AVOIDANCE OF MV SWITCHGEAR FAILURE CASE STUDIES OF ON-LINE CONDITION MONITORING

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ABSTRACT

This paper considers, through a series of practical case studies, the avoidance of major incidents through the targeted use of on-line condition monitoring of MV indoor switchboards. A technique to pin point the location of partial discharge (pd) using time of flight measurement techniques is discussed.

INTRODUCTION

MV switchboard failures are fortunately rare but a single incident can affect many thousands of customers for prolonged periods and consequently have a major impact on customer interruption statistics as well as on customer and regulatory perception, and pose risks to operational staff. The devastation which can be caused by failure of switchgear is illustrated in figure 1. The financial impact of compensation payments, regulatory penalties and the costs of emergency and remedial works can be considerable.

Figure 1 Damage to substation following a catastrophic switchgear failure

There was an average of 32 switchgear faults per year affecting the 1150 primary (33 kV and 11 kV) substations on the EDF Energy Networks systems over the past three years (incidents on 2.7% of substations pa). The effect of these faults varied from no interruption in supply to the equivalent of 12 customer years of interruption.

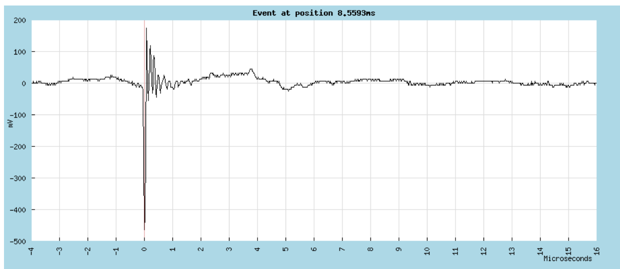
EDF Energy Networks have deployed extensive multi-sensor on-line monitoring systems together with web based analysis and alarm tools to monitor the condition of some 60 key substations, comprising over 1000 panels of switchgear with on-line monitoring of both cables and switchgear provided by some 1800 sensors. These include substations in London and the Southern and Eastern areas of the UK, as well as in France. Early warnings from these systems are routinely providing opportunities for timely targeted interventions by field maintenance teams before catastrophic failure.

The on-line monitoring system is available through remote web-access displaying the latest and historic pd information, together with a switchboard and circuit criticality assessment. Alarm thresholds can be set to enable SMS text messages to automatically be sent to key staff.

This paper details three instances where partial discharge on switchgear has been successfully identified remotely by the on-line monitoring system and looks at recent advances which have been made in the analysis of switchgear partial discharge (pd) to pin point an incipient fault.

Switchgear pd pulses are characterised by their fast rise time and narrow shape as illustrated in figure 2.

Figure 2 Example of switchgear pd



PARTIAL DISCHARGE SENSORS

Five types of sensors are deployed at some of the substations. A discussion of the sensors with respect to switchgear pd follows:

<u>AA sensors</u>

Airborne Acoustic ultrasonic sensors are presently located on some higher risk switchboard panels. AA sensors are very effective at picking up local partial discharge provided there is an air path. Location of the source of the pd using AA sensors and acoustic triangulation techniques have been used on-site in the past, but the practicality of remote location using these techniques requires AA sensors to be placed elsewhere in the substation, e.g. on the ceiling, and this remote location technique has yet to be validated

TEV or CC sensors

Transient Electric Voltage (TEV) or Capacitive Coupled (CC) sensors are presently located at some substations on the switchboard panels and busbar sections.

Large TEV signals can travel the whole length of a busbar without significant attenuation and their relative amplitudes can be affected by their actual locations and the type of switchgear panel. Accurate pd source location using TEV sensors should therefore be undertaken by simultaneous timing, not by amplitude or counts alone. Investigations have been undertaken to determine the optimum location for TEV sensors e.g. at the end of each busbar section and separately for endboxes and at each end of busbars.

CT Sensors

High Frequency Current Transformer (CT) sensors are located on the cable end boxes of the switchboard panels. CT sensors primarily capture cable pd but CT inputs can contribute to switchgear pd assessment as they can also see pd within fully screened enclosures which are not seen by TEV or AA sensors - such as discharge in cable endboxes. The use of CTs to provide location timing signals for switchgear pd is being further investigated as detailed later.

