NON-INTRUSIVE PARTIAL DISCHARGE MEASUREMENTS ON HIGH VOLTAGE SWITCHGEAR

Paper presented by
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1 Introduction

Partial discharges in high voltage metal-clad switchgear can result in catastrophic failure of the individual plant and in some cases of the substation. There has been a need for detection and location of the damaging discharges without the plant or substation being taken out of service. The conventional partial discharge detection technique requires direct connection to the high voltage busbars and therefore is limited in application

The EA Technology Partial Discharge Locator and Partial Discharge Monitor are designed to fulfil this important requirement. These instruments are complemented by ultrasonic detection to provide a comprehensive service to both Regional Electricity Companies and industry.

The Partial Discharge Locator and Partial Discharge Monitor both use the Transient Earth Voltage (TEV) measurement technique. The Partial Discharge Locator is a portable instrument used to survey switchrooms taking approximately an hour to survey a ten panel switchboard. The Partial Discharge Monitor is installed for a week monitoring a switchboard and provides a means of detecting intermittent partial discharge activity which may be missed by a survey with the Partial Discharge Locator.

2 Transient Earth Voltage (TEV) Measurements

If a partial discharge occurs in the phase to earth insulation of an item of high voltage plant such as a metal-clad switchboard or a cable termination, a small quantity of electrical charge is transferred capacitively from the high voltage conductor system to the earthed metal-cladding. The quantity of charge transferred is small and is normally measured in pico-coulombs. The transfer occurs, typically, in a few nanoseconds.

Figure 1 is a simplified cross section showing just one phase of a high voltage busbar with a gasketed joint on the left hand side.

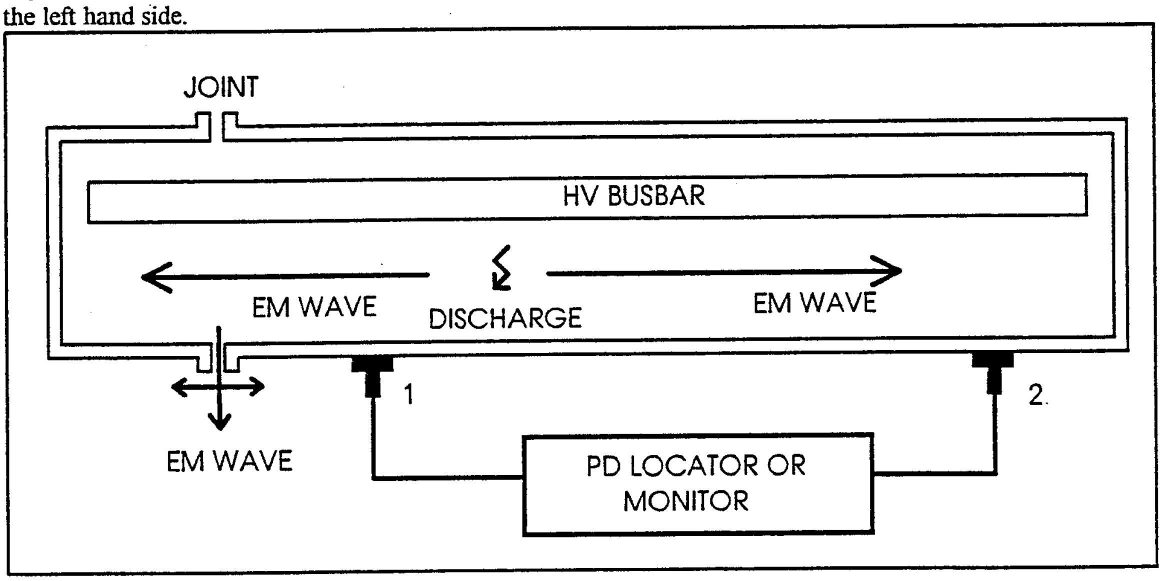

Figure 1 : Transient Earth Voltage Detection of Partial Discharge Activity

When the partial discharge occurs, electromagnetic waves propagate away from the discharge site in both directions. Due to the skin effect the transient voltages on the inside of the metalwork cannot be directly detected outside the switchgear. However, at an opening in the metal cladding, such as the gasketed joint in Figure 1 the electromagnetic wave can propagate out into free space. The wave front impinges on the outside of the metal cladding generating a transient earth voltage on the metal surface. Hence the technique is called TEV for transient earth voltage. The transient voltage has a nanosecond rise time and an amplitude which varies widely from millivolts to volts.

