Cable Discharge Mapping

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1 Introduction

Cable discharge mapping is a technique regularly used for the condition assessment and monitoring of high voltage cables. The technique has been used for well over a decade to obtain condition information on installed cable circuits. Although originally developed to assess the condition of ageing paper insulated cables, the technique may also be applied in the commissioning of new cable circuits.

The main difference between traditional discharge measurements and partial discharge mapping is that discharge mapping allows location of partial discharge activity within cable systems. Since discharge pulses travel at a finite speed along a cable and are reflected at impedance mismatches along the route, these characteristics may be used to identify where discharge activity originated along a cable route. By combining information from a number of partial discharge events, a final graphical plot, known as a 'discharge map' may be produced. This displays discharge magnitude as a function of distance along the cable route.

The ability to identify specific deteriorating areas allows remedial work to be planned and often saves on replacement costs. On new XLPE cables, some defects may not be detected by a simple withstand test leading to a defective circuit being put into service.

2 Test Equipment

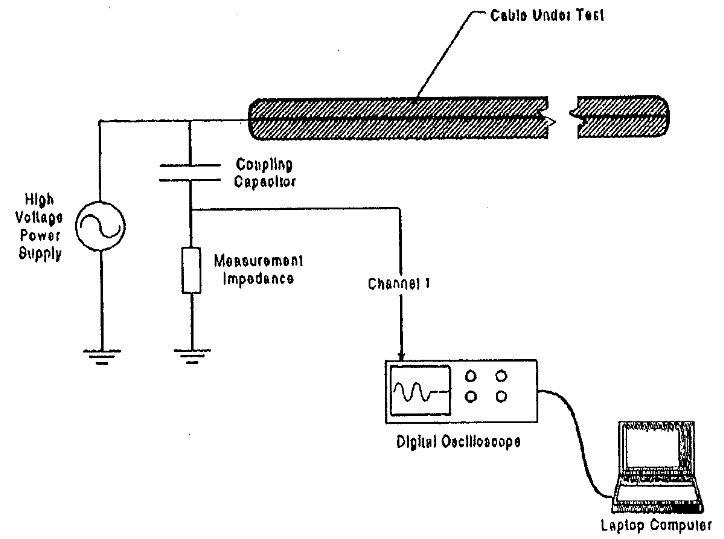


Figure 1: Test circuit

The simplified test circuit used for the measurements is shown in Figure 1. It consists of a discharge free AC power supply to energise the circuit; a coupling unit (coupling capacitor and detection impedance) to filter out the high frequency discharge pulses; a means of displaying the high frequency signals and a computer for processing the data.

At the beginning of the test, the cable length is calibrated in terms of the time taken for a pulse to travel from the test site to the remote end and back. This gives the 'calibration time' for the cable to be tested.

The cable is then energised and any high frequency signals generated are recorded and analysed. Each time a discharge takes place, two pulses propagate towards the ends of the cable from the discharge site. If we are recording at end A in Figure 2, we see the pulse which has travelled directly to A from the discharge site followed by the pulse which has travelled to the remote end and been reflected back towards A. The time difference between these pulses, Δt, allows us to calculate the location of the original discharge. The pulses are attenuated as they travel along the cable resulting in a signal which deviates from the ideal.

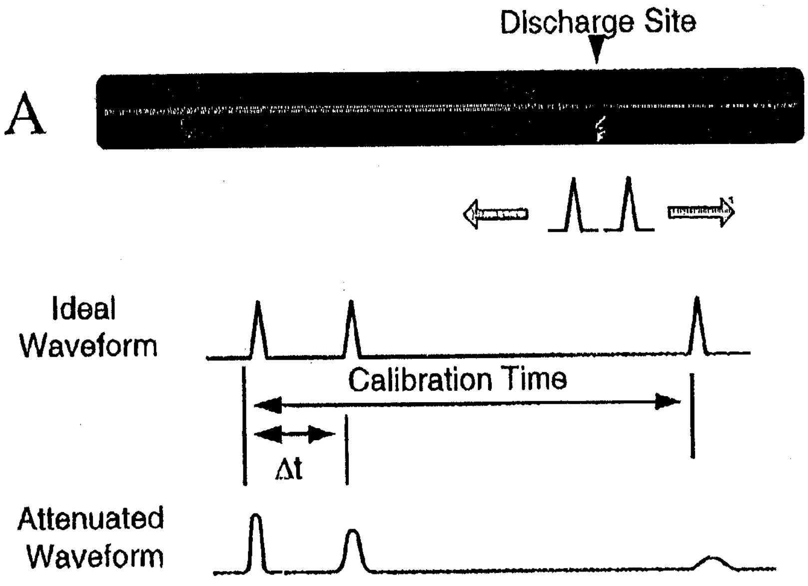


Figure 2: **Partial discharge waveform generation**

The traces from individual partial discharge events give information on the size and location of each discharge. This information is then stored to be included on the final map.

