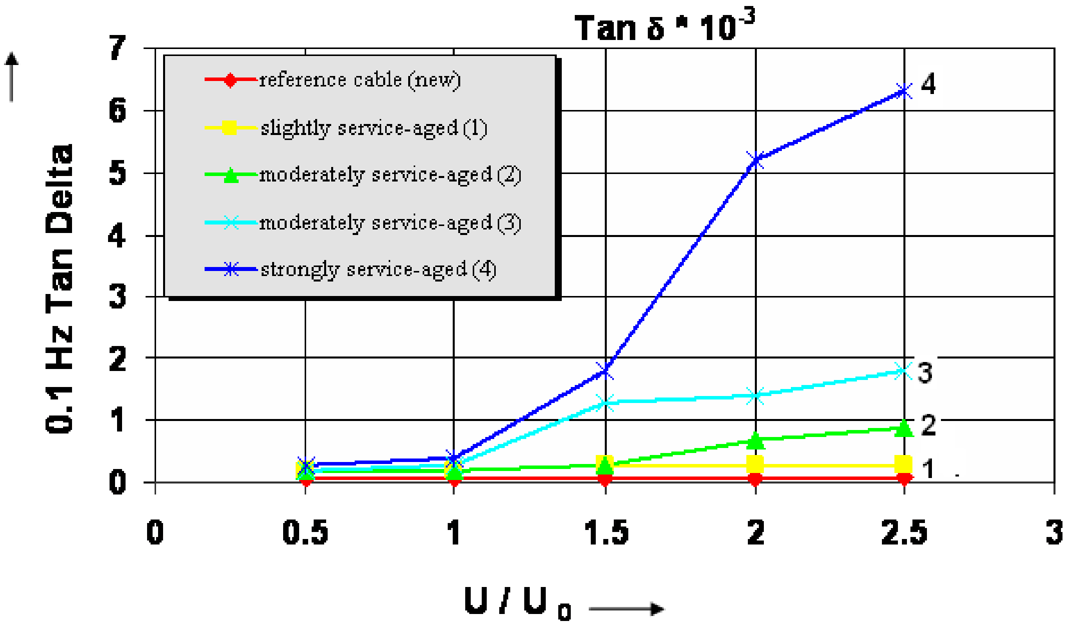


Fig 4. Typical Tan delta measurements for a polymeric cable

As can be seen from the two graphs above tan δ can be used to give an indication if a circuit is beginning to deteriorate for the worse. It will give an average for the circuit overview of the 'quality' of the complete circuit under test.

The above graph (Fig 4) shows the type of results that will be obtained by Tan Delta testing of typical polymeric circuits. If the Tan Delta results are similar to the blue line (4) shown on the above graph, then the circuit needs to be investigated to see what is causing that 'kick' in the Tan Delta line. If a poor Tan Delta result is obtained, PD mapping of the circuit should then be undertaken to find the section of cable or accessory that is causing the problem.

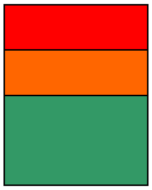
3 EVALUATION OF TAN DELTA RESULTS

Having completed the Tan Delta of the circuit under test, a quick comparison of the three phases to each other as they increase over the voltage range will show if there is an issue with one of the phases. These values should then be checked against the evaluation criteria given below.

3.1 Evaluation criteria: -

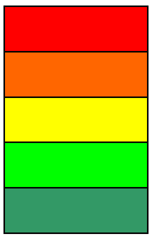
The evaluation criteria for cables that are different from XLPE need to be found and defined by comparing the first 40-50 test results. General criteria as per the PILC example over leaf have to be defined according to the local cable type. It should be noted that EPR cables are completely different from XLPE.

XLPE cables: -



tan delta (2 Uo) > 2,2 %
[tan delta (2 Uo) - tan delta (Uo)] > 1,0 %
tan delta (2 Uo) < 1,2 % and / or
[tan delta (2 Uo) - tan delta (Uo)] < 0,6 %

PILC Cables: -



> 50 % cable highly degraded, cable overlay is recommended.
30 – 50% it is recommended to repeat the TD measurement after 6 – 12 months.
20 – 30 % Service aged but still O.K.
< 10-20 % cable still O.K.
10 % cable is in good condition.

Some reasons for inordinately high tan delta readings.

Busbars together with SF 6 switchgear can be one reason for high tan delta values - because of their design. It is not possible to determine their influence on the measurement. Always try to carry out tan delta on a “clean” cable circuit.
Ground type, where the cable was laid, was it in (water, sand, chemicals, hilly, wood,…)
Usage of cable (to the limit or well below the limit…)

4 BACKGROUND INFORMATION ON PARTIAL DISCHARGE MAPPING

The majority of distribution cables in operation at the moment are traditional PILC (paper insulated lead covered) cables, many of these being installed in the 1950's and 1960's. Although over the last 10 years almost all cables installed have been polymeric. Expert opinions vary but it can be generally accepted that the PILC cables will last in the region of 80 to 90 years, meaning that a large part of the distribution network will be at EOL (end of life) within the next 20 to 40 years; a large investment proposition. It would therefore be prudent to initiate a process of gathering other information to allow a more robust assessment of the cables condition and ultimately more confidence when predicting the expected life.
Uses for partial discharge measurements

- Commissioning tests
- Condition assessment
- Condition monitoring
- Troubleshooting

Benefits of carrying out PD Measurements

- Detects defects prior to fault
- Proves quality of jointing work
- Reduces outages
- Increases reliability of network
- Adds more value to cable testing
- PILC cables can be monitored
- Guidelines for "how to proceed" exist

Limitation of carrying out PD Measurements

- Interpretation of results strongly depends on the knowledge of test object
- Judgment of severity of defects sometimes difficult
- Interpretation requires experience
- Assessment of cable lifetime very difficult

Partial discharge mapping techniques can provide valuable additional information on the condition of cables and the quality of a new cable installation

- The techniques have been reliably and successfully applied for over a decade
- Immediate financial benefits can be obtained
- Location of partial discharge activity can be accurately determined
- Early stages of problems can be identified
- Remedial action may be planned with full information
- Multiple partial discharge sites can be located in a single test

At the beginning of the last century HV technology was introduced which recognised Partial Discharges (PD) as a harmful ageing process for electrical insulation. Since then standards have been introduced which define PD as quantity apparent charge, which is expressed in terms of pC. A partial discharge is defined as a localised electrical discharge that only partially bridges the insulation between conductors and which can or cannot occur adjacent to a conductor. Partial discharges are in general a consequence of local electrical stress concentrations in the insulation or on the surface of the insulation. Generally, such discharges appear as pulses having a duration of much less than 1μs.

With PD the current pulses are characterised by a duration as short as a micro second, as shown in Figure 2, consequently the frequency spectrum covers the VHF and UHF range. The shape of such pulses is strongly distorted if travelling from the PD site to the terminals of the test object. As a consequence, not the peak value of the PD current pulses but the current-time integral is measured.

The level of interest in condition monitoring of MV cable systems has grown rapidly in recent years. The majority of which concentrate on the detection and location of partial discharges and/or the measurement of tan delta and the change of loss angle with voltage. Offline systems and associate guidance as to the criticality of results are now routinely employed by many utilities using Very Low Frequency (VLF) i.e. 0.1Hz, the merits of which continue to be of far greater diagnostic value and potentially less damaging to insulation than conventional DC HiPot testing.

Recent developments have however been mostly concentrated in the area of online partial discharge location and detection systems. On-line condition monitoring of equipment – partial discharge (PD) monitoring is becoming more widespread in the worldwide electricity industry. Accurate condition assessment and the subsequent management of in-service, high voltage plant is becoming more economically viable, with continuous advances and cost reductions being made in sensor technology, data acquisition / processing and intelligent diagnostic software.

4.1 Partial discharges

Partial discharge (PD) is a localised dielectric breakdown of a small portion of a solid or fluid electrical insulation system under high voltage stress, which only partially bridges the insulation between conductors. Figure 1 shows a schematic of partial discharge system in insulation layer. When the electric field strength exceeds the breakdown strength of the dielectric medium, partial discharge occurs. Partial discharge can occur at any location within the insulation system. Partial discharge can occur in voids, across the surface of insulating material due to contaminants or irregularities, within gas bubbles in insulation or around an electrode in gas i.e. corona activity. When partial discharge activity occurs, it emits energy in the form of 1) electromagnetic i.e. light, heat and radio form, 2) acoustic i.e. audio and ultrasonic and 3) gases i.e. ozone and Nitrous oxides.

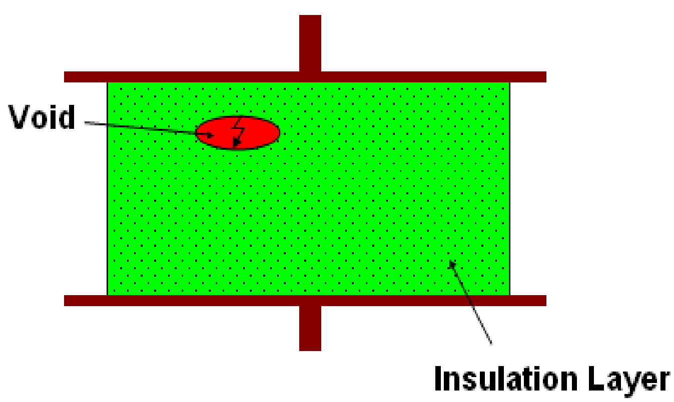


Figure 1: A partial discharge in the insulation layer due to void

PD can result from: -

- Discharge in a cavity within the insulation media or between the insulation and the semiconductor
- Tracking discharge along an interface
- Discharge from electrical tree growth
- Discharge between a metal and semiconductor
- Discharge from water tree growth

Partial discharge reveals itself in a number of ways. It is accompanied by a charge displacement in the cavity that causes current in the leads to the object, radiation emitted by exited particles, ultrasonic sound, heat from particle impact and chemical reactions.

Partial discharge occurs when a high voltage breaches the insulation of a conductor. The insulating material (dielectric) has very low electrical conductivity, but can sustain an electric field. The insulation material can be in any of these three states of matter, gas, liquid, and solid. Gas insulators commonly used are nitrogen, argon, or SF6. Where a vacuum is used this is sometimes grouped as a gas insulator, it is difficult to achieve a perfect vacuum in practice. Liquid insulators are usually mineral oils, and increasingly common due to environmental considerations, vegetable oils. Solid insulators can be glass, ceramic, mica, paper, epoxy resin and many other polymers such as PVC. The purpose of the insulator is to prevent the flow of electrons (current). Partial discharges can occur not only in cables, but also in switchgear, motor windings, generator windings, and generally in situations where the insulator dielectric strength is insufficient to prevent the flow of electrons due to the electric field. The correct design of equipment relying on insulation to maintain electrical integrity ensures that under normal operating conditions the dielectric strength of the insulator is sufficient to prevent partial discharge. Partial discharge occurs when the electrical stress exceeds the dielectric strength of the insulator, and in correctly designed equipment this is commonly as a result of a failure in the insulation, although as in the case of a gas circuit breaker for example, it can be due to contact or other physical degradation or malfunction leading to insufficient dielectric isolation, for example during contact opening. In oil insulation the dielectric strength can be reduced due to impurities in the oil. Suspended particulates such as paper from degraded transformer winding insulation, can lead to stress enhancement (due to reduced dielectric strength) causing partial discharge to occur. In solid insulation the dielectric strength is reduced where there are any physical imperfections or degradation, such as cracks, voids, or contamination of the insulating material. When partial breakdown occurs it causes further damage to the insulation, fortunately in most cases partial discharge occurs long before critical insulation failure. It is therefore important that the problem is detected at an early stage to avoid economic and environmental impact, and to ensure safety.

4.2 Partial Discharge Mapping Technique

Paper insulated lead covered (PILC) cables form the vast majority of the installed asset base in the UK, even though such cables have not been routinely installed for some time. PILC with its continuous lead sheath, traps PD signals within the sheath preventing signals from being detected outside. In such cases the only possible location for an external PD sensor is at the cable end(s) in a substation.

Partial discharge (PD) mapping is currently the best way of estimating service performance of high voltage insulation in cables. For high voltage cables, no published criteria exist for the PD parameters which can be used as an 'alarm level', but several utilities are trying to establish exactly this. The PD mapping system is designed to locate sites of PD along a high voltage cable, and display the data in an easy and understandable way. There are currently two techniques for carrying out cable mapping on-line which record the required information while the circuit is still energised and off-line where the circuit is switched out.

5 PD MAPPING OF CABLES

5.1 Off-Line Measurements

Partial discharge mapping has been used for over fifteen years and was developed for condition assessment of ageing paper insulated cables. The testing up to the last number of years has predominately been carried out off-line which require a cable outage and access provide to the cable ends to attach the PD monitoring equipment.

Off-line PD location usually involves time-of-flight techniques, either by comparing the time of arrival of the pulse at two positions or by comparing the time of arrival of the pulse with that of its reflection from the far end. The cable requires to be energised by an alternating voltage source.

The Baur system uses the latter system namely, by comparing the time of arrival of the pulse with that of its reflection from the far end, part of the procedure for the PD mapping is the production of a report for the completion of the circuit. The cable data, circuit length, terminations details are recorded along with all the joint positions and type by the operator, prior to testing.

5.1.1 Very Low Frequency (VLF) test

This Partial Discharge Mapping system allows the measurement of the magnitude and origin of partial discharge activity within high voltage cable insulation. By capturing many partial discharge events, a graphical representation of the discharge activity along a length of cable may be generated.

In order to measure partial discharge activity, the cable must be energised at a voltage level the will cause localised dielectric breakdown; this initiation is called the inception voltage.