The TEV magnitude is a function of the amplitude of the discharge and the attenuation of the propagation path. The attenuation of the propagation path is itself a function of the internal structure of the switchgear and the size of the opening e.g. the thickness of the gasket in our example above.

The TEV is measured with a capacitive probe placed on the earthed metalwork of the switchgear. If two probes are placed on the metalwork it is possible to locate the item of plant containing the discharge by comparing the arrival times at the probes. In Figure 1 the signal will arrive at probe 1 before it arrives at probe 2.

3 Electromagnetic Partial Discharge Detection Instrumentation

3.1 Partial Discharge Locator

The Partial Discharge Locator is capable of detecting and locating continuous partial discharge activity within high voltage metalclad switchgear provided the background noise level is not excessive. In order to be confident that the source of the activity is from within the switchgear it is necessary to measure the background noise level, in air and on an item of metalwork which is not part of the high voltage switchgear e.g. on a metal substation door. If the source is from within the switchgear then the level on the switchgear will exceed the background noise by at least 10dB as attenuation of the signal occurs away from the switchgear as well as along the switchgear away from the panel containing the source. The 10dB value is also chosen to take into account variation of the background noise with time and position.

The instrument has two probes, only one of which is used for amplitude measurement during a survey of a switchboard. The survey is carried out by placing the probe on the surface of the switchgear near openings e.g. on the busbar chamber hatch cover, on the band joint, cable termination box etc. The amplitude of the signal generally decays away from the source but internal reflections and the attenuation of several possible paths makes location based solely on amplitude uncertain. Therefore, location is performed by placing probes on two items of switchgear and the precedence circuit in the Partial Discharge Locator will discriminate to 2ns which is equivalent to a path length of 600mm in air. Therefore, continuous partial discharge sources can usually be located to the correct panel on a multi-panel switchboard and often to an individual cable end box, voltage transformer, current transformer or switch-tank.

3.1 Partial Discharge Monitor

Partial discharge activity may be intermittent in nature. The discharge site may lie dormant for hours on end and then be initiated by a voltage surge or by changes in temperature or humidity. The site may then remain active for a few minutes or several hours before becoming dormant once more. This form of discharge activity is very difficult to detect during a site survey as the measurement period is so short e.g. each measurement takes approximately 10 seconds and the whole survey may take only an hour. Therefore, the Partial Discharge Monitor has been developed for installing in a substation for a period of about a week which is considered sufficient time to cover changes in load, ambient temperature, humidity and switching.

The instrument has eight probes and four aerials. The probes are magnetically clamped onto different items on the switchboard and the aerials are positioned around the switchboard.

