NEW TECHNIQUES FOR ON-LINE PARTIAL DISCHARGE TESTING OF SOLID-INSULATED OUTDOOR MV AND HV PLANT

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ABSTRACT

The authors present a paper detailing new techniques for on-line partial discharge (PD) testing of in-service, solid-insulated, medium and high voltage plant located in outdoor environments. Detection of electromagnetic radiation is a well known and documented method for location of PD signals. However interference signals from RF sources, corona and surface discharges can be a major problem when testing outdoors, obstructing the observation of internal PD and confusing measurements. Experience in these situations has led to the development of various new tools and test techniques for PD identification and discrimination of interfering signals and background noise. Shielding sensors have been employed with a multi-channel measurement system to assist in detecting signals that are external to the equipment under test with time-of-flight (TOF) analysis. Methods for automating the test procedure and data analysis have also been a key part in this research and will be fundamental to future developments.

Keywords: Partial Discharge On-line Electromagnetic

1 INTRODUCTION

Detection of partial discharges in high voltage plant gives indication of degradation in the insulation and can act as an early warning system to insulation failure. Wideband electromagnetic detection methods for on-line detection and localisation of partial discharge in cables and switchgear at distribution voltage levels have been available for 10 years [1]. More recently these particular methods have been developed for on-line testing of solid-insulated outdoor plant at transmission and distribution voltages [2]. Plant that can be tested includes current and voltage instrument transformers and cable sealing ends. A major problem that has been encountered when testing this equipment is the detection of interfering electromagnetic signals from PD, surface discharges and corona on other equipment. Radiometric methods can be used for detection and location of these signals in which arrays of RF antennas are employed [3], [4]. This paper documents some new techniques that focus upon correlating the signals received by local and remote electromagnetic sensors in order to better understand the nature of the discharge signals and crucially, determine if they are internal or external to the insulation.

2 PARTIAL DISCHARGES IN SOLID-INSULATED PLANT

2.1 External Discharges

The term external discharge refers to discharges on the insulation surface caused by dirt or water on the outer of the insulation sheds and also discharges into air (i.e. corona). Optical, acoustic, electrical and electromagnetic methods are employed to detect these discharges. Optical and acoustic signals are often observable by eye (under low-light conditions) and ear; although ultraviolet and ultrasonic methods are often used for detection. These discharges are a well known and to a certain extent, accepted phenomenon in high voltage switchyards. Figure 1 shows a low-light photograph of corona discharge on a 400kV cable sealing end arcing horn.

Figure 1. Low Light Photograph of Discharge on Sealing End Arcing Horn

2.2 Internal Discharges

Internal insulation discharges can be due to voids in the insulation, poor conductor-insulation interfaces or poor insulation-insulation interfaces. Oil discharges will also be considered as internal for some solid-insulated equipment such as cable sealing ends, where the insulation system comprises polymeric, composite, ceramic and oil insulants. The focus of detection methods for these discharges is predominantly electromagnetic. Internal discharges pose a more serious threat than external ones due to the consequences of a failure if the PD escalates to the point that a conductive path is formed between two conductors or between a conductor and earth. Should this happen the resulting arc can cause the insulation to explode out of the equipment.

3 MEASUREMENT SYSTEM

3.1 Detection Hardware

The measurement system applied is based around the wideband (0-400 MHz) OSM-Longshot test unit from IPEC HV which utilises a high-speed Digital Storage Oscilloscope (DSO) front-end to make high-resolution measurements of PD signals. After collection of the PD signals a range of analysis software is then used to categorise and analyse the data collected. The latest DSO hardware allows for entire 50/60 Hz power cycles to be sampled synchronously on four channels at up to 500 MS/s or one sample every 2ns. This detection system has been used predominantly for short-term spot tests of around 5 to 30 minutes, although site-permitting, short-term monitoring can be carried out over a period of up to around 24 hours.

3.2 Sensor Connections

Although RF electromagnetic energy radiates from internal PD, in solid-insulated equipment the energies of these signals can often be too low for accurate detection remotely and thus direct coupling of sensors is seen as the best option. A split-core High Frequency Current Transformer (HFCT) is connected around the earth connection cable of the plant under test to electromagnetically detect PD signals flowing to earth. A Transient Earth Voltage (TEV) probe is also applied to the nearest earthed surface, for example the plant's base plate to detect electromagnetic radiation that has been induced onto the earthed surface. In addition to these local sensors, remote electromagnetic sensors, such as RF antennas are used to aid in the discrimination of interfering signals from other items of plant, be those partial discharges or other impulsive interference.

The placement and number of antennas used is very much dependent on the location of the plant under test with regards to the other items of plant that are potential sources of interfering signals. With the current detection hardware a maximum of three additional RF sensors with only one local sensor may be used. This has been found adequate for most cases in which interference arrives from several directions. An example of sensor connections on a cable sealing end is shown in Figure 2.