Supplying this test voltage for long cables is difficult due to the high power requirements necessary to provide the charging current to energise the cable capacitance. To reduce the power requirements, a Very Low Frequency (VLF) high voltage test supply is used. This allows long lengths of cable to be energised at the required test voltage from a standard 240V 13A outlet. The frequency of the test voltage is dependant on the cable length but is typically 0.1Hz.

Partial discharge events are detected via a high voltage coupling filter connected at the end of the cable under test (see Figure 3). The signals are captured on a digital oscilloscope and transferred to a computer for storage and analysis.

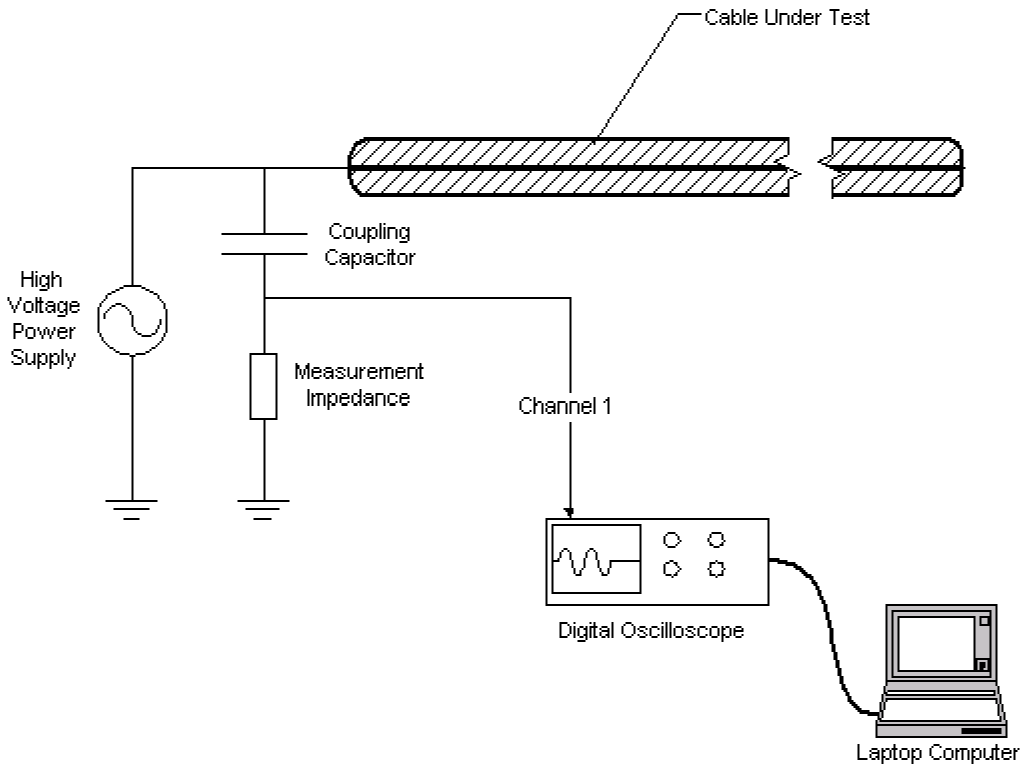


Figure 3: Connection diagram for off-line detection of partial discharge

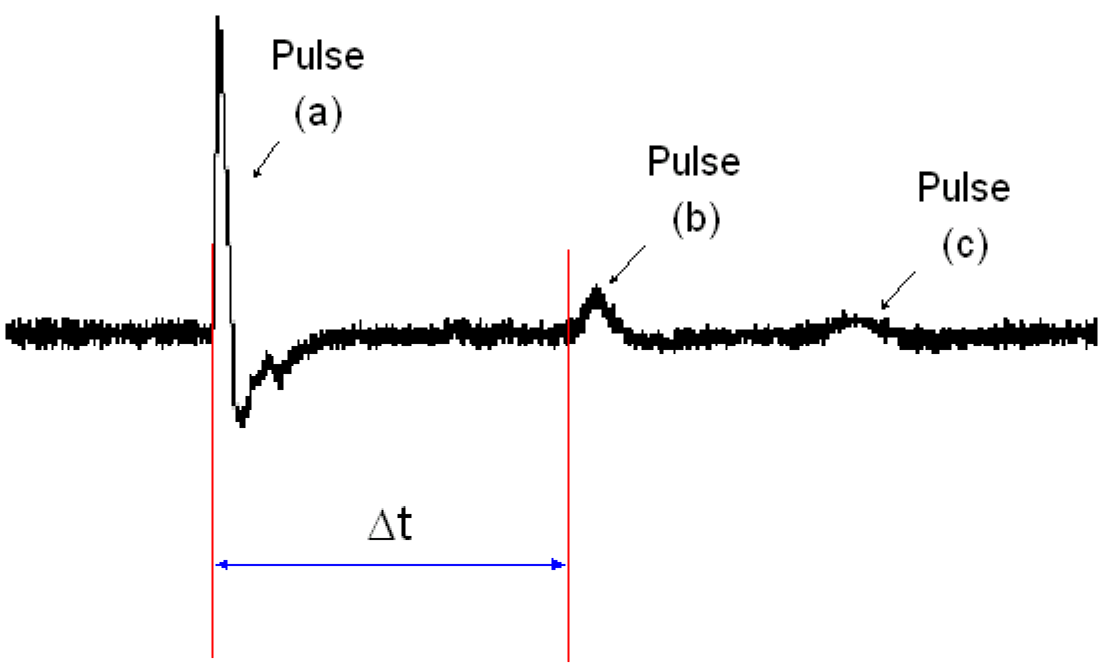


Figure 4: Partial discharge location

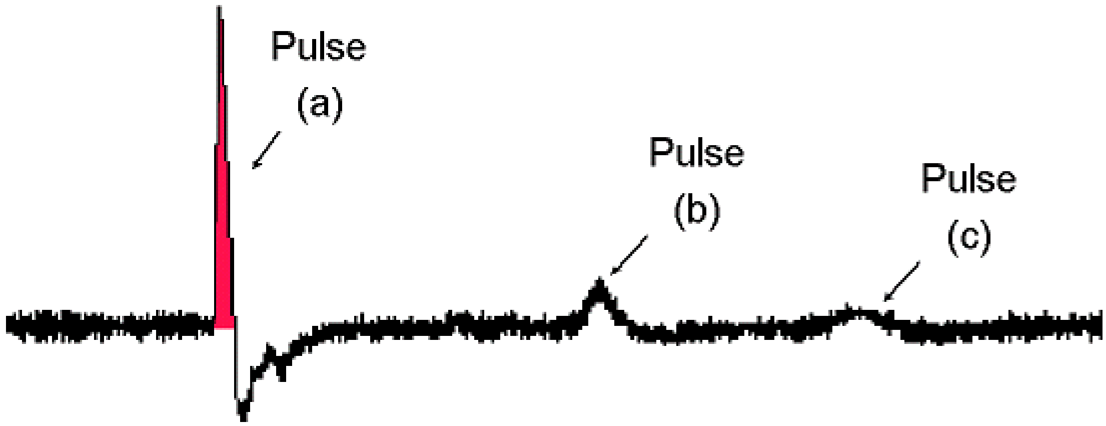


Figure 5: Partial discharge magnitude

The recorded partial discharge traces are subsequently processed to determine the origin (see Figure 4) and the magnitude (see Figure 5) of each individual partial discharge event. Finally, the processed data is used to produce a graphical representation of the discharge activity along the route length in the form of a partial discharge map as shown in Figure 6. The map shows three phases plotted together with any known joint positions to permit geographical comparisons as seen below.

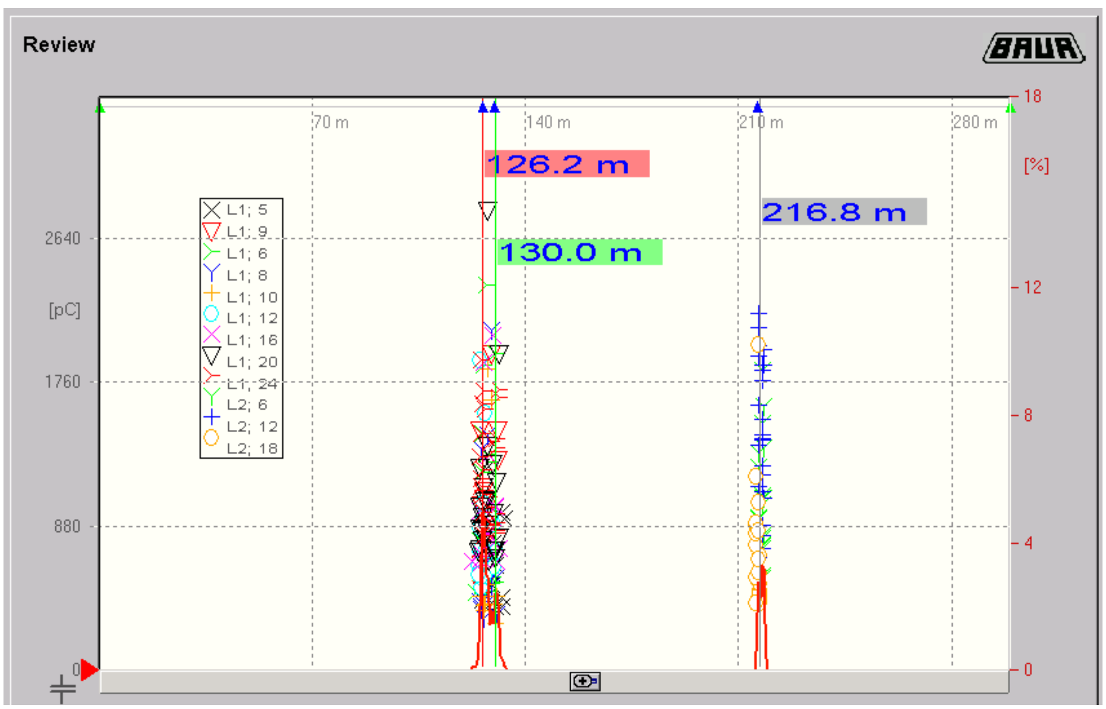


Figure 6: Example of Partial discharge cable map

When a PD event occurs, the PD pulses travel outwards in both directions along the cable earth sheath (and conductor) from the originating PD site as illustrated in Figure 7. The first pulse 'Direct Pulse' to arrive at the measurement end of the cable is the pulse which has travelled directly to that end. The pulse which then allows the PD site to be located is the 'Reflected Pulse' which originally sets off in the opposite direction, and is then reflected back from the remote end back to the measurement end. This technique is called 'Single-Ended PD Location' and is, when possible in ideal conditions, the simplest and quickest way to provide PD mapping of cables.

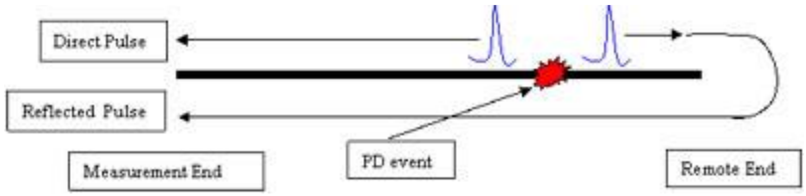


Figure 7: Single-Ended PD Site Location Method

If both the 'Direct Pulse' and the 'Reflected Pulse' are identifiable (as in the ideal case) then location of the site of the PD event is relatively easy with the Single-Ended Location Method. Results would look like:

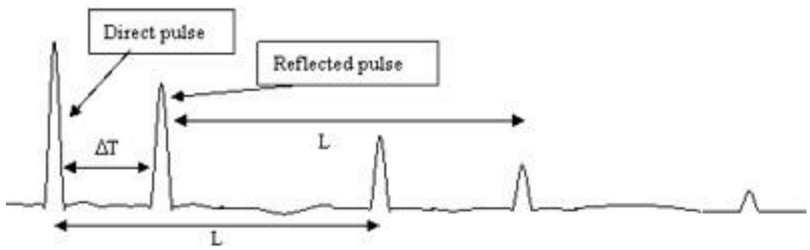


Figure 8: PD Pulse Trains as seen from the Measurement End

With reference to Figure 8, the time difference between the first two pulses (the direct pulse and the reflected pulse) ΔT, locates the site of the PD event. It can be noted from Figure 8 that the two pulses will continue to travel up and down the cable, until they become too small to be seen above the noise level. During this time, the pulses are reflected at exactly a 'cable return time = L' away from the previous arrival at the measurement end. This gives rise to sets of pulses of diminishing size, each spaced at the cable return time, ‘L’ i.e. the return time of the cable length which can be measured with the cable mapping software. Therefore then the location of the PD event is: -

Location of PD event from Measurement End (in % Cable Length) = 100*(1- ΔT/L)