3 Site Measurements

Carrying out partial discharge mapping measurements on site presents a number of issues. There are some issues associated with noise immunity and how to capture and analyse the data produced when testing. However, the main issues are those of the physical difficulties associated with the size of test equipment, reliability and convenience.

3.1 Equipment Size

For short lengths of cable, it is possible to carry out tests using a mains frequency transformer, applying a voltage which matches the service conditions exactly. But even for short lengths of cable the power requirements are large and quickly make high voltage transformer test supplies impracticable, both from a physical size point of view and also a low voltage supply point of view.

For example:

Assuming 500m of 33kV single core 185mm^2 XLPE cable

$$\text{Capacitance} = 0.22\mu\text{F / km}$$

$$\text{Test Voltage}, V = \frac{33 \cdot 10^3}{\sqrt{3}}$$

$$= 19.05 \cdot 10^3 \text{kV}$$

$$\text{Test Frequency}, f = 50\text{Hz}$$

$$\text{Power} = V^2 \cdot 2\pi f \cdot C$$

$$= (19.05 \cdot 10^3)^2 \times 2 \cdot \pi \cdot 50 \times 0.11 \cdot 10^{-6}$$

$$= \underline{12.5\text{kVA}}$$

Alternatives to the traditional test power supplies are available to address this issue.

Discharge free Very Low Frequency, VLF, generators will reduce the power requirements by the ratio of the frequencies used. For example testing a 50Hz system at 0.1Hz will reduce the required power by a factor of 500. The equipment, even for testing several kilometres of 33kV cable at twice the normal voltage, can be mounted in a medium size panel van. Smaller, portable test sets are also available for lower voltages.

A further alternative is the use of high voltage resonant test sets. These use an inductor in the test circuit to create a resonance condition with the cable capacitance. This may be achieved by varying the frequency of the test voltage or the value of the inductance. Fixed.frequency test sets operate at the mains frequency while variable frequency sets typically operate at between 20-200Hz. The equipment is large and heavy requiring good vehicular access which is often difficult for some 11kV substations. For testing of cables up to 33kV the equipment would normally be mounted in a 7.5 tonne vehicle while a test set for 132kV cables may be mounted on a 40 tonne trailer. A trailer mounted generator is also normally required to provide the low voltage supply.

3.2 Reliability and Convenience

The equipment must be able to withstand the rigours of road travel on a daily basis. It must also be discharge free in the environmental conditions usually found in substations.

The efficiency of testing is also important, particularly if trying to minimise the cost of testing. It must be possible to carry out tests in a short time - tests on a cable circuit typically take about 1.5 hours.

3.3 Noise Immunity

During laboratory measurements, external interference can be successfully screened. However, using wide band detection techniques in substation environments often leads to unwanted radio frequency interference being detected.

Since the pattern of the waveform generated by partial discharge activity from within cables contains three characteristic peaks (Figure 3), it is possible to gate out activity which does not correspond to this pattern (Figure 4). It is also possible to distinguish between partial discharge activity from cables and interference from other sources during the analysis of data.