Temperature and Humidity Sensor

Substation air temperature and humidity are found to be major factors in the inception of discharge in indoor switchgear. A new range of fully compatible sensors has been designed and wide scale deployment to switchrooms is planned for 2009 to enable improved understanding of the criticality of discharge events and of the environment.

MERTON CASE STUDY

AA sensors detected partial discharge on a bus section circuit breaker and a bus coupler circuit breaker at Merton substation throughout 2008. Investigation revealed discharge between the circuit breaker bushing and the lid of the vacuum bottle shroud. The particular circuit breakers were found to be very dirty with greasy dust covering the bushings as can be seen from figure 3.

General substation environment improvements together with switchgear cleaning in October have reduced the pd levels significantly as can be seen in figure 4.

BRIGHTON TOWN CASE STUDY

Significant partial discharge was recently detected on two different panels at Brighton Town substation by CTs. An example of a pd signal obtained remotely from the CT sensor on panel 10 is shown in figure 5. Note that the signal is so large that it is saturating the acquisition at ±800 mV. A similar pd signal was detected on panel 15.

Figure 5 Partial discharge observed at Brighton Town

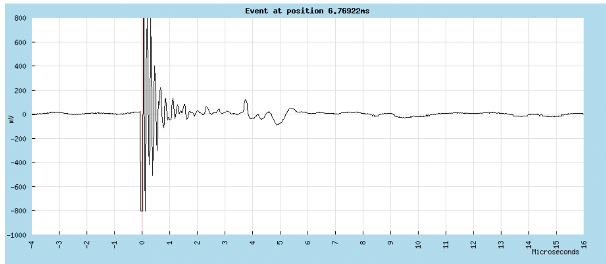


Figure 6 details the discharge over time for a pulse observed at the same time over a period of five weeks in December. The discharge can be seen to appear at the same point in phase or 180° apart indicating that it is a single phase event. During a site visit a series of pd timing tests were carried out across adjacent panels using CC sensors to confirm the suspected panels were the source of the discharge. Further timing tests were undertaken around the circuit breaker and the cable box with the circuit breaker and downstream circuit both in service and out of service to locate the exact source of the pd.

Figure 4 Merton Front Bus Section Peak and Count readings (Counts > 9mV)

Key to figure 4:
Green vertical lines indicate when the breaker was switched; red vertical lines indicate other operational changes.

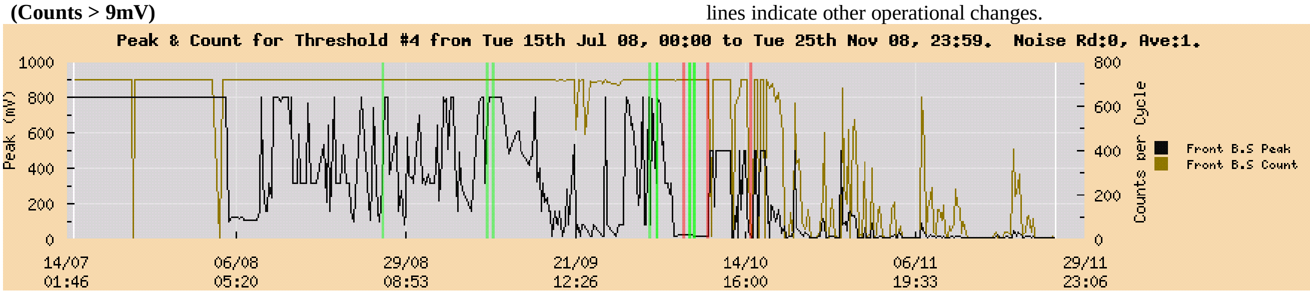
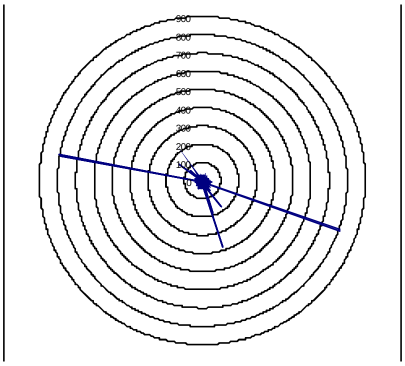


Figure 6 Phase plot of discharge at Brighton Town



Discharges were located in CT chambers in the case of panel 10 and in the circuit breaker in the case of panel 15 for investigation and remedial work. In neither case was ultrasonic acoustic noise detected.