5.1.2 Output from the PD Mapping

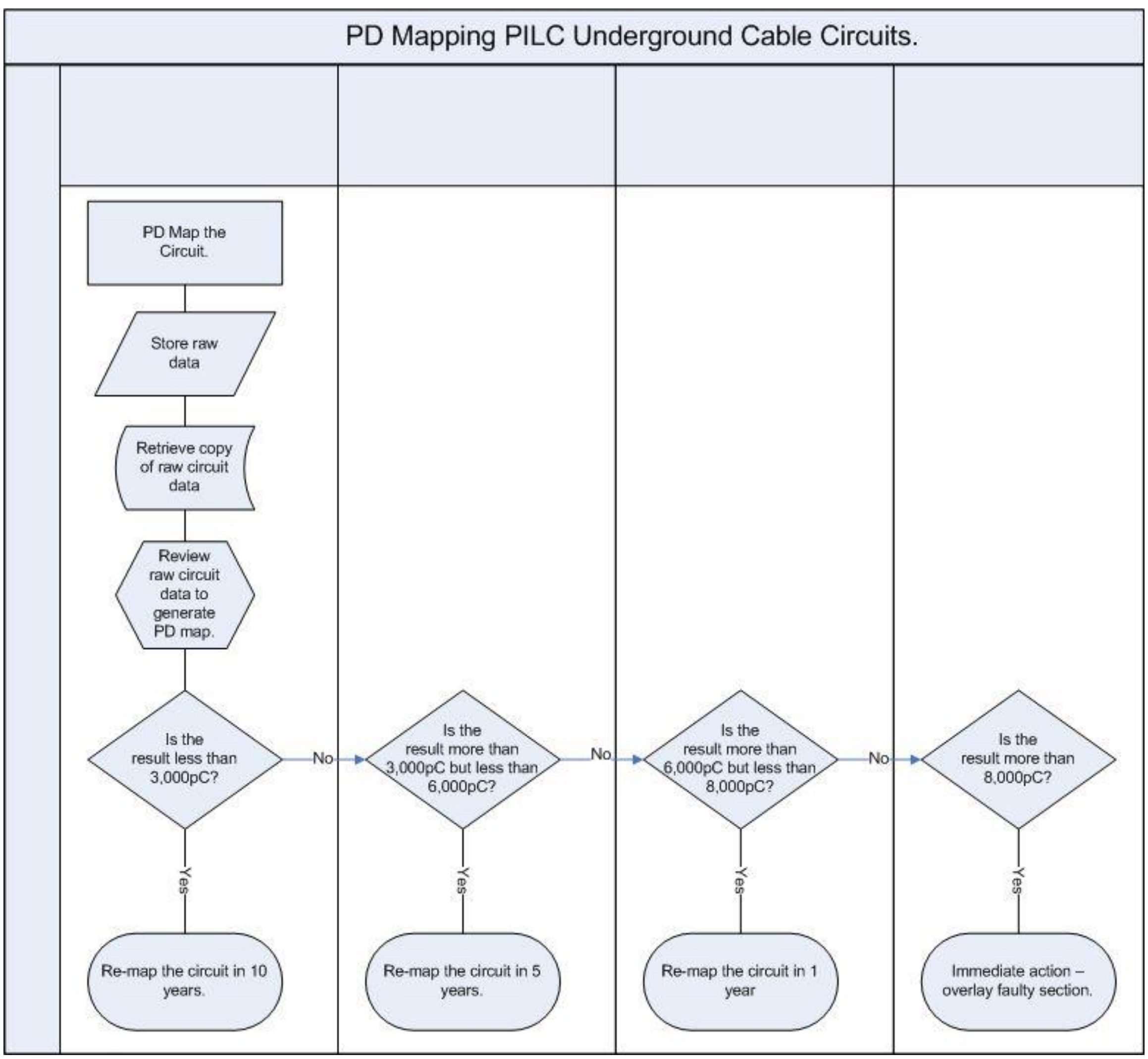
PD mapping technology is proven and has been used throughout the industry over a number of years. The wealth of experience gained over the years provides a high level of confidence in the interpretation of results and the associated conclusion and or recommendations that are given with each report. But the interpretation of the waveforms generated by the PD mapping strongly depends on the knowledge of PD mapping system, and this interpretation requires experience.

The PD mapping technique allows the test voltage to be slowly increased and decreased. Inception and extinction voltages can be recorded which can provide further information with regards to the integrity of the cables installation. The availability to change the test voltage gives the test engineer the flexibility to test to working voltage and record the necessary data before deciding to increase the test voltage still further stressing the insulation and gathering further information.

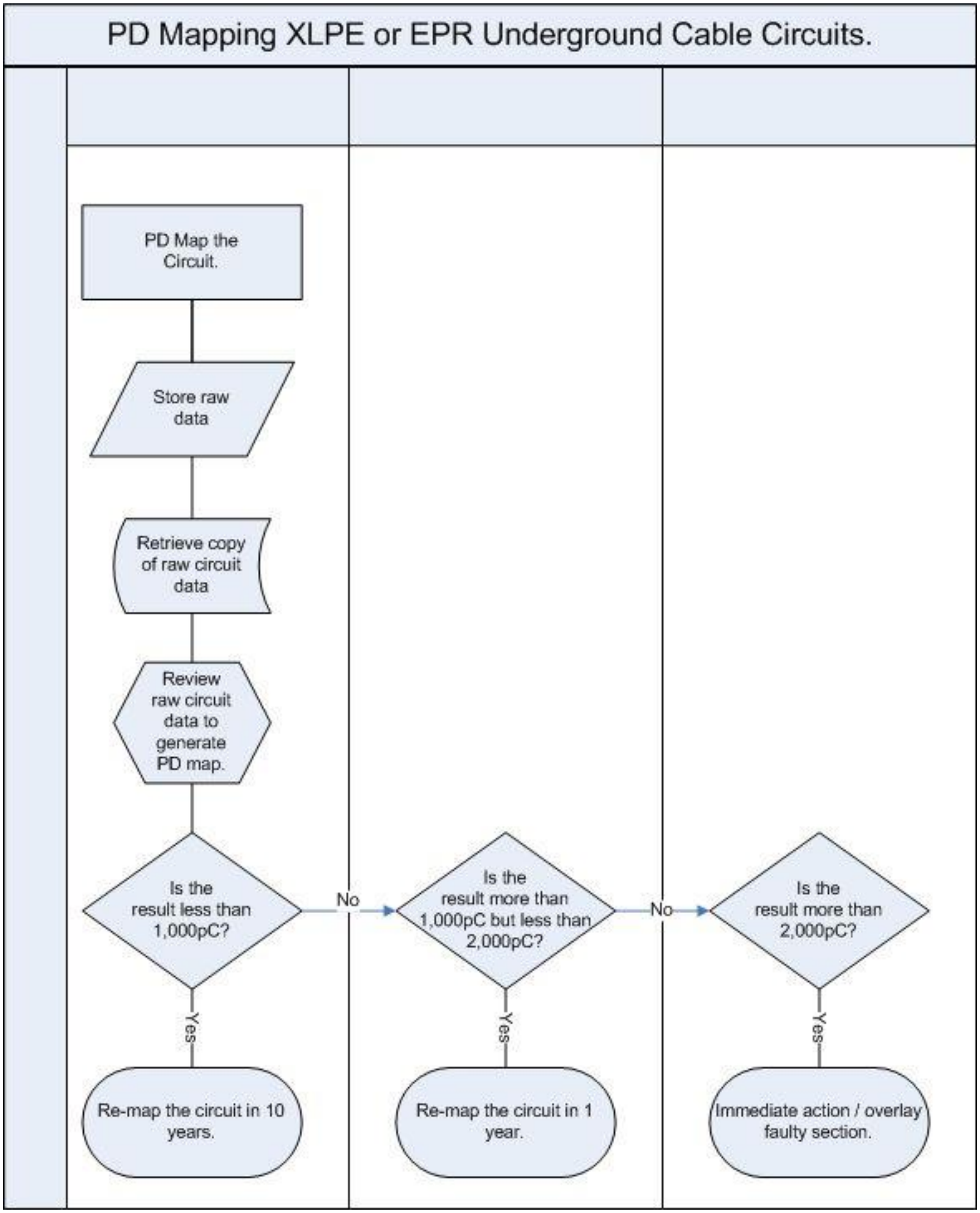
From anecdotal experience the levels of pico Coulombs developed during the testing of the cable circuits will determine the type of response required to prevent the circuits from causing CML's and CI's. The Table below gives these typical values: -

	PILC Cable Circuits.		**Clean EPR or XLPE Cable Circuits.**	
Baur PD Mapping	**<3,000pC**	Acceptable level of discharge	**<1,000pC**	Some concern, Monitor / Investigate possible source (normally accessory or termination)
	>3,000pC	Raised concern, Monitor	**>1,000pC**	Increased concern, plan retest in 12 months / repair
	>6,000pC	Increased concern, plan retest in 12 months / repair	**>2,000pC**	Immediate concern, urgent repair.
	>8,000pC	Immediate concern, urgent repair	Not applicable	

Flow diagram for PILC cables.

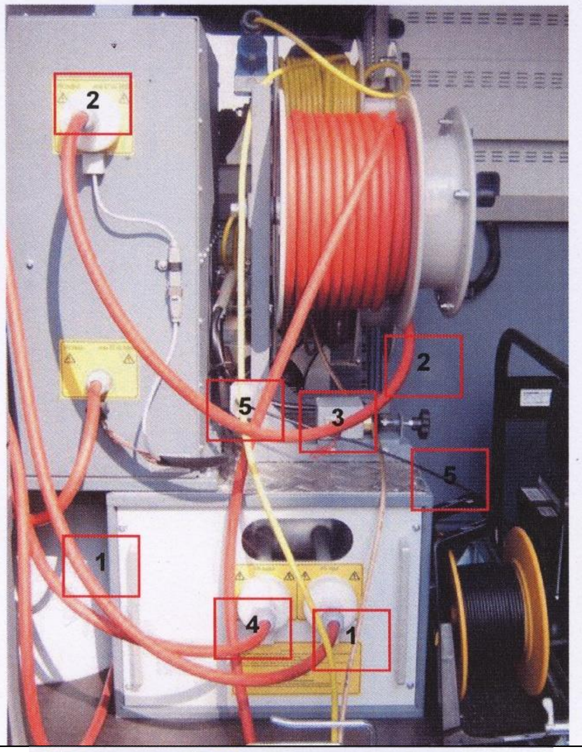
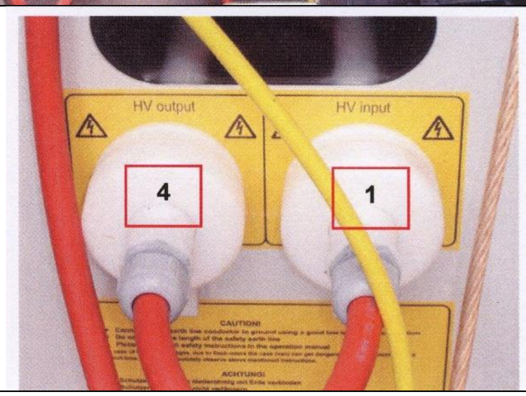
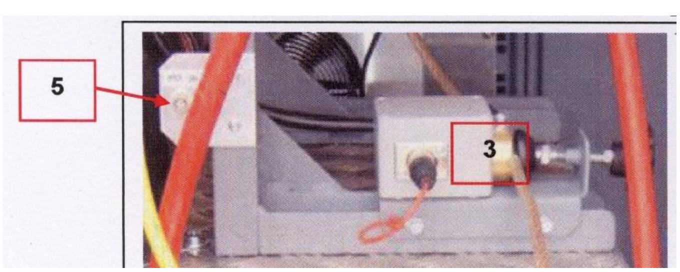


Flow diagram for XLPE or EPR cables.

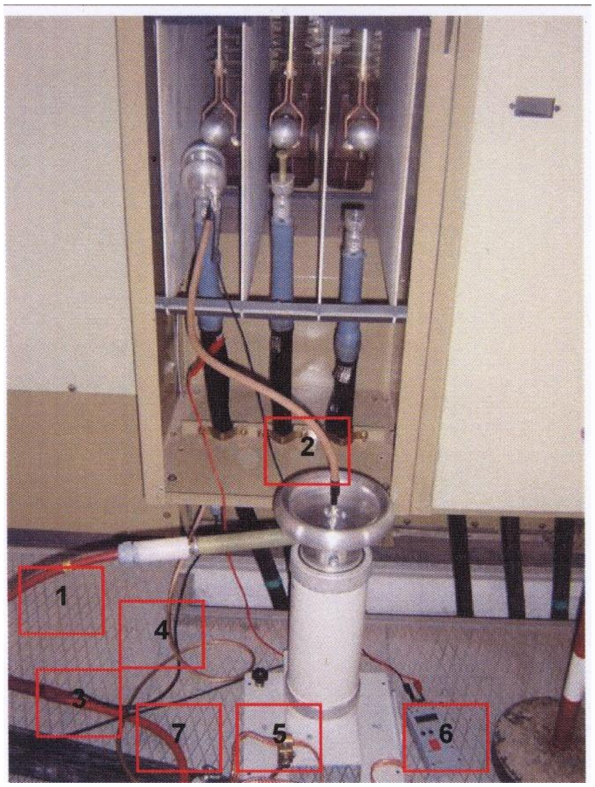


1 Connecting the Baur System of P D Measurement

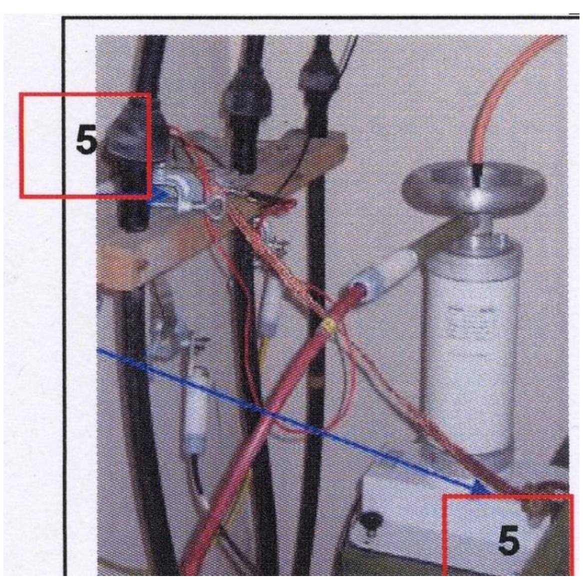
Once the circuit to be PD mapped has been isolated and earthed as per the DSR's and all the other relevant Company documentation has been issued, then the circuit can be 'connected up' prior to the PD mapping taking place.

