THE LOCATION OF SWITCHGEAR PARTIAL DISCHARGE BY PANEL AND TECHNIQUES TO CORRELATE SWITCHGEAR AND CABLE PARTIAL DISCHARGE WITH LOAD AND SUBSTATION ENVIRONMENT.

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ABSTRACT

This paper considers recent developments in on-line condition monitoring techniques both in terms of new hardware and software developments and new analysis and classification techniques.

INTRODUCTION

As discussed in our previous paper [1], MV switchboard failures, whilst rare, can affect many thousands of customers and UK Power Networks have deployed an online monitoring system to provide early warning of potential switchgear failure on a number of substations.

This paper outlines the recent progress made with the development and installation of precedence detection to accurately locate discharging switchgear panels and discusses some of the analysis undertaken in respect of new classification techniques for switchgear and circuit partial discharge (pd) specifically:

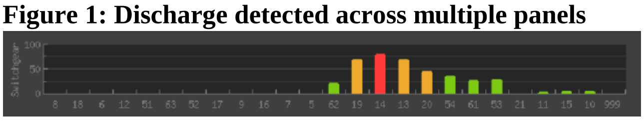
- Discussion and findings of an investigation into the correlation of load, temperature, humidity and pressure with switchgear discharge.
- The use of hysteresis techniques to determine relationships and enhance criticality assessment between pd and load for both cables and switchgear.

SWITCHGEAR PARTIAL DISCHARGE AND PRECEDENCE DETECTION

Partial discharge in air insulated switchgear induces transient voltages that propagate rapidly over the switchgear metal panels. Due to the very high frequency of these pulses, the energy travels across the panel surface by the 'skin effect' and will easily move to panels adjacent to the one with the source of discharge activity. This means that switchgear pd energy can often be detected on multiple panels.

The diagram in Figure 1 shows the levels of pd activity detected across a switch panel in the South of England where there is a single source of activity on Panel 14.

Figure 1: Discharge detected across multiple panels



It can be seen that the pd magnitude (measured in dBmV) generally diminishes with distance from the discharge source.

However, owing to the complex nature of RF energy dissipation, the amplitude of the detected signal is an unreliable way of determining the pd activity source. The magnitude of the pd detected at any given point is influenced by many factors that are difficult to control or measure. The problem becomes more complicated when there are multiple sources of pd as can be seen in Figure 2. Here there are two switchgear panels with pd and the activity can be seen across many channels. It is not possible to tell from magnitude alone which panels have the active sources.

Figure 2: Detected pd in site with 2 sources of activity

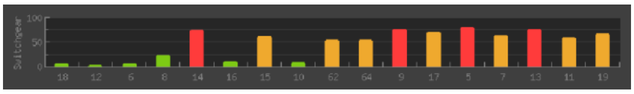


Figure 3: Activity after introduction of precedence

In order to overcome this, a field-programmable gate array, FPGA, based stage has been developed and introduced into the pd detection system that can determine which detecting channel was first to 'see' a pd signal that is picked up by multiple channels. The discharges detected by channels that are not precedent, i.e. were not detected first, are then re-classified such that they do not contribute toward the criticality of that channel. In this way the panels that have the discharges are the only ones for which detected pulses are not re-classified and their criticality remains high as can be seen in Figure 3. This shows the detected activity at the same substation as that in Figure 2 but after the introduction of the precedence time of flight technology. There were two discharging panels at this site, one on panel 14 and the other on panel 5.

As the PD sensors on an installed monitor are likely to be connected with signal cables of different lengths, these are measured and used automatically by the monitor to offset the recorded signal propagation times.

This method of signal arrival time discrimination has now been implemented in over 10 substations and has been shown to be accurate with a spatial resolution of approximately 40cm.

SWITCHGEAR PARTIAL DISCHARGE AND THE ENVIRONMENT

Several indoor substations with pd monitoring equipment were equipped with internal temperature and humidity sensors to monitor the substation environment in Spring/Summer 2009. A weather station was installed externally at a substation in southwest London.

At the substation in southwest London the recordings showed that during the period from mid July until mid December 2009 the internal substation temperature gradually fell. After this period the temperature dropped to 5 ℃ on December 21st and then rose to 14 ℃ at the end of December and beginning of January 2010 when there was another cold period from Jan 7th – 15th. Some of the largest switchgear pd correlated to this cold period.

Humidity fluctuated between 50% and 60% during the summer 2009, with more variation during the winter (peaks of 76% between 16/12/2009 and 15/01/2010). For some periods in December 2009 and January 2010 the internal substation temperatures wereclose to the dew point indicating that the moisture in the air was high and consequently the likelihood of discharges was higher.

The pressure fluctuated between 1040 and 982 mbar during the studied period. In some but not all instances the high discharge periods appear to be associated with relatively high pressure values.