The recommended layout is as follows:-

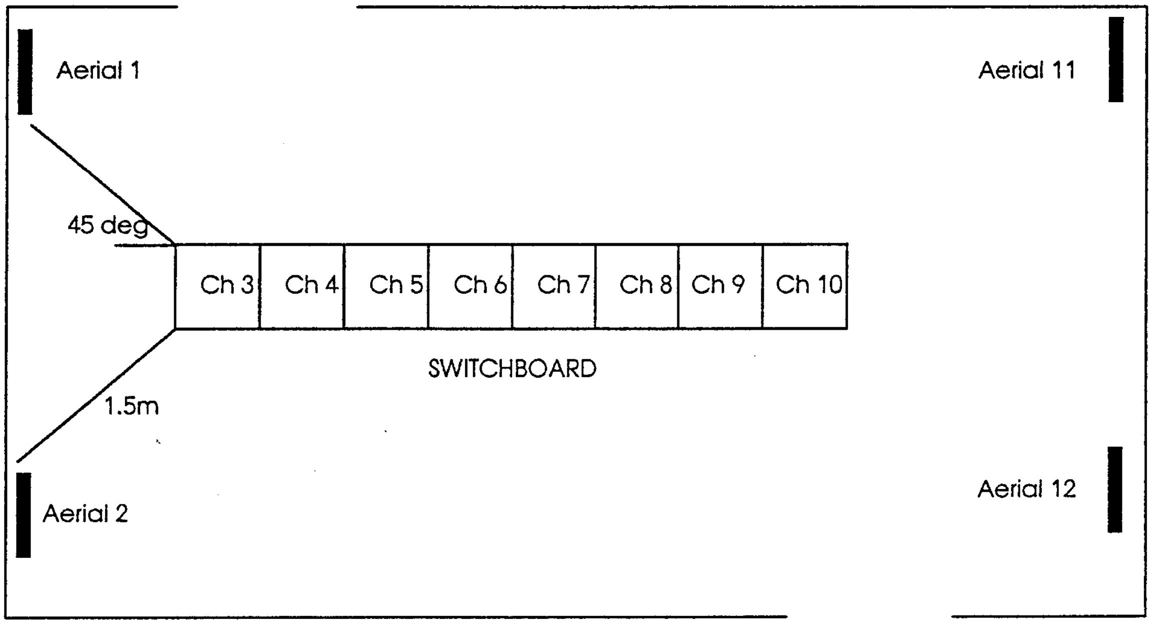

Figure 2 : Recommended layout of the probes and aerials of the Partial Discharge Monitor in a switchroom

The instrument records each pulse detected and allocates it to the channel at which the pulse arrives first. In every period (2 , 5 or 15 minutes) the number of pulses allocated to each channel together with the maximum pulse amplitude is recorded in a data file.

4 Ultrasonic measurements

In dry termination cable boxes partial discharge activity can occur within the termination and these can be detected with the electromagnetic instruments described. However, low levels of surface discharges have been found which are less than 50 pC and emit very low levels of electromagnetic signals. The electromagnetic signal is below the sensitivity of the Partial Discharge Locator or Monitor and if these instruments were made more sensitive the signals would be within the background noise level of many substations.

Provided a direct air passage is available through the skin of the cable box the airborne ultrasonic signal generated by these surface discharges is detectable with an ultrasonic detector. With a vented cable box the ultrasonic transducer is placed outside the vent hole, however, with a sealed cable box it is necessary to remove a bolt from the bottom of the cable box cover plate to be assured of a direct air passage.

5 Interpretation of Measurements

5.1 Partial Discharge Locator

The amplitude of the TEV measurement is a function of the amplitude of the discharge and the attenuation of the propagation path. Also the amplitude displayed on the instrument is measured in dBmV, therefore, the measurement is a relative indication only. An 11kV extensible switchboard may have 10 panels normally of the same manufacturer and type. Therefore a survey of the switchboard would produce sets of measurements on identical plant e.g. cable termination boxes. First it has to be established that there are some results which are above the background noise and therefore due to internal partial discharge activity. If more than one panel or item of plant satisfies this criteria then the double probe technique is used to locate the source.

Having established that there is a partial discharge source within an item of plant the seriousness of the finding needs to be established. If this was a one off set of measurements then a reading 20 or 30dB above any other readings on the switchboard would justify a further investigation. However, comparing the results with the same type of switchgear in the EA Technology Partial Discharge Measurement Database provides better interpretation.

5.2 Partial Discharge Monitor

The data collected by the monitor is stored on a disk and may be analysed on an IBM compatible PC using the post processing software provided with the monitor. The software generates a text file of the instrument setups and a summary table for each monitoring session. Each summary table is also placed in an individual file suitable for importing into the database. Finally a data file is generated for each session for importing into Microsoft Excel. Figure 3 shows the increase of discharge activity on an indoor switchboard when humidity increased during rainfall.

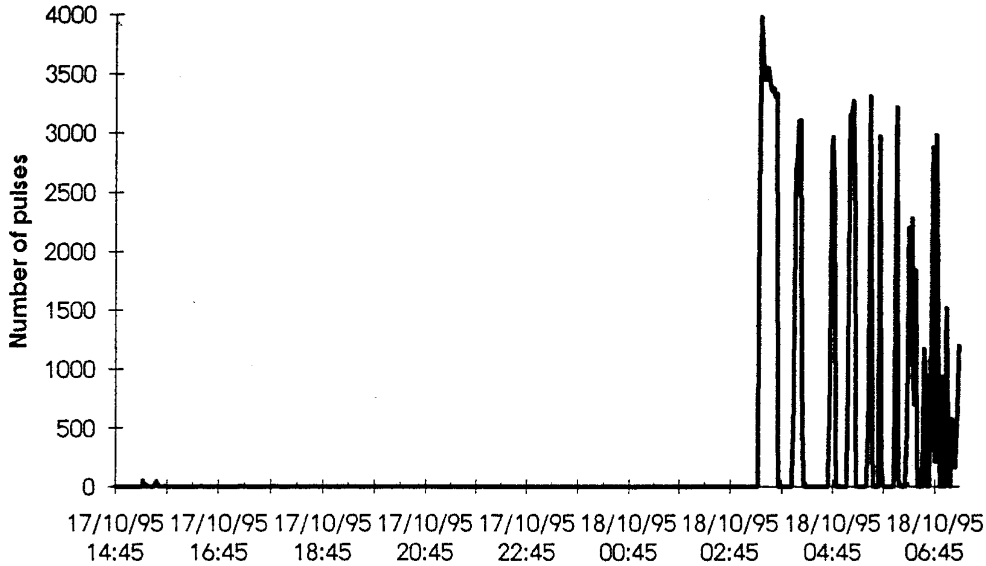

Figure 3 : The number of pulses that arrive first at the rear of an 11kV Bus Section Panel