<table>
<tr><th colspan="2">Connection of the Test Van.</th></tr>
<tr><td>
</td><td>1) The generator HV lead shall be connected to the HV input of the discharge unit.
2) The HV lead of the test van shall be connected to the output of the PD filter.
3) The test vans earth lead shall be clamped to the earth connection point of the test van.
4) The HV cable from the generator shall be connected to the output of the discharge unit.
5) The BNC cable shall be connected between the coupling capacitor and BNC terminal on the test van.</td></tr>
<tr><td>
</td><td>1) The generator HV lead shall be connected to the HV input of the discharge unit.
4) The HV cable from the generator shall be connected to the output of the discharge unit.</td></tr>
<tr><td>
</td><td>3) The test vans earth lead shall be clamped to the earth connection point of the test van.
5) The BNC cable shall be connected between the coupling capacitor and BNC terminal on the test van.</td></tr>
</table>

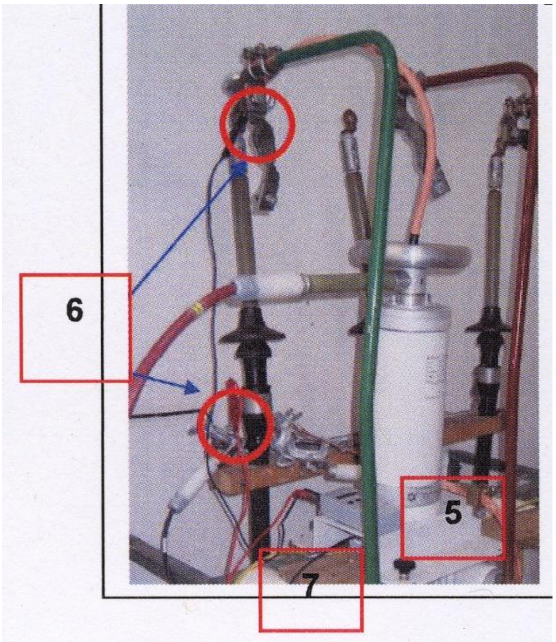
Connection to the Cable Under Test



1) The HV test lead from the test van is to be connected to the coupling capacitor.
2) The HV electrode of the coupling capacitor is connected to the cable circuit under test via the un-shielded cable. Corona shields are to be fitted to the termination.
3) The screen of the HV test lead shall be earthed to the sub station earth.
4) The test van's earth shall be connected to the sub stations earth.
5) The test vans earth shall be connected to the G clamp earth of the coupling capacitor. The screen of the cable under test and the coupling capacitor shall be earthed in the most direct and shortest route possible.
6) Prior to testing the calibrator shall be connected to the cable under test.
7) The coax cable shall be connected to the BNC connector on the coupling capacitor.



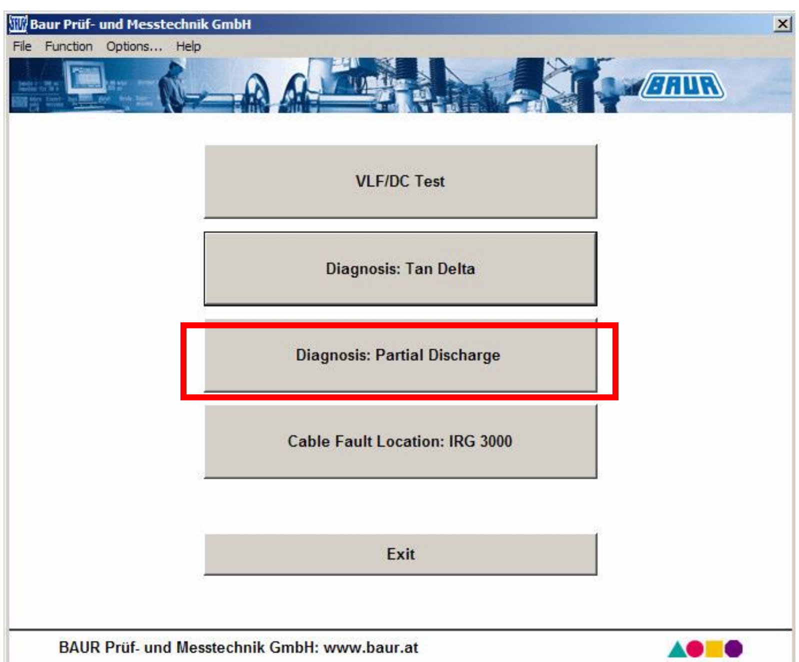
5) The test vans earth shall be connected to the G clamp earth of the coupling capacitor. The screen of the cable under test and the coupling capacitor shall be earthed in the most direct and shortest route possible.

<table>
<tr><th colspan="2">Connection to the Cable Under Test (continued)</th></tr>
<tr><td>
</td><td>5) The test vans earth shall be connected to the G clamp earth of the coupling capacitor. The screen of the cable under test and the coupling capacitor shall be earthed in the most direct and shortest route possible.
6) Prior to testing the calibrator shall be connected to the cable under test
7) The coax cable shall be connected to the BNC connector on the coupling capacitor.</td></tr>
</table>

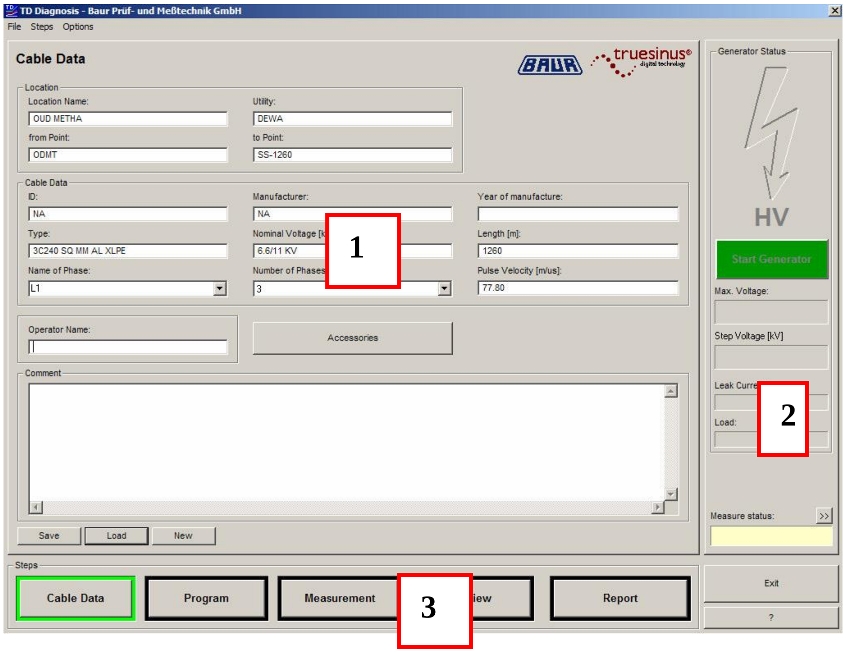
2 Operational guide to PD Map Circuits using the Baur System

When pd mapping, using the Baur system, (the assumption made here is that the Baur test van has already been connected to the cable circuit which is to be pd mapped and the right equipments within the test van have been selected) the operator selects the Diagnosis: Partial Discharge button, as shown overleaf, on the touch screen.

This will take the operator to the first screen, click on Diagnosis: Partial Discharge.



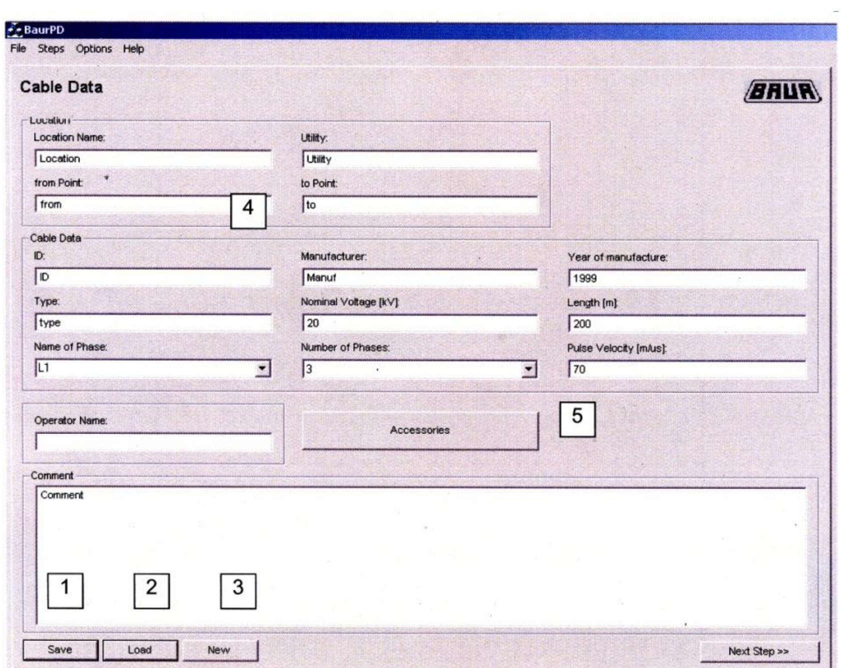
This will bring the operator to the Cable Data screen where the operator enters the critical cable circuit data into the system via the screen shown below, this screen can be broken up into three discreet sections



1) The main display, showing the actual task in hand.
2) The Generator bar used to control the VLF generator.
3) The Navigation bar, used to navigate through the PD mapping.

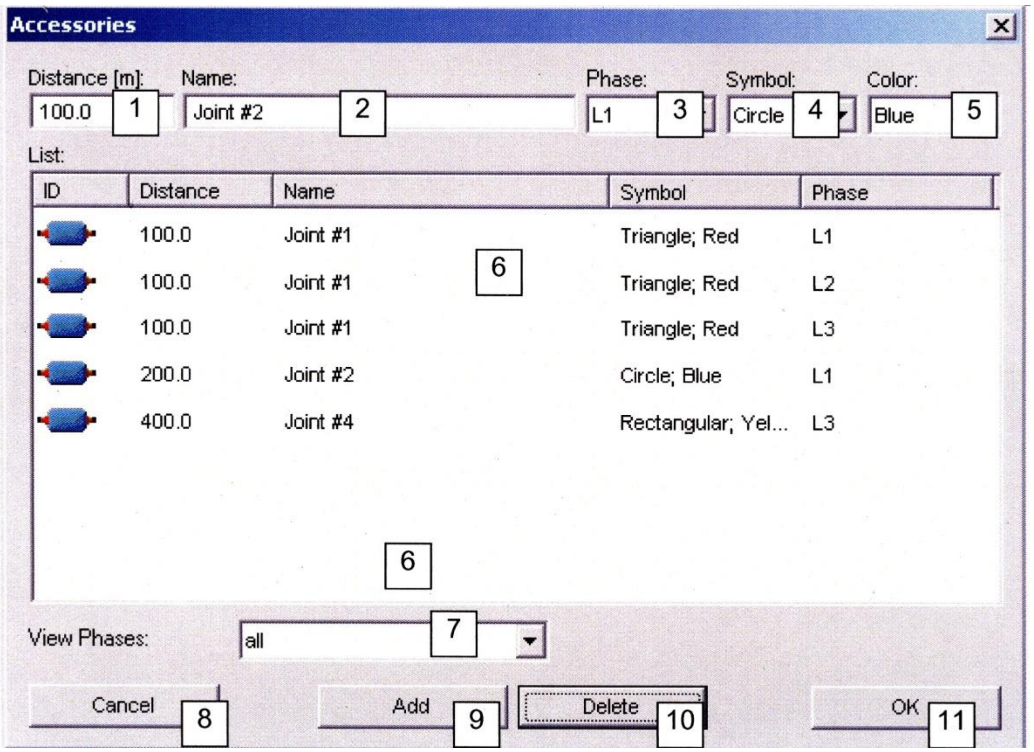
2.1 Cable Data Screen

The cable data, circuit length, terminations details etc. shall be recorded along with all the joint positions and type of accessory by the operator, prior to testing, see picture below.



1) Press to save the changes manually. When leaving this screen, the changes will be saved automatically.
2) Press to load, or export, or import, or delete a project. The load dialog will be displayed.
3) Press this button to generate a new project. Pushing this button will generate a new project.
4) Input cable circuit data screen.
5) Input accessories along the cable circuit.

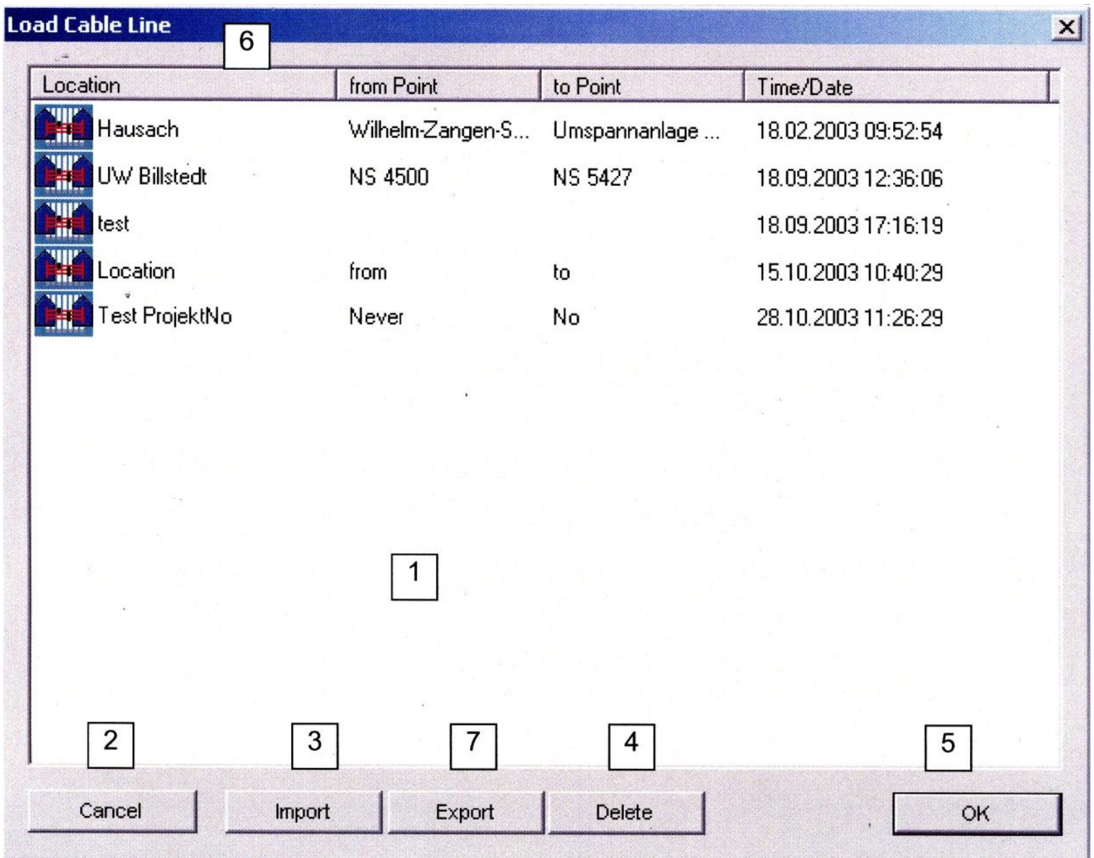
The picture below illustrates the inputting of the accessories for a cable circuit.