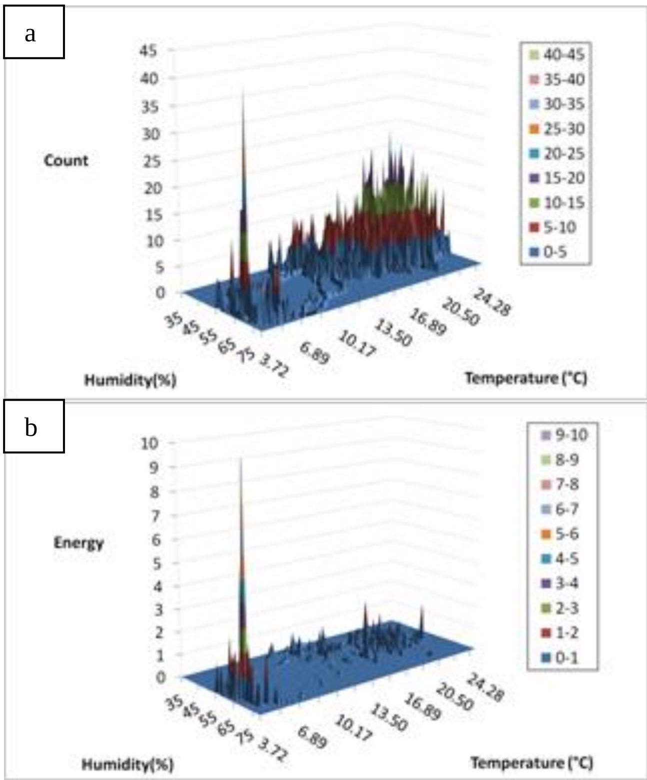
A model was developed to investigate whether it is possible to classify and predict the likelihood of pd activity in terms of the load, temperature, humidity and pressure ranges. A switchgear panel with a known seasonal history was chosen for the initial model development. The model was optimised in terms of the influences of load, temperature, humidity and pressure.

A sensitivity analysis indicated that the results were very sensitive to the limits used for both temperature and humidity and investigation showed that the occurrence of discharges was high in two different regions of temperature and humidity. Figure 4 shows the interrelationship between temperature and humidity; Figure 4 (a) shows number of discharges for each temperature and humidity occurrence whereas in Figure 4 (b) the energy of discharges at each temperature and humidity occurrence is calculated. It can be seen that whilst a large number of discharges of significant magnitude occur at temperatures less than 5 ℃ the large number of discharges which occur at higher temperatures have a much lower magnitude.

The model developed using data from July 2009 to February 2010 indicated that discharges on the panel under investigation are more likely to occur when temperature is between 3.5 and 5.5 ℃ and 17 and 23 ℃ with corresponding humidity ranges 45-55% and 60-70% and pressure between 1000-1040 mbar. The number of matched discharges was 96%.

The model was optimised for use at other panels and substations by changing the boundaries of the parameters. It was found that in some cases switchgear pd appears to correlate with load and environmental conditions and different types of events on different types of switchgear have different environmental boundaries; whilst for other panels no environmental dependency was observed.

Figure 4 Interrelationship between temperature and humidity



Conclusions

In some cases switchgear pd appears to correlate with load and environmental conditions. Different types of events on different types of switchgear have different environmental boundaries.

The ability to predict the likelihood of occurrence of switchgear discharge presents an opportunity to actively control indoor substation environments to avoid further discharge activity and improve the health of the switchgear assets.

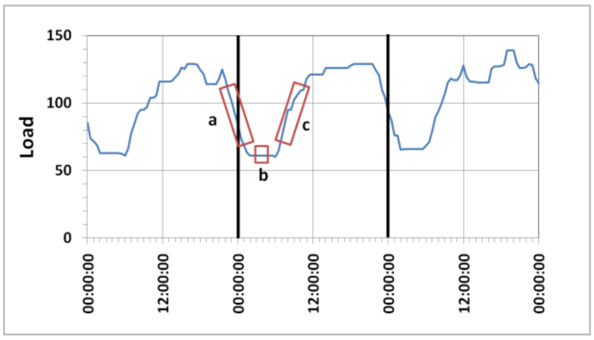
INVESTIGATION OF THE RELATIONSHIPS BETWEEN PARTIAL DISCHARGE AND LOAD

Pd on switchgear and paper insulated cables has been observed to be associated with the daily load profile in the following ways:

- On the falling edge (following the cooling which occurs as the load falls) – Figure 5 (a),
- On the rising edge (following the heating which occurs as the load rises) – Figure 5 (c),
- At a minimum – Figure 5 (b),
- Or continuous and indepedent of load.

The changes are believed to be associated with the thermal expansion or contraction of insulation. This is illustrated in Figure 5.

Figure 5 Pd observations on load profile

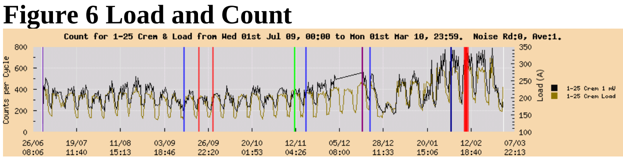


In some cases cable failures have occurred following load increases and in other cases following load a decrease. Determining a measure for the relationship between load and pd is another key factor to take account of in assessing circuit or switchgear criticality.

North London Substation

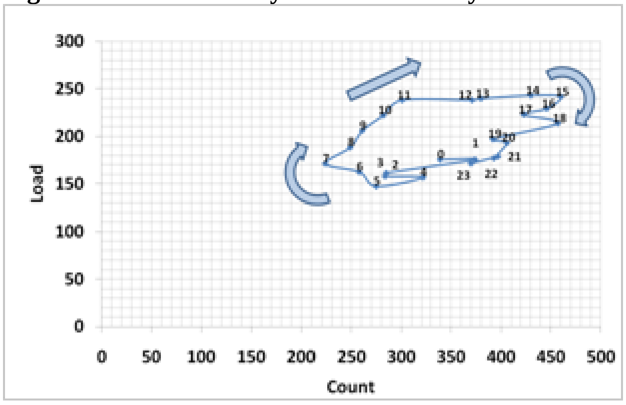
This is an example of positive correlation between load and pd where the pd count follows the load cycle as can be seen in Figure 6. Red lines in Figure 6 indicate when the monitor underwent a service upgrade and when incipient fault location was being undertaken. Green lines represent switching events.

Figure 6 Load and Count