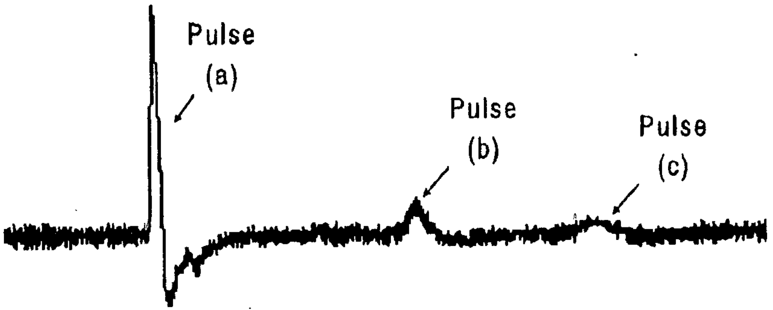


Figure 3: **Partial discharge waveform**

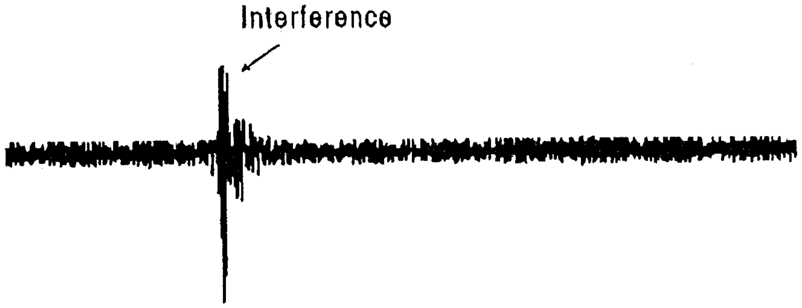


Figure 4: **Interference waveform**

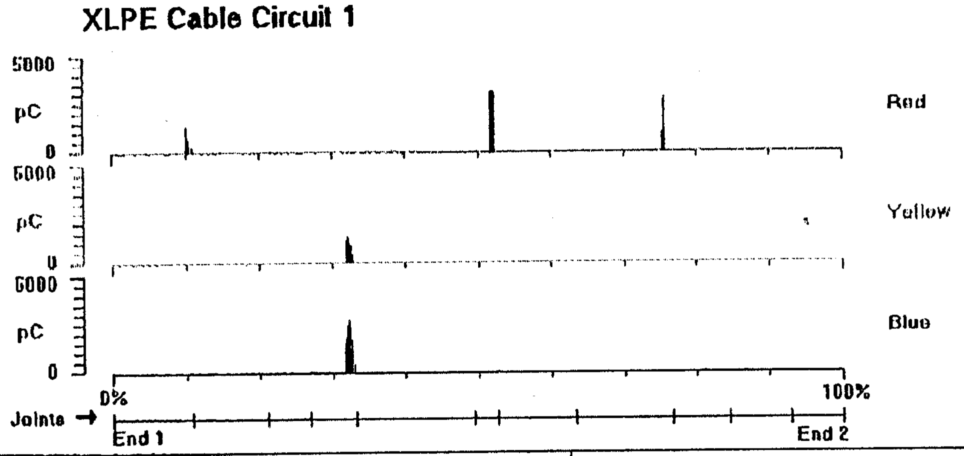
3.4 Length Limitations

The attenuation of high frequency signals in cables leads to limitations on cable lengths which might be tested. The limitation is usually as a result of the loss of the pulse reflected from the remote end of the cable. If this pulse cannot be identified from the background noise then the location data is lost. It may still be possible to detect and locate very large discharge sites but the final discharge map may not give a complete picture of the activity.

The attenuation in paper insulated cables is much greater than in XLPE cables and generally results in a limit of approximately 3km. This means that at 3km, it is likely that some significant data will be lost. For XLPE cables, circuits as long as 8km have been tested successfully.

4 Test Results

The following examples show results from a number of different tests on installed cables.



	Red	Yellow	Blue
Inception voltage (kV rms):	17.5	19.05	15.8
Number of cable events:	06	07	05
Max. cable discharge (pC):	3141	1326	2673
Ave. cable discharge (pC):	1406	639	1224
Max. term. discharge (pC):	0	0	0

Termination end effects: 2 %
Cable length: 2448 m
Cable return time: 26.95 μs
Cable type: 33kV XLPE

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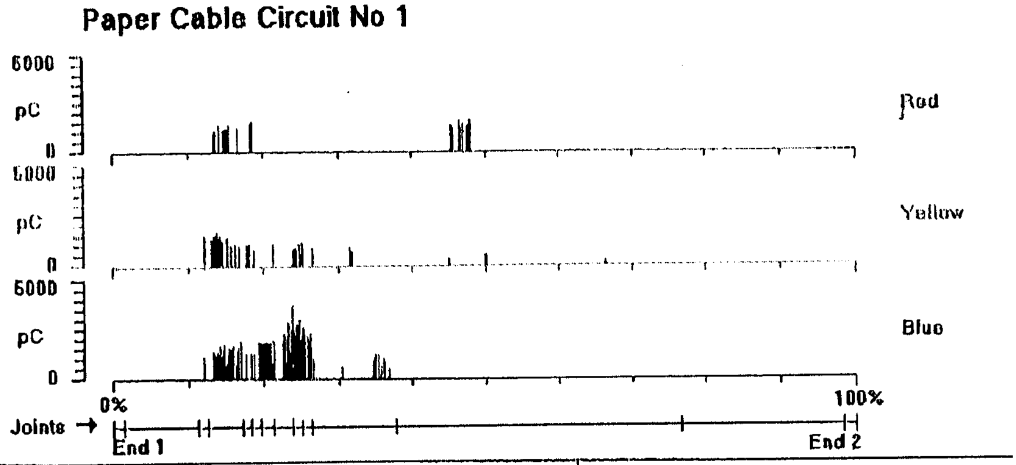
Figure 5: Discharge map from 33kV polymeric cable circuit