1) Distance between accessories.
2) Name or type of accessory.
3) Which phase the accessory is on i.e. all phases.
4) Select symbol type.
5) Select the symbol colour.
6) List of cable circuit accessories.
7) Filter select, usual to select 'All'.
8) Reject changes.
9) Add additional accessory.
10) Delete marked accessory from list.
11) Confirm changes.

By recording the joint location details of the circuit, a more complete report is generated as the joint locations are shown alongside the PD mapping details, thus enabling the reviewer to make a better judgement call.

If a cable circuit has already had the data inputted then the data can be accessed by the following method. See overleaf for details.



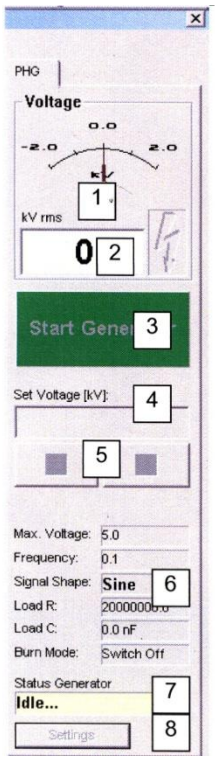
From the cable data screen click on 'Load'. This will bring you to the screen above, where: -

1) Lists all he projects saved in the system.
2) Click to cancel and come out of this screen.
3) Click to import a project from an external storage device.
4) Click to delete a project permanently.
5) Click load the highlighted project.
6) Click on the 'Location' header to sort the list of projects.
7) Click the export button to export a project including the measurements.

2.2 The Generator Bar

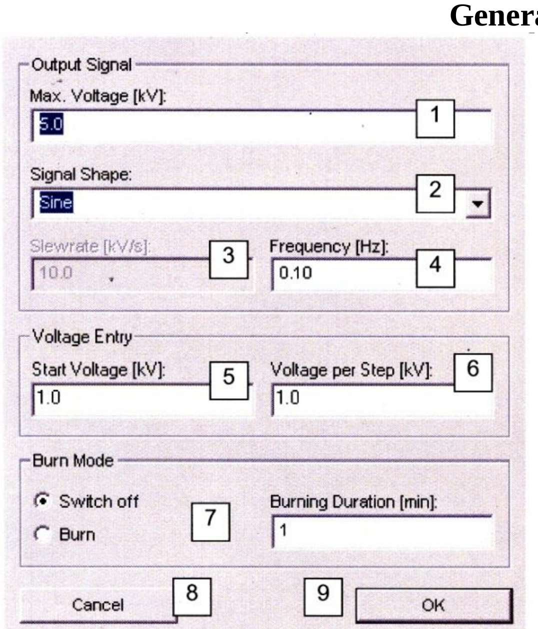
The generator bar is used to control the VLF generator, e.g. starting, stopping and changing the output voltage level.

The Generator Bar



1) Instantaneous reading of Output Voltage in kV.
2) Digital value of Output Voltage given RMS kV.
3) Start / Stop button.
4) Set value of Output Voltage in kV RMS (sinusoidal output voltage).
5) Buttons to increase or decrease the output Voltage.
6) Indication of defined maximum Output Voltage, test frequency, wave shape, measured capacitance and resistive load.
7) Indication of the generators status.
8) Click this button to go to the generator setting screen.

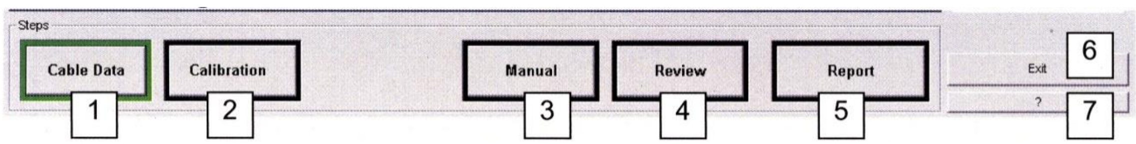
Generator Screen.



1) Input maximum Output Voltage level.
2) Input Output Voltage wave shape.
3) Input slew rate, used with rectangular wave shape only.
4) Input the output frequency.
5) Input the start Voltage.
6) Input the Voltage incremental steps.
7) Input the burn mode parameters.
8) Click to reject changes.
9) Click to confirm inputs.

Note: -
When using PD Mapping, select sinusoidal Output Voltage and 0.1Hz frequency and turn the ‘Burn mode’ to ‘Switch Off’.
The maximum Output Voltage is the ‘Maximum Voltage’ that you want to apply to the circuit under test.

2.3 The Navigator Bar



The Navigator bar allows the user to select the various options with regard to PD Mapping diagnosis, the bar is read from left to right.

1) Click on '*Cable data*', allows the user to enter detailed information about the circuit under test.
2) Click on the '*Calibration*', allows the user to calibrate the test prior to use.
3) Click on the '*Manual*', takes the user to the manual measurement screen.
4) Click on the '*Review*', allows the user to review the measured data.
5) Click on the '*Report*', takes the user to the Report screen.
6) Click on '*Exit*', terminates the current task.
7) Click on '*?*', takes the user to the help pages.

3 Calibration

To get the best PD Mapping results two parameters have to be calibrated these are: -

1) The charge in pC (pico Coloumbs).
2) The length of cable circuit under test in respect to the propagation velocity of the PD pulses in the cable.

3.1 Connecting the Calibrator

It is important that ***NO High Voltage*** is applied to the Calibrator during calibration.

Using the calibrator supplied, connect it across the high voltage electrode of the coupling capacitor and the earth connection of the coupling capacitor. The coupling capacitor must not be short circuited during calibration. The polarity of the calibrator is not important.

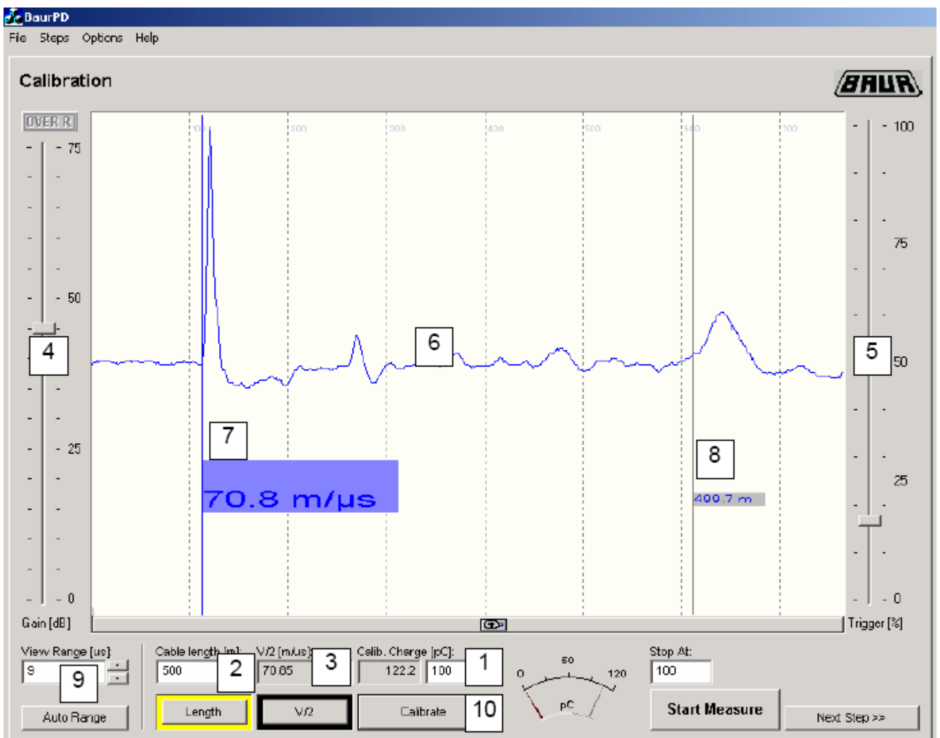
Note: - The calibrator automatically switches off after 5 minutes.

Practical advice: -
Calibration is only possible, if there is a parallel path of the metallic sheath, or copper wire screen and the conductor core/s exist for the complete length of the cable. Every PD impulse is seen like a travelling echometer impulse. Every impedance change and every discontinuity of the parallel lines are indicated. Therefore, in the case of an unsuccessful calibration, make sure that all connections have been correctly made, i.e. the ground or earth line has been connected in a straight line from the closest accessible point of the screen to the grounding or earth clamp of the coupling capacitor. Likewise the connection to the conductor or phase needs to be as short as possible. Even corrosion on the screen termination can cause problems in getting a parallel path. To confirm that a parallel path exists, perform a TDR measurement before starting the PD measurement.

Calibration value: -
The calibration value, at which the calibrator has to be set, is such that the far end reflection appears visible on the screen!

Settings: -
Gain level: - The gain level setting has to be such that it allows that the expected value of partial discharge to be displayed on the screen without reaching the over range value. Partial discharges that are recorded with the over range working, are cut. It should be noted the measurement of the PD charge is based on the area under the PD curve.

Trigger level: - frequent triggering of the incoming pulses is required. The trigger level defines the edge, to display (trigger) the incoming signals. The trigger level setting enables the software to filter out the noise signal. As long as the far end impulse reflection is higher than the noise level, the reflection peak can not be filtered. If this is not the case, then increase the calibration value!



1) Enter the calibration charge set at the calibrator.
2) Cable length display.
3) Pulse velocity display.
4) Gain setting slider.
5) Triggering level slider.
6) Calibrator generated waveform.
7) Start cursor.
8) End cursor.
9) Calibration button.

To activate a cursor, click on its banner. The activated cursor can be recognized by the enlarged banner, (see 7 above). To move the active cursor, click on its new position or keep the mouse pointer 'left clicked' on the banner and drag the cursor to the new position.

With the calibration charge on the calibrator set to say 100 pC, the gain and the trigger levels should be adjusted until a picture similar to that shown on page 46 is achieved.
The first impulse, shown on curve 6, is the calibration impulse, the second, shown by the grey line at 8, is the reflection of the calibration impulse at the far end of the cable. Set the first cursor to the beginning of the first impulse and the second cursor to the beginning of the second impulse.

Assuming the cable circuit data has been collected then enter the Calibration mode: -

With regard to the calibration, there are two modes that are needed for calibration: -
1) If the cable length is known, select the cable length mode and input the known cable length in the cable length field. The pulse velocity will be calculated automatically after calibration.
2) If the pulse velocity is known, then select the pulse velocity mode and input the pulse velocity in the pulse velocity field. The cable length will be calculated automatically after calibration.

Note: - the pulse velocity of a XLPE 1-phase medium voltage cable is approx. 80m/μS.

Type in the calibration charge that has been set on the calibrator in the calibration charge field then press the calibration button. Check that the calibration charge entered into the software has not changed the cable length or the pulse velocity, depending on which method calibration the operator choose, the respective figure should have remained constant. If necessary repeat the calibration step.

After calibration disconnect the calibrator from the coupling capacitor. Calibration is now complete and the diagnosis can be started. When making diagnosis on a three-phase cable, it is sufficient to calibrate one phase, as the other phases should have the same parameters.

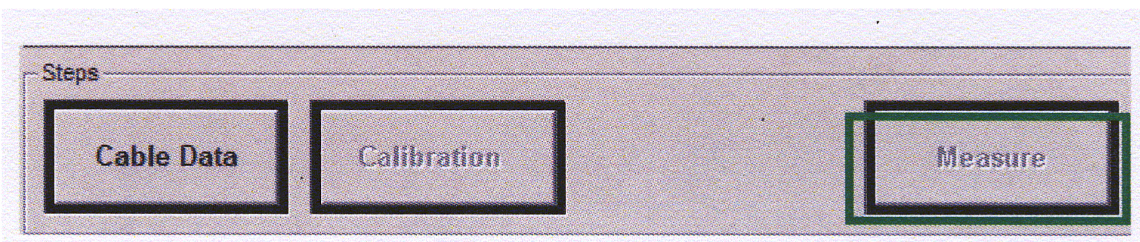
Troubleshooting for calibration

Problem	Possible Remedy
No signal is displayed	1) Check if measuring system is working (see chapter 7.1) 2) Check, if the system in connected correct to the device under test (see chapter 4) 3) Check, if the calibrator is connected correct and working. Note: - Calibrator switches off automatically after 5 min. 4) Set the trigger level to 50%. 5) Increase the gain step by step.
A lot of signals are displayed, but no signals like shown on page 46	1) Set the trigger level to 50 % 2) Decrease the gain step by step.
No reflection can be seen	1) Increase the view range. 2) Increase the calibration charge on the calibrator step by step

Problem	Possible Remedy
The calibrated and the known cable length differ strongly	1) For PD location, the sheath of the cable has to be grounded properly at both ends. 2) On every single joint in the cable circuit, the sheath of the incoming cable has to be connected properly to the sheath of the outgoing cable. If this connection has a high impedance, or if the sheath is not directly connected, the partial discharge location cannot be correctly obtained.
The signal is very small	1) Increase gain.
The signal is too high and overdriving	1) Decrease gain.
A lot of interference signals are displayed	1) Increase triggering level.
Signals are displayed Infrequently.	1) Decrease triggering level.