CARSLAKE CASE STUDY

In a substation with switchgear discharge it is common to see a histogram similar to that shown in figure 7 where the switchgear discharge is indicated to be high at several of the panels. This is usually the same discharge being picked up by several sensors and currently it is difficult to pinpoint the source of discharge to the individual circuit breaker, busbar or cable end box remotely.

In order to improve the pd switchgear monitoring system a trial system using time of flight analysis was set up at Carslake Substation at the end of October 2008. The monitoring system was reconfigured to acquire two CC channels at opposite ends of the bus bar simultaneously.

The initial trials involved the simultaneous recording of data from CCs at Panel 24 (Dover House) and Panel 19 (BC 2). Large pd of the order of 400 mV was detected early in the morning on several occasions.

From figure 7 it is thought that one of the discharges originates at Panel 18, 19 or 20. Simultaneous switchgear pd was acquired by the CCs as illustrated in figure 8.

The first pulse in the cycle in each case is clearly from the same pd source. The pulses are displaced in time with the pulse arriving at the sensor connected at BC2 before it arrives at Panel 24 (Dover House) as shown in figure 9.

Figure 7 Carslake remote monitoring system summary histogram. Note: the panel numbers (horizontal axis) are in the same order as the physical arrangement in the substation.

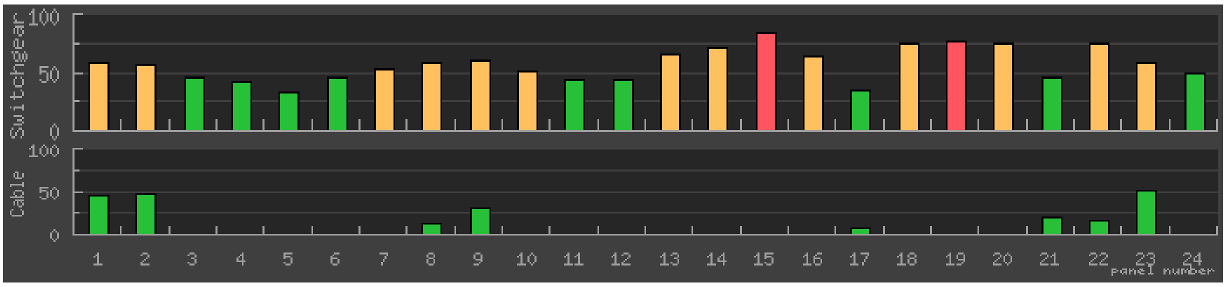


Figure 8 Switchgear pulses acquired over one power cycle

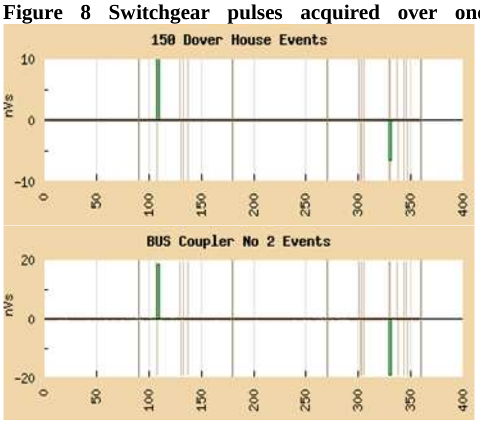
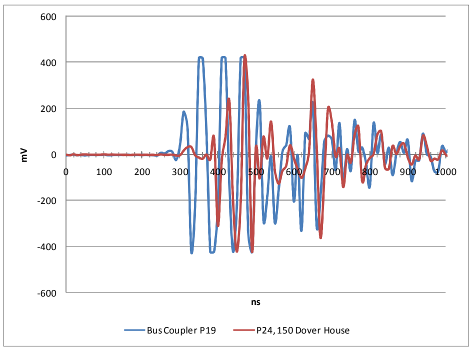
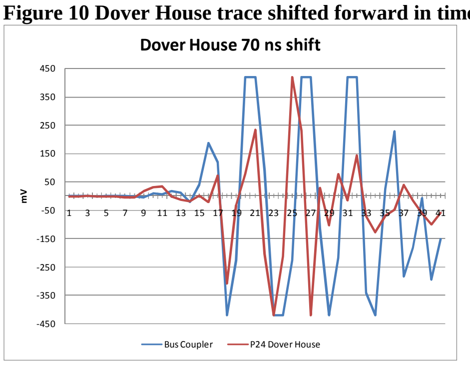


Figure 9 Pulses detected at Carslake Road on P24 and BC2



Although the pulses originate from the same source they have travelled a different route, their attenuation is different and they have different rise times, fall times and magnitudes. As a result the accurate alignment of the CC pulses to determine the time delay between them is problematic. Several sets of pulses from Carslake Road were analyzed and the time delay between them was found to vary between 60 and 90 ns. A time delay of 70 ns for the pulses given in figure 9 is illustrated in figure 10.