Figure 5 shows the results from a test on a new polymeric cable circuit. Partial discharge activity can be clearly seen at a number of the joint positions.



Paper Cable Circuit No 1

	Red	Yellow	Blue
Inception voltage (kV rms):	17.0	16.5	14.3
Number of cable events:	27	62	276
Max. cable discharge (pC):	1590	1635	3629
Ave. cable discharge (pC):	1260	1025	1519
Max. term. discharge (pC):	0	0	0

Termination end effects:	2 %
Cable length:	1014 m
Cable return time:	12.47 µs
Cable type: 33kV 3 Core Paper	

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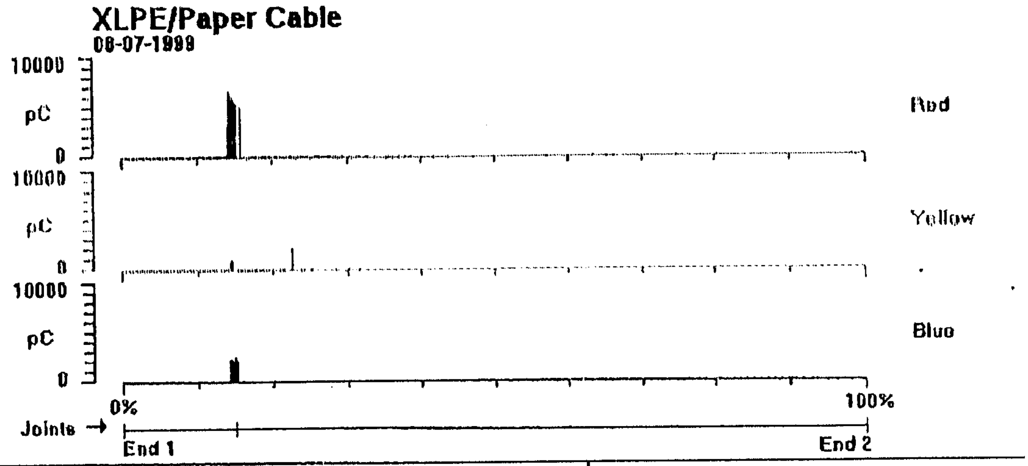
Figure 6: Discharge map from 33kV paper cable circuit

Figure 6 shows the result from a 33kV paper cable circuit. There is an area of activity near to a part of the circuit where failures have occurred in the past. Patterns such as this suggest further failures are likely. Earlier tailoring of fault repairs would have eliminated the suspect area and improved reliability.



XLPE/Paper Cable
08-07-1999

	Red	Yellow	Blue
Inception voltage (kV rms):	6.0	13.1	9.0
Number of cable events:	130	4	33
Max. cable discharge (pC):	6472	2061	2348
Ave. cable discharge (pC):	3675	1112	1579
Max. term. discharge (pC):	0	0	0

Termination end effects:	2 %
Cable length:	1450 m
Cable return time:	18.15 µs
Cable type: 33kV XLPE/Paper	

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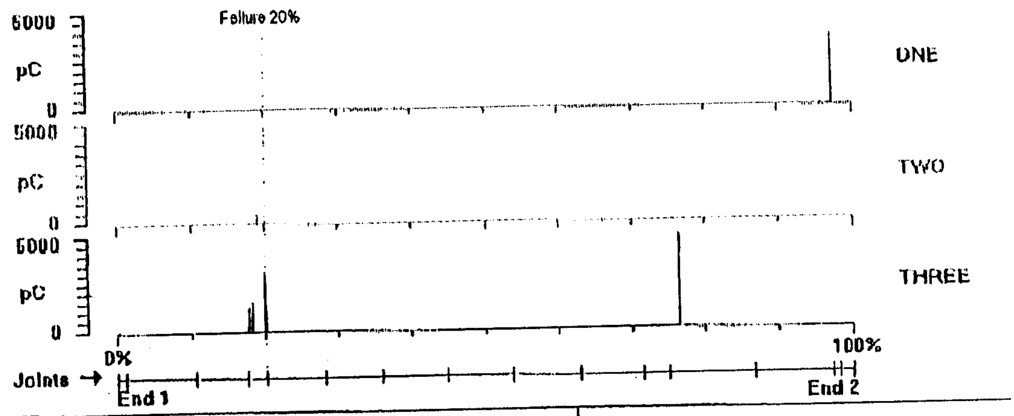
Figure 6: Discharge map from 33kV mixed insulation cable circuit