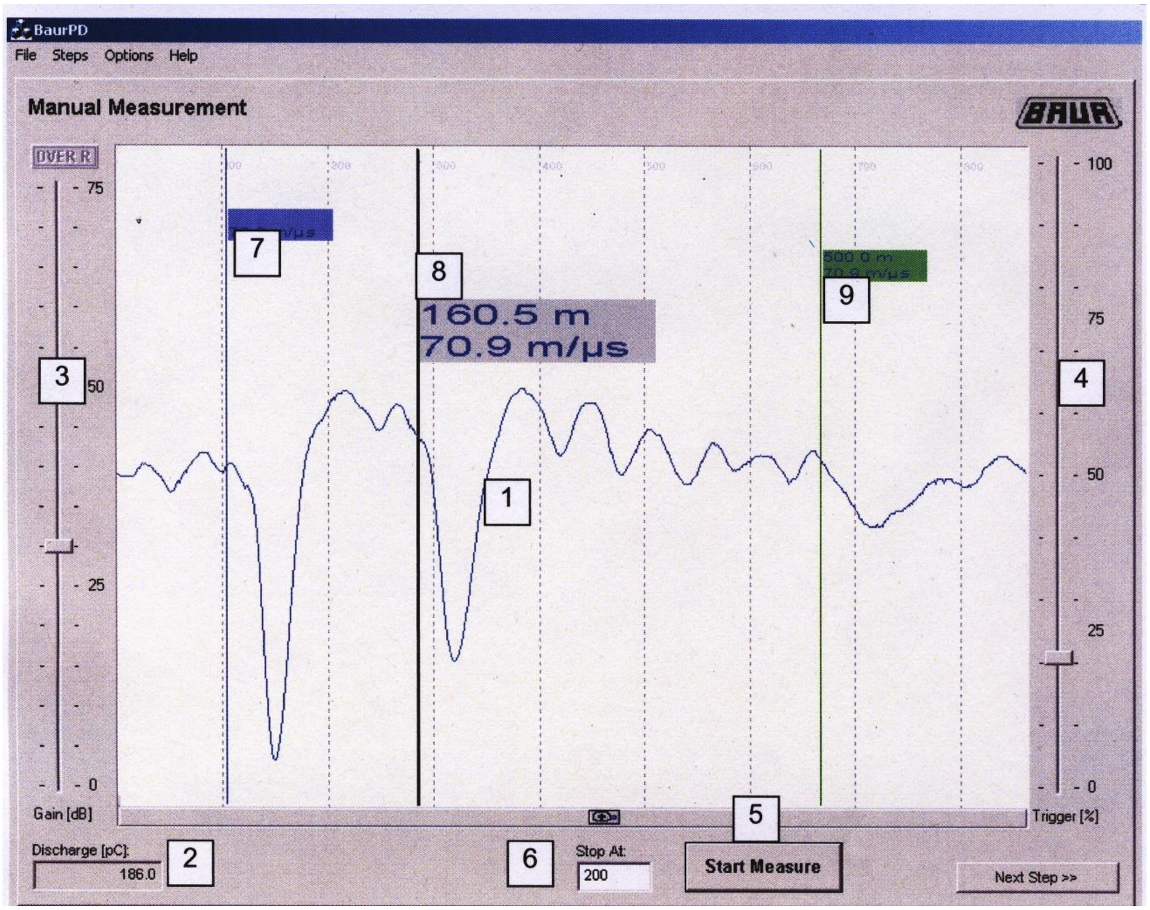
4 Measuring

After removing the Calibrator, the next step is to start measurements, click on the measure button.



The procedure in PD Mapping mode can be divided into three main steps: -

1) Setting the capture parameters.
2) Recording the PD signals.
3) Offline evaluation of the recorded PD signals.



1) Last recorded signal is displayed.
2) Measured PD value of the displayed signal.
3) Set the gain level (amplification of the input signal) in dB.
4) Set the threshold level in %.
5) Press to start the recording of the displayed signals.
6) Auto-stop recording after that number of signals captured.
7) Start-cursor.
8) Location-cursor.
9) End-cursor.

4.1 Setting capture parameters

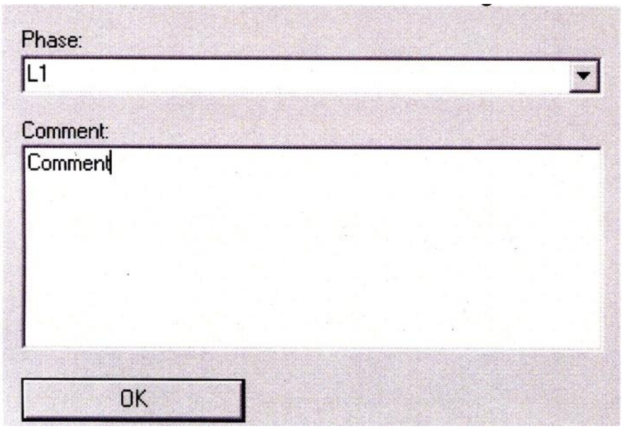
Set the generators options (see Generator bar) and apply the desired value of high voltage to the VLF generator using the generator bar.

Note: - Before starting the generator, make sure that: -

1) The calibrator has been disconnected from the coupling capacitor.
2) The generator settings are correct.
3) All ground connections are set and OK.
4) All high voltage connections are ready for operation.
5) All safety rules and standards are followed.

4.2 Recording the signals

Press the "Start" button to record the signals continuously.



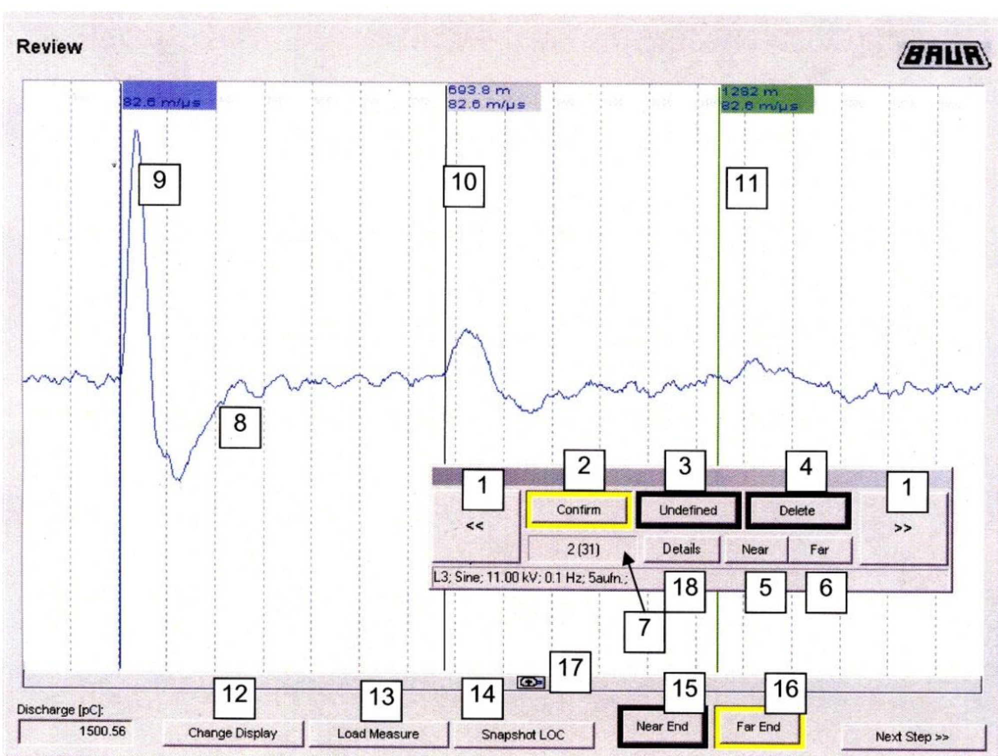
Select the phase and type in a comment if necessary.

While recording, the recorded signals are displayed. For the best performance, adjust gain, the trigger level and the output voltage to your demands. Press the "Stop" button to stop the measurement.

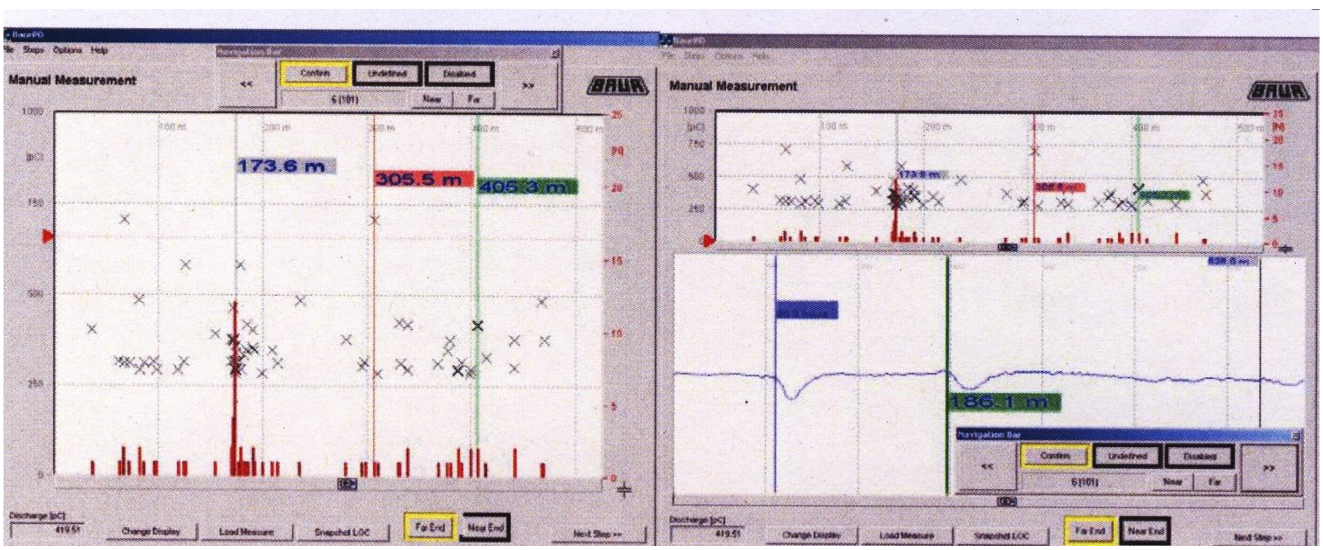
4.3 Offline evaluation of the measurements

Measurements have to be evaluated. If the review is done via the *Auto Review* button then that record cannot be evaluated manually unless a prior copy of the record has been made. It should be noted that the Auto Review mode can miss PD discharge sites so this method of evaluation should not be relied on.

For the evaluation process, switch off high voltage and select the review screen.



1) Press to see next or last record.
2) Press to confirm that this is a PD signal and the cursors are set on the correct position.
3) Pressed if this record was not evaluated until now
4) Press to disable this record for report generation, e.g. if it is not a PD pulse.
5) Shortcut: PD on near end termination
6) Shortcut: PD on far end termination
7) Number of actual record and number of saved records in this measurement
8) Actual record
9) Start peak cursor
10) Location cursor
11) End cursor (automatic)
12) Press to change the view mode: PD signal only, PD signal and location graph, location graph only.
13) Press to load, report or delete a measurement. The measurement selection dialog will appear.
14) Snapshot: - Press to save the actual location graph view for reporting
15) Press to set far end reference
16) Press to set near end reference
17) Zoom bar: - press (+) and (-) to adjust scale, double-click for default view
18) View and edit the parameters and Comments of this measurement

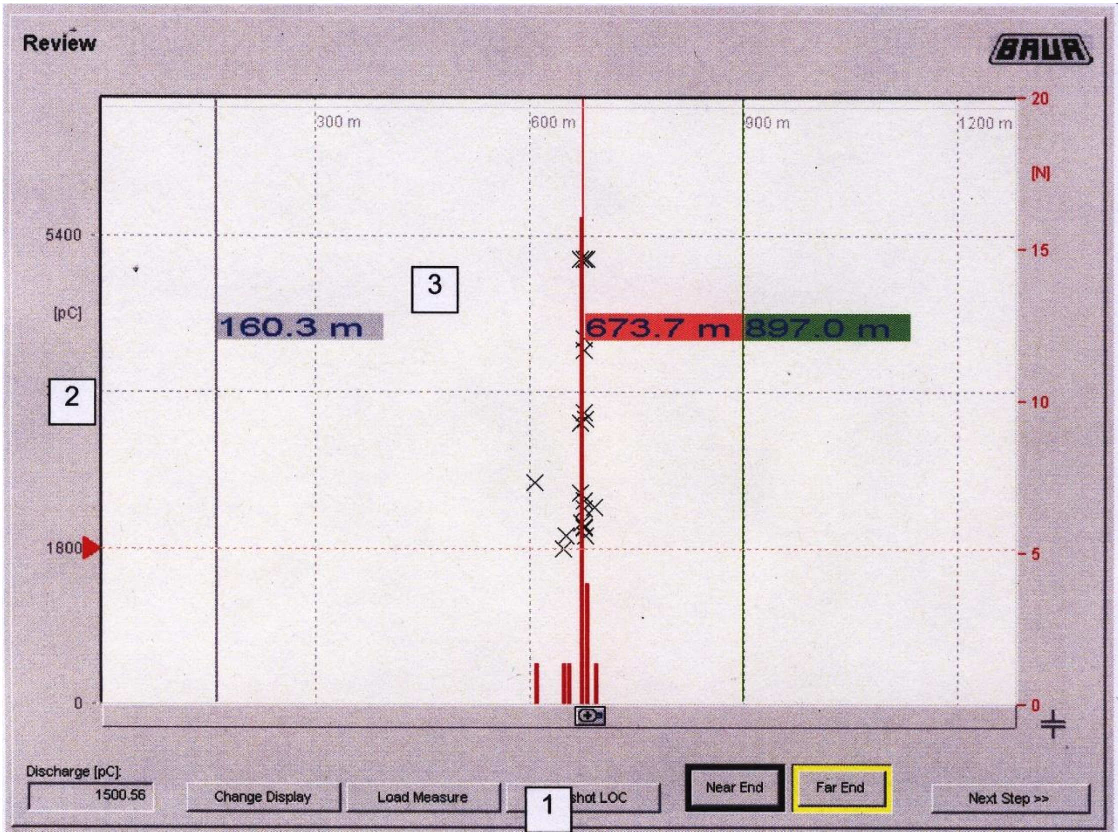


After changing the signal status, the next record is displayed automatically. Only the records with confirmed status are used to generate the report. Records without three cursors cannot get status confirmed because they are not evaluated correct so far. Records with a location cursor right of the end cursor or left of start cursor cannot be marked as “confirmed” because they are not evaluated correct so far.