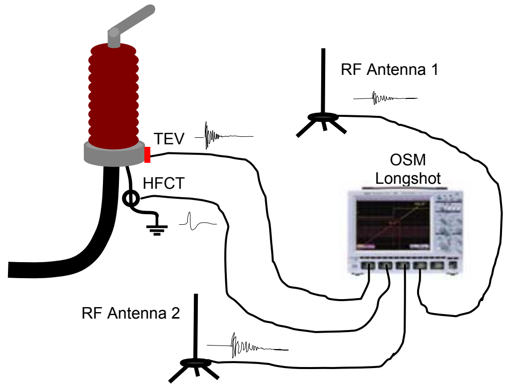

Figure 2. Typical PD Sensor Arrangement

4 DETECTION METHODOLOGY

The flowchart in Figure 3 outlines the data capture procedure employed by the measurement system. Due to the abundance of interfering signals, raw data is captured from all channels synchronously with the power cycle, as opposed to capturing individually triggered events. This ensures that any low level internal PD events will still be captured for recovery in the post-processing stage and also allows phase relationships of the pulses to be observed. Event recognition is then carried out in software to find all the transient events that occur over the power cycle and segregate them into PD events and noise. The PD events which occur on more than one sensor are then precedence detected, by measuring the time at which the first edge of the transient signal rises above a set threshold, to determine if the signal arrives at the local sensors first. As a final stage the PD events are diagnosed as being local internal PD, external PD or other interference.

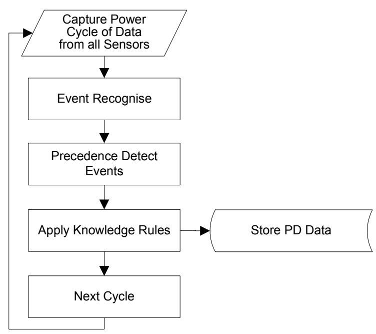

Figure 3. Data Acquisition Flowchart

5 DIAGNOSTIC RULES

Through field and laboratory experience, rules have been developed for the diagnosis of internals PD signals from on-line measurements. In general these rules are:-

- Signal arrives on local TEV sensor first
- Rise time of first edge is fastest on the local TEV sensor.

- Internal events have a strong signal on the HFCT coincident with the local TEV.
- The first peak of the signal should be the largest on the local sensors.
- Non-local signals will commonly have a “preamble” before their peaks, possibly due to multipath effects.
- Signal peaks must be at least twice the standard deviation for accurate detection.

6 ON-LINE FIELD MEASUREMENTS

6.1 Internal PD Detection

The measurement system described has been applied extensively in the field, predominantly to carry out partial discharge surveys of a particular type of plant (fleet survey). As an example Figure 4 shows PD activity across one power cycle for four sensors when testing an HV XLPE cable sealing end. Several impulses are clearly observable on the TEV sensors, whilst the majority of the activity on the HFCT is noise from the cable earth strap. Short impulses are however still observable through event recognition.

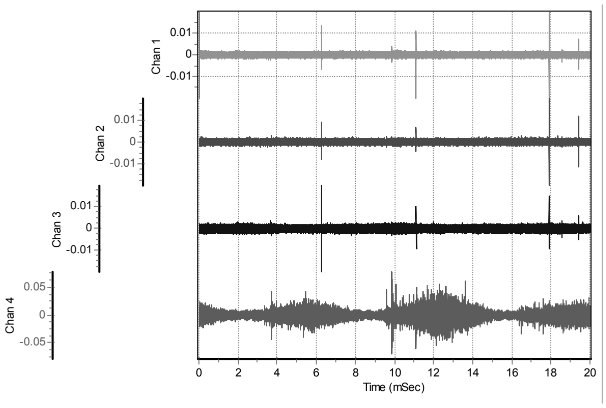

Figure 4. PD Activity across Power Cycle
Channel 1: Local TEV, Channels 2: Remote TEV 3m from plant, Channels 3: Remote TEV 6m from plant, Channel 4: HFCT

Figure 5 shows an internal PD pulse identified by the event recognition software, it is clear from this that the local TEV sensor detects the pulse in advance of the two remote sensors and also has the fastest rise time and peaks on the first edge. A large mono-polar pulse is observable on the HFCT coincident with the local TEV; a second pulse is also observable on the HFCT. The time difference between the two pulses on the HFCT confirms the second pulse to be a reflection from far end of the cable and thus the source to be the sealing end.