The amplitude measurements can be used in the same manner as those obtained by the Partial Discharge Locator to determine the seriousness of the readings. However, additional information is available from the Partial Discharge Monitor data.

The number of pulses per cycle enables the type of source to be determined. A partial discharge source in a void if continuously active would discharge at least once per cycle dependent on the inception voltage and the working voltage. However, discharge sources are often intermittent in nature. Such intermittent sources may have periods of at least one discharge per cycle but others have been found to discharge once in every 20 cycles for example giving a maximum number of pulses per cycle in the summary tables of 0.050. Therefore, activity of greater than 0.050 pulses per cycle are associated with partial discharges. If the number of pulses per cycle is more than 2 This corresponds to one site with a low inception voltage, i.e. multiple discharges per cycle or alternatively to more than one site which is often associated with surface discharge activity.

Three severity terms are also used to interpret the results, these being:

SHORT TERM SEVERITY
Maximum pulse amplitude × Number of pulses per cycle

MAXIMUM SHORT TERM SEVERITY
Maximum value of (pulse amplitude × Number of pulses per cycle) calculated for every period

LONG TERM SEVERITY
Average maximum pulse amplitude × Average Number of Pulses per cycle × Fraction of Time when pulses detected

The first two terms relate to the damage caused by high discharge levels which may be from an intermittent source. The third term relates to continuous or nearly continuous discharge sources.

The values of severity obtained with different types of plant can be compared to determine the seriousness of the measurements.

A measurement on a 33kV compound filled end cap had a maximum level of 31dB, maximum number of pulses per cycle of 1.9, maximum short term severity of 48 and a long term severity of 33. In this case, breaking down the end cap revealed blistering of the bakelised paper insulation which was wrapped around the busbar. Therefore, analysing all the information obtained from the Partial Discharge Monitor enables a better assessment to be made of the condition of the switchgear insulation.

5.3 Ultrasonic measurements

The amplitude of the ultrasonic signal depends on the characteristics of the transducer and instrument as well as the discharge activity and the attenuation of the transmission path. Unfortunately these instruments are not standardised in the manner of a sound level meter for acoustic measurements. Therefore, the readings obtained with ultrasonic measurements must be related to the instrument in use. By including these measurements into the EA Technology Partial Discharge Measurement Database a greater understanding is obtained.

6 Conclusions

The Partial Discharge Locator and Partial Discharge Monitor are designed for use on indoor metalclad high voltage switchgear up to 33kV containing compound, oil or air insulation. At higher voltages the sensitivity of the instruments may not be sufficient and in outdoor applications discharges from bushings and busbars above the switchgear may confuse the results. These electromagnetic techniques are complemented by ultrasonic detection when examining dry termination cable boxes.

The understanding of the seriousness of the observations can be enhanced by pooling together measurements on large numbers of similar switchgear in the EA Technology Partial Discharge Measurement Database. Introducing short and long term severity terms allows a more knowledgeable assessment to be made. This assessment may recommend direct action or a further investigation to establish in more detail the location of the partial discharge activity. For example which CT is discharging in a CT chamber, or whether the discharge is in an orifice bushing or inside a busbar chamber.

The instruments enable the condition of the switchgear insulation to be assessed whilst it remains in service. The network operator is given confidence in the continuing safety and reliability of the switchgear and is provided with a technical basis for making financial decisions on the need for refurbishment or replacement.

Biography

Peter Brown was born in England in 1945. He received his BSc in Physics from the University College of North Wales, in 1967. In the same year he joined the Nelson Research Laboratories of English Electric. In 1969 he joined E A Technology where he is currently a member of the Substation Plant Services Group. In addition to his work on the detection of partial discharge activity he has developed a thermodynamic model for power transformers. The model is used to determine the maximum cyclic rating of transformers based on monitoring their thermal performance in service.