4.3.1 Location graph

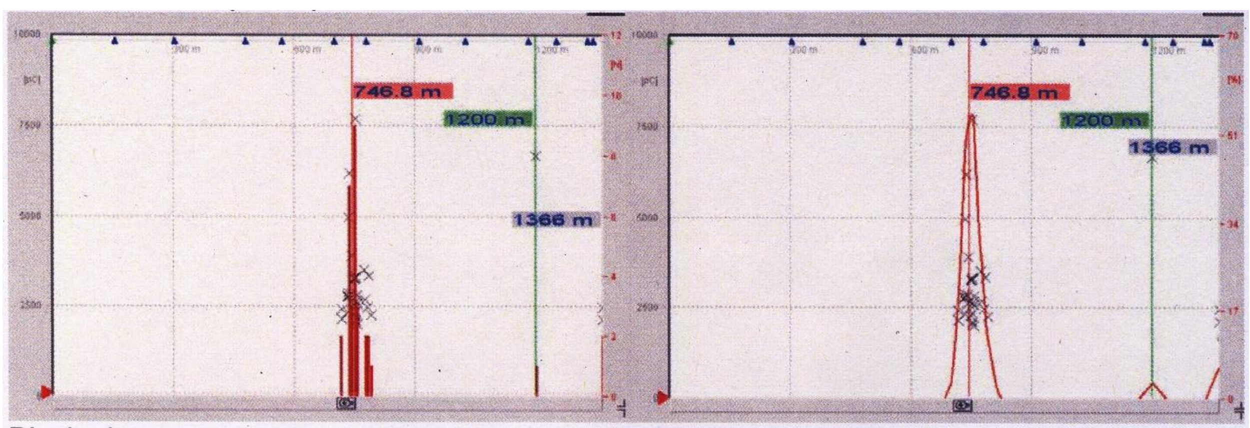
The location graph displays every confirmed record as a cross. The X-axis shows the position of the partial discharge in the cable. The left Y-axis (black) shows the measured charge in pC. The capacitor-symbol symbolizes the position of the coupling capacitor and therefore indicates if near-end or far-end reference is set. To measure the distance of a recorded discharge, use one of the cursors.

The right Y-axis (red) shows the number of partial discharge pulses at discrete positions in the cable for easy interpretation. You can select different view modes in the menu: -



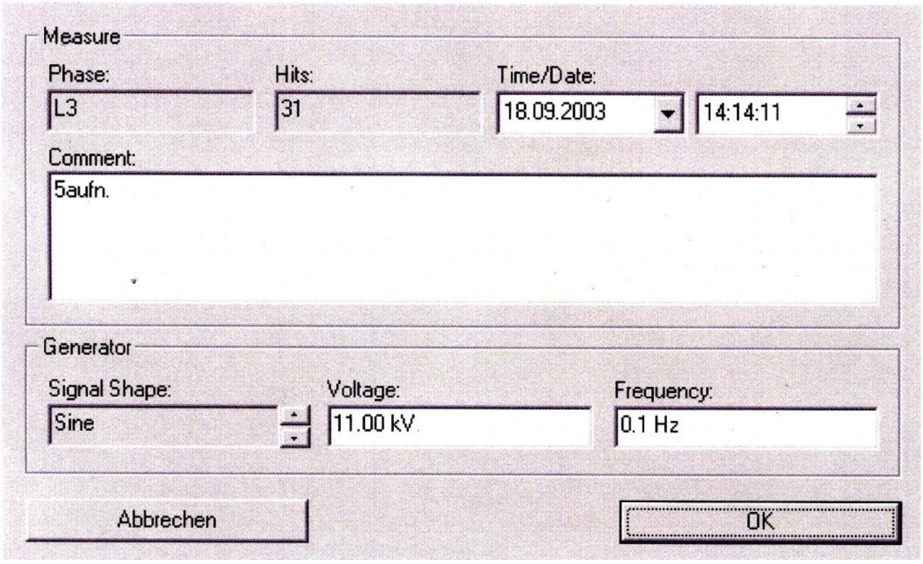
1) Zoom bar: press (+) and (-) to adjust scale, double-click for default view
2) Slider to hide small PD signals in location graph
3) Location cursors for measuring reasons

The partial discharges can be viewed in two different formats, shown below.



Block-view Line-View

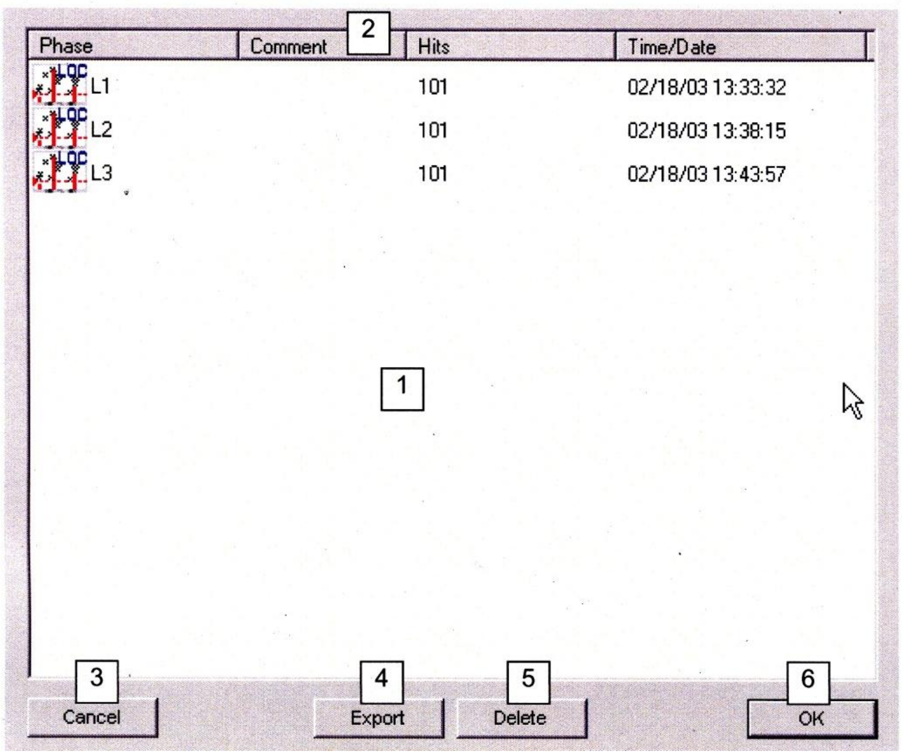
4.3.2 Properties of a recording block



The properties displayed in the report can be adjusted afterwards here.

5 Loading, exporting or deleting an existing measurement

Use the load button to select the measurement: -



1) List of all measurements made in this project
2) Press header to sort the list

3) Press to cancel
4) Press to export the highlighted measurements
5) Press to delete the highlighted measurement permanently
6) Press to load the highlighted measurement

Highlight measurement by clicking on the list. To highlight more than one measurement (e.g. for exporting), press the *Shift Control*-button on the keyboard and click on any measurement you want to highlight.

Note: - To view multiple PD measurements in one location graph

Different PD measurements of the same cable circuit can be displayed in one location graph e.g. all measurements of one phase measured at different voltage levels.

In the select measurement: - view hold down the *Control*-button and mark all measurements to be displayed with the mouse. Confirm with OK. A localisation diagram with all these measurements with different symbol and colours will be displayed.

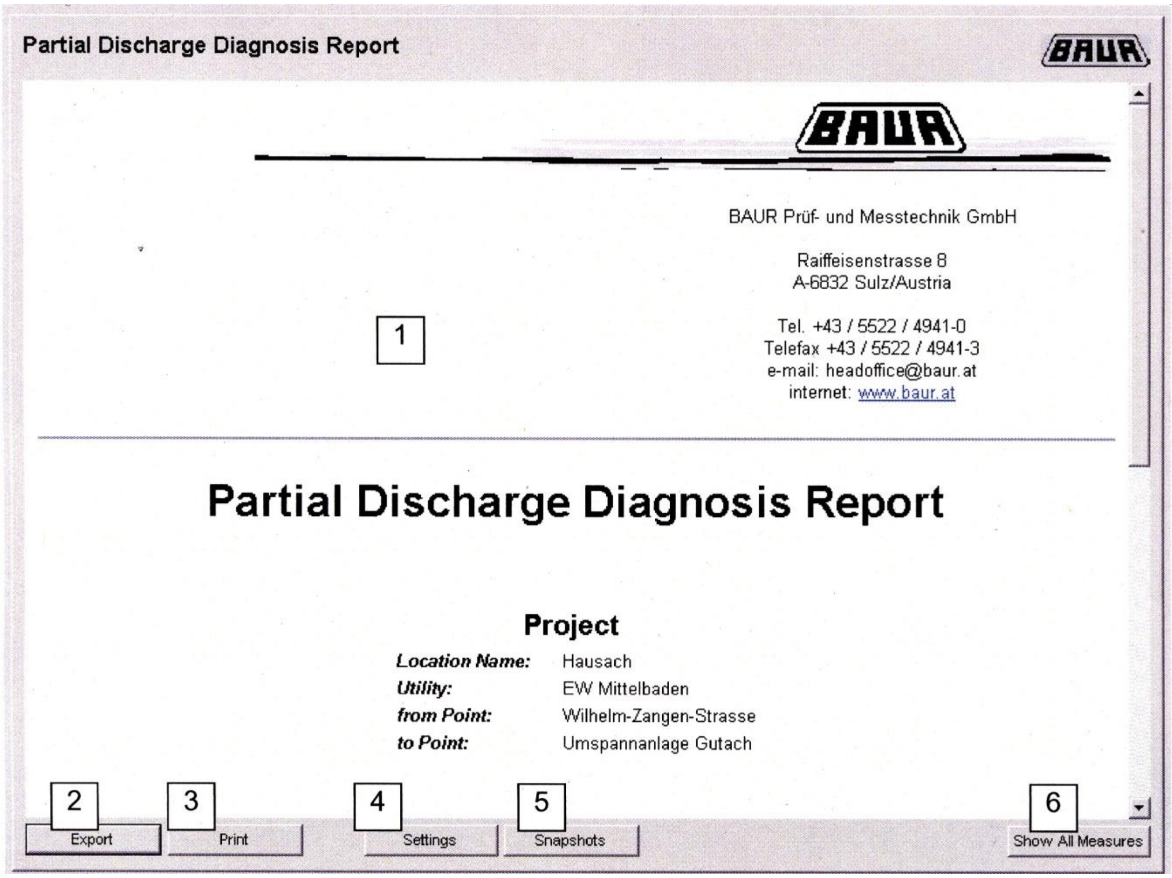
To export data from the PD measuring system, or to import data to a Laptop: -
- press Cable Data
- Load

To export data on to a memory stick: -
- select the data file (including Tan Delta and PD mapping files)
- press Export
- Files have to be exported one by one.

To import files to a Laptop: -
- press Import
- select the path / file
- the file is added to the project file list
- select the project
- press O.K.
- files have to be imported one by one

6 Report

The PD Diagnosis report is created automatically and shown on the display; Comments on the Diagnostics result can be entered in the comment field under Cable Data and are automatically transferred to the report. To **save the report**, press Save and define the required path for file storage.