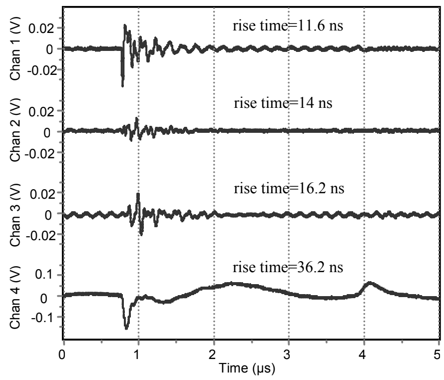

Figure 5. Internal PD Pulse Waveform
Channel 1: Local TEV, Channels 2: Remote TEV 3m from plant, Channels 3: Remote TEV 6m from plant, Channel 4: HFCT

6.2 Interfering Signals

Although in the previous case the pulse on the cable earth strap was key to the diagnosis, the multiple propagation paths of discharge signals can also be a frequent cause of disturbance to measurements. Figure 6 shows an example of a discharge pulse received when testing a cable sealing end which has arrived at the measurement set-up both through air and the high voltage cable. As the antenna detects the pulse first, the source is deemed to be from another item of plant. The HFCT clearly shows two pulses. The first pulse having travelled through air and the second through the cable, with the time difference due to the difference in pulse travel speeds for air and XLPE cable, 3×10^{8} ms^{-1} and $\approx1.6\times10^{8}$ ms^{-1} respectively. This also explains why the signals on the TEV sensors appear to have two transients.

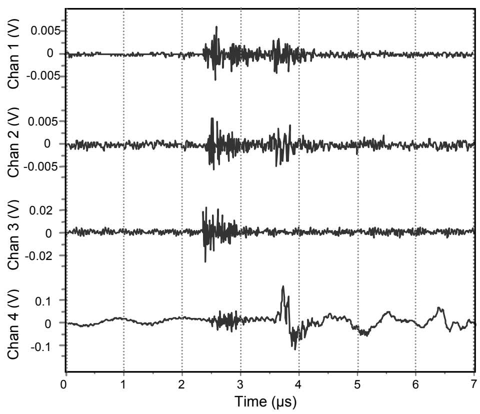

Figure 6. Interfering PD Pulse Waveform
Channel 1: Y Phase TEV, Channel 2: B Phase TEV, Channels3: Antenna 13m from plant, Channel 4: HFCT

7 CRITICALITY FOR ON-LINE PD MEASUREMENTS

When any internal PD is detected on-line it is crucial to diagnose the severity in order to establish the danger that it is posing. Unlike testing of cables and MV air and solid insulated switchgear, where extensive on-line and off-line PD testing has led to the development of PD tolerance guidelines, there are no such guidelines readily available for testing of the outdoor plant described in this paper.

The main parameters used to calculate criticality are the pulse amplitude of the first edge and number of pulses per cycle. With these, levels of severity can be calculated based on the recurrence of PD activity. For internal PD within solid insulated plant there is very little tolerance and thus it could be said that if any internal PD is detected, the plant is in a very critical state and action should be taken. However the focus should be put onto those items of plant with the highest PD levels. Figure 7 shows such results from a survey of 100 25kV Voltage Transformers which had PD within the cast-resin insulation due to a flawed manufacturing process. From this information an asset replacement strategy was developed, with criticality determined against the ambient PD level.

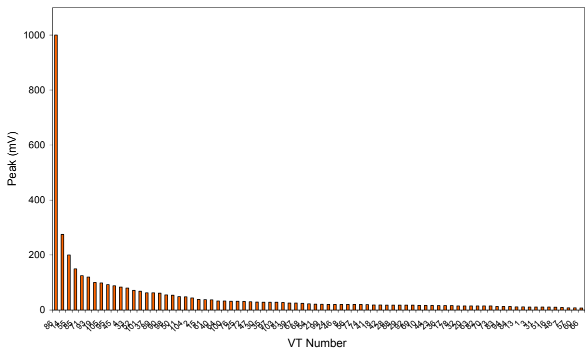

Figure 7 25kV Voltage Transformer PD Level Survey

8 FUTURE DEVELOPMENTS

Many PD measurements have been taken with the system described herein, however these have mainly been relatively short spot tests of around one hour. Experimentation by the authors and many other bodies has found variations in PD activity with load, humidity, and various other parameters. Monitoring for extended periods of time (24 hours to 1 week) would allow significant knowledge to be gained of these variations. The measurement system is currently constrained by the number of channels on the oscilloscope used. Clear advantage can be seen in increasing this, in order to allow more sensors to be used to help discriminate interfering signals in noise-harsh environments and also to allow all three phases of an item of plant to be tested simultaneously.

The extended application of the precedence detection methods to the PD testing of other types of equipment is also thought to be a feasible development. Some examples include PD testing of cable feeders on a common busbar where PD signals can radiate across the bus to adjacent feeders and testing of metal-clad switchgear where multiple TEV probes can be used to located signals to a switchgear panel [5].

9 CONCLUSIONS

The methods documented in this paper have been proven through extensive field experience to enable detection of internal PD signals whilst they are still at a low level, and the threat is minimal. The combination of raw data capture and advanced signal analysis in software has ensured the ability to detect low-level internal PD signals amongst high numbers of interfering signals and observe their synchronicity with the power cycle. Scope has also been realised for future developments of the system in order to monitor more items of plant for longer periods of time.

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