Figure 10 Dover House trace shifted forward in time by 70 ns



This indicates that the pd source is closer to BC2 than P24 or even beyond BC2. A site visit confirmed that the pd source is in the bushing spout of the P20 circuit breaker which is the panel next to BC2.

With the time difference between remote sensors on P1 and P19, together with physical busbar and circuit lengths and measured typical propagation velocities, time of flight calculations from the source of discharge can be undertaken. Preliminary results confirm the location of the discharge to panel 20 (plus or minus one panel). Subsequent trials using combinations of CC and CT sensors on P1 and P24 appear to overcome some of the difficulties in aligning pulses arriving at remote sensors and with long sensor cables. Trials with remotely captured synchronized waveforms are underway and appear similarly encouraging

The remote monitoring system also highlighted the fact that the main discharges were rapidly increasing and occurring during the night and early morning and are correlated with times of low load as indicated in figures 11 and 12.

Figure 11 Discharge activity and circuit load over time

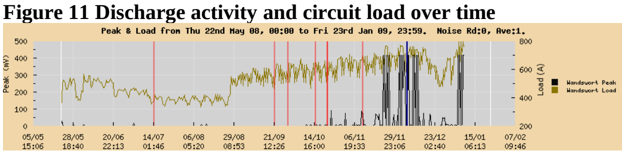
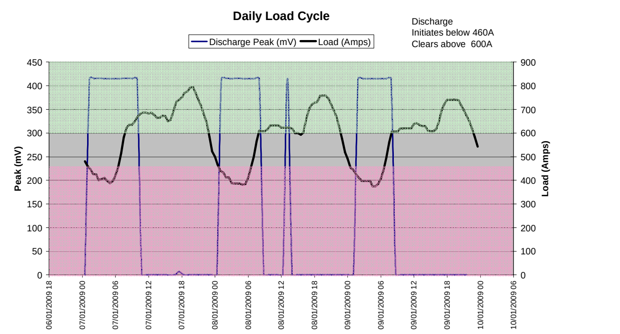


Figure 12 Daily load cycle of discharge activity and circuit load



As it appears this pattern of activity may be connected with the humidity, a project has been initiated to place on-line environmental monitoring sensors in the switchrooms, which will be integrated with the pd monitoring system.

BENEFITS

The financial and economic benefits of the avoidance of major incidents through the targeted use of on-line condition monitoring of MV switchboards are considerable. The immediate benefits are to

- Provide robust, automated early warnings to provide the opportunity for timely, targeted interventions by field maintenance teams before catastrophic failure.
- Identify discharge patterns associated with load and environment conditions at times that may not be picked up by routine manual inspections.
- Prevent loss of supply to customers.
- Provide enhanced safety for those entering substations.
- Enable monitoring of the effectiveness of remedial interventions.
- Remove misleading common switchgear pd trends from individual cable circuit data.

The supply cost of the monitoring system is small in comparison with the cost of the power system equipment and may be readily justified for installation in substations where the risk of a failure is high due to known problems with a particular type of switchgear, known environmental issues, supplies to continuous process industries or for substations feeding high profile customers such as in City Centres.

CONCLUSIONS

This paper illustrates that continuous pd monitoring is routinely being used successfully for the early identification of high levels of discharge at switchgear and associated equipment at substations across the EDF networks. Five different sensor types have been discussed, all of which individually and in combination, can contribute to the detection of switchgear pd.

Options for remotely pinpointing the source of the pd using time of flight analysis have been discussed. Further development of these techniques will reduce the amount of manual testing required in a substation and enable accurate inputs to real-time risk assessments

The benefit of such systems for the avoidance of catastrophic failure or loss of supplies to customers and timely effective intervention is high compared to the small cost of the system in comparison to the cost of the power system equipment.

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