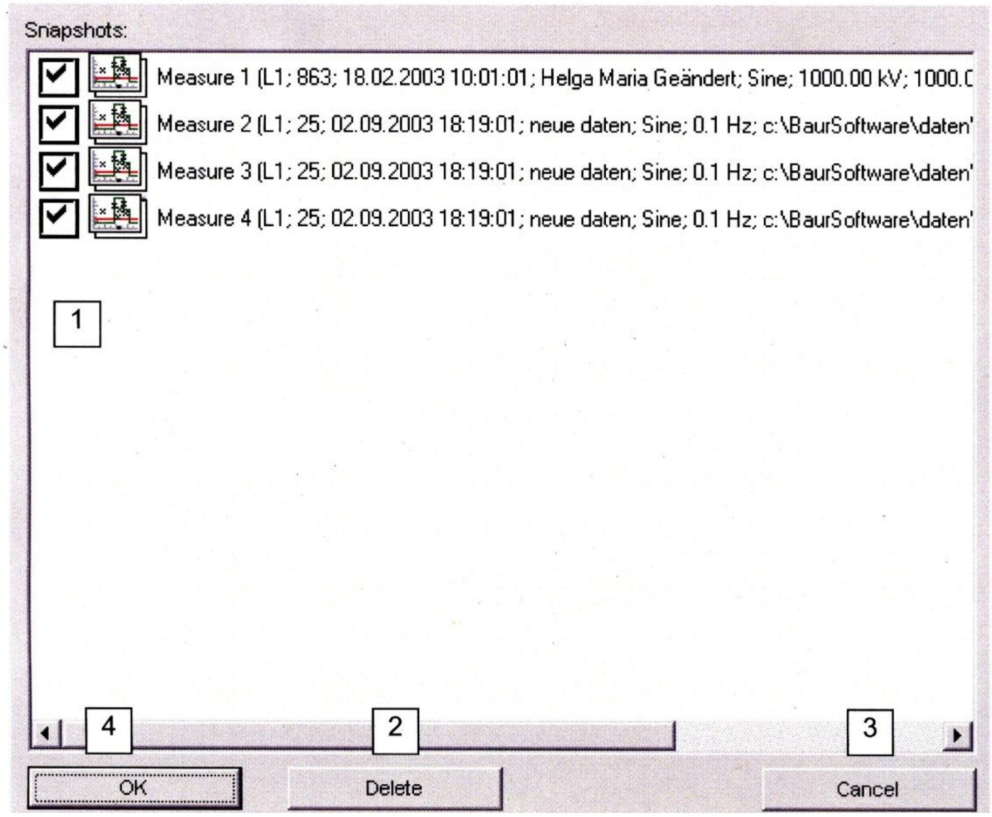
1) The actual report
2) Press to save the report to an external storage device
3) Press to print the report to an attached printer
4) Press to set view options of the report. The report customizing screen will be displayed
5) Press to select the snapshots to be displayed in the report
6) Press to auto-show all measurements of the project in the report. Old snapshots will be disabled

6.1 Saving the report

The report can be saved for archiving reasons or for transferring to a different PC.
Select the destination storage device and path and type in the desired file name.
The report will be saved in MHTML format. To view the report, use Microsoft Internet Explorer Version 5 or later for best results.

6.2 Snapshots

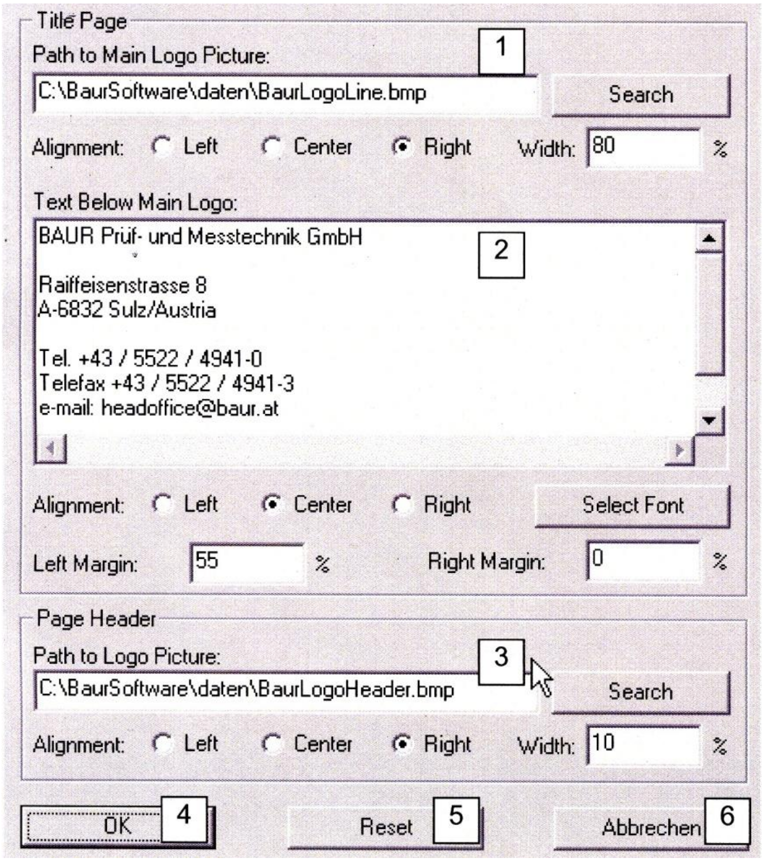
Press to get a list of all snapshots:



1) Select the Snapshots you want to include in the report.
2) Press to delete all snapshots.
3) Press to reject changes.
4) Press to confirm.

6.3 Setting report options

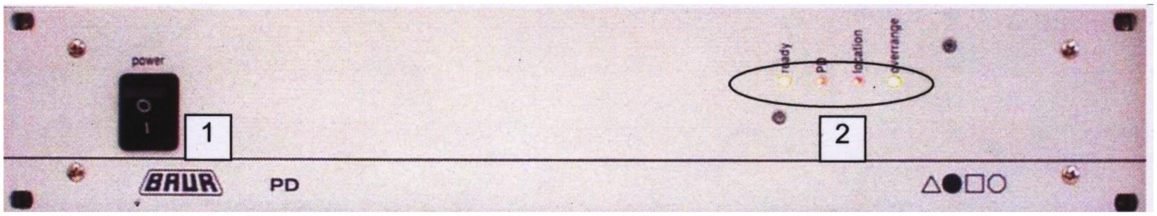
The layout and header of the report can be customized using the customizing screen: -



1) Select company logo, alignment of the logo and width.
2) Define text below the logo, the alignment, the font and margins left/right.
3) Select header logo, alignment and width.
4) Press to save settings.
5) Press to use default settings.
6) Press to cancel.

7 Hardware

7.1 PD Measurement System

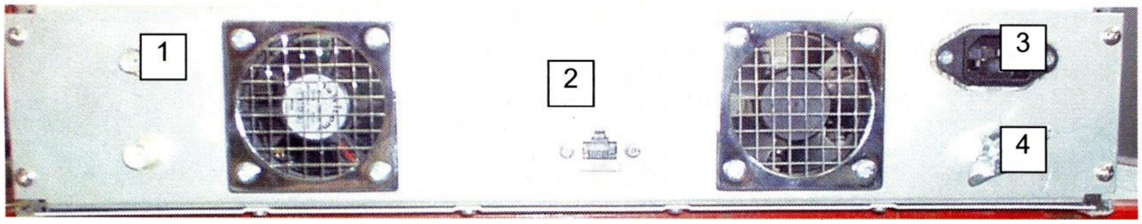


1) Mains switch.
2) Status information.

Status information (from left to right): -

- System ready (changing colour frequently when ready)
- PD capture (red = not active, green and yellow = active)

- PD location (red = not active, green and yellow = active)
- Input over range (green = in range, red = over range)



1) PD input signal, signal line to coupling unit.
2) Data connector, data cable to PC.
3) Mains, 230V, 50/60 Hz.
4) Safety earth: connection to safety earth.

The PD measurement system needs approximately 90 seconds to be ready after switching on.

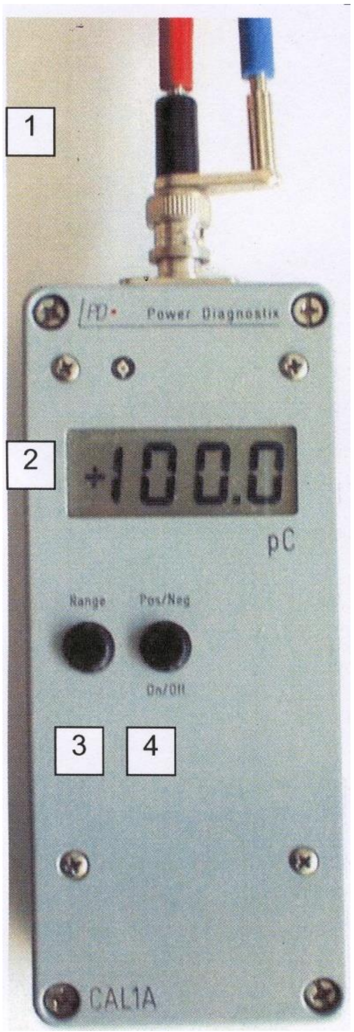
7.2 Coupling Capacitor Unit

1) High voltage connector
Connect high voltage line from high voltage generator here. Connect the cable circuit under test high voltage line here.
Note: - When calibrating no high voltage to be applied, discharge coupling capacitor unit first. When calibrating connect the red cable lead from the calibrator here.
2) Safety earth connectors
Connect to safety earth here.
When calibrating connect the black cable lead from the calibrator here.
3) Measuring output
Connect BNC cable leading to PD measuring system here.

Maintenance: -

For best results keep the surface of the coupling capacitor clean.

7.3 Calibrator



1) Output signal connectors
Metal terminal is ground connector
Black terminal is signal output.
2) Display
actual calibration value in nC.
3) Range button
press to toggle actual calibration value
0.1, 0.2, 0.5, 1, 2, 5, 10 nC selectable
4) Pos/Neg and On/Off button
press 3 seconds to turn calibrator on and off press short to toggle calibration polarity

Maintenance
If the battery is low (battery-symbol shown on display) un-screw the cover and replace the battery. Use a 9V block battery type DIN/IEC 6F22

Note: - After 5 minutes the calibrator will turn off automatically, for longer battery life. Turn on the calibrator again if you need more time for calibration.

8 Technical specifications

8.1 PD measuring system

General

Mains power supply	**110…230 VAC, 50/60 Hz**
Input power	< 50 W
Signal amplification	0..75 dB
Dimensions	19”, 2 U, 340 mm (13,4”)
Weight	5 kg (11 lb)
Temperature range	-10°C – 50°C, non condensing

PD location

Sampling rate	100 MHz
Sampling resolution	8 Bit
Bandwidth	100 kHz to 5 MHz
Sampling time Max.	160 us
Max. cable length	12.8 km at 80 m/us

PD measurement

Sampling rate	20 MHz
Sampling resolution	12 Bit
Bandwidth	10 kHz to 500 kHz

8.2 Coupling unit

Max. voltage VLF Sinewave	57 kV RMS
Capacity of coupling capacitor	10nF
Dimensions	304 mm x 315 mm x 550 mm (12” x 12.4” x 21.7”)
Weight	15 kg (33lb)

8.3 Calibrator

Calibration Charges selectable [pC]	100, 200, 500, 1000, 2000, 5000, 10000
Battery type 9 V block,	DIN/IEC 6F22

SAVING THE GENERATED DATA

To ensure that all the circuits that are PD mapped in WPD have an auditable trail there will be a PD Mapping server set up this server will allow all the data that has been generated with the PD mapping of the circuits to be stored in such a manner that if Ofgem want to view the data from any stage then the data will be available.

It is envisaged that read / write access will be granted to operators of the Baur PD mapping systems, Cable Specialists and Company Cable Engineer. Read access to the data will be granted to the 11kV and 33kV Planners, read access to all relevant TM's, DM's and NSM's.

The data shall be saved too: -

<XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX>

The format will be as follows: -

From the Root director a Master Folder shall be created and called '*South Wales*' and '*South West*'. Using South Wales as an example; In each of the master folders there will be a sub folder called '*Raw Data*', from this sub folder there will be another sub folder called for example '*Cardiff Depot*', this will give the name of where the PD mapping is being undertaken, in that sub folder there will be another sub folder called '*Cardiff East Grid*,' this gives the substation name, in this sub folder there will be another sub folder called '*Colchester Ave.*,' this give the breaker or feeder name, then finally there will be a sub folder giving the year of test '*2009*'.

Root >>
↳*South Wales >>*
↳*PD Mapping >>*
↳ *Tan Delta>>*
↳ Ditto
↳Raw Data >>
↳Cardiff Depot >>
↳Cardiff East Grid >>
↳Colchester Ave. >>
↳2009 >>
Data
Data
↳Brecon Depot >>
Etc. >>
↳Ty Coch Depot >>
Etc. >>
↳Reviewed Data >>
↳Cardiff Depot >>
↳Cardiff East Grid >>
↳Colchester Ave. >>
↳2009 >>
Data
Data
↳Brecon Depot >>

This process shall be replicated in the South West, with a master folder coming of the Root.

Root >>
↳*South West* >>
↳*PD Mapping* >>
↳*Tan Delta*>>
↳ Ditto
↳Raw Data >>
↳Bristol Depot >>
↳St Paul’s BSP >>
↳Broadmead Baptist Chapel >>
↳2009 >>
Data
Data
↳Radstock Depot >>
Etc. >>
↳Weston Depot >>
Etc. >>
↳Reviewed Data >>
↳Bristol Depot >>
↳St Paul’s Grid >>
↳Broadmead Baptist Chapel. >>
↳2009 >>
Data
Data
↳Radstock Depot >>
Etc. >>

APPENDIX A

SUPERSEDED DOCUMENTATION

This standard technique supersedes Company Directive ST:OS10C/3 dated July 2017, which should be withdrawn.

APPENDIX B

ASSOCIATED DOCUMENTATION

POL: OS10	Pressure Testing and Commissioning of High Voltage Apparatus.
ST: OS10A	Pre-commissioning Apparatus that cannot be connected to the Distribution System by normal Switching.
ST: OS10B	Pre-commissioning Apparatus connected to the Distribution System.

APPENDIX C

KEY WORDS

Pressure testing, VLF Testing, Tan Delta Testing, PD Mapping testing, Insulation resistance testing, Site commissioning.