Figure 6 shows the result from a mixed dielectric circuit. The joint between the different cable types shows up clearly as being suspect.

Failure 398m (2 days following test)



	ONE	TWO	THREE
Inception voltage (kV rms):	13.0	16.1	14.0
Number of cable events:	0	1	7
Max. cable discharge (pC):	0	440	4779
Ave. cable discharge (pC):	0	440	2004
Max. term. discharge (pC):	3614	0	0

Termination end effects:	3 %
Cable length:	1992 m
Cable return time:	25.9 µs
Cable type:	33kV 3 CORE .3sqin H TYPE

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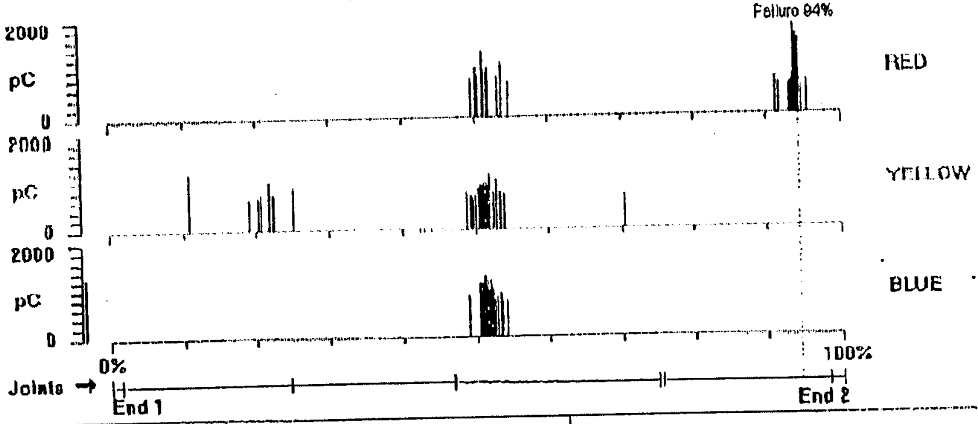
Figure 7: Discharge map from failed 33kV cable circuit

Failure 1003m (3 years following test)



	RED	YELLOW	BLUE
Inception voltage (kV rms):	-	-	-
Number of cable events:	51	45	60
Max. cable discharge (pC):	1806	1156	1274
Ave. cable discharge (pC):	903	773	923
Max. term. discharge (pC):	0	1221	1310

Termination end effects:	2 %
Cable length:	1067 m
Cable return time:	13.60 µs
Cable type:	33KV 3 CORE (300sqmm)

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Figure 8: Discharge map from a 33kV failed cable circuit

The failures of the circuits shown in Figures 7 and 8 have both occurred at sites of partial discharge activity. The magnitudes of activity are similar at the two failure sites are similar (2000-3000pC) but the time to failure following the test are very different. Although it is possible to predict ***where*** failures will occur, the two failure examples illustrate that the prediction of exactly ***when*** failures will occur is very much more difficult.

As more data is compiled, it may be possible to improve predictions about the time to failure. However, even without this added information, it is still possible to make firm recommendations based on the data.

5 Benefits

The main benefits of carrying out work of this type are clear.

By building a picture of the condition cable network, it is possible to delay replacement schemes and make large capital savings.

By replacing known suspect areas following faults, it is possible to reduce operational expenditure on finding and repairing subsequent failures near to the original failure site. Network reliability may also be improved.

By carrying out quality checks on newly installed cables, it is possible to identify defective parts before switching the cable onto the network.

6 Summary

Partial discharge mapping techniques can provide valuable information on the condition of existing installed cable circuits. The technique may also be used as a quality control check on new installation.

The technique has been used reliably and successfully for over a decade.

Immediate financial benefits can be obtained from better informed replacement and repair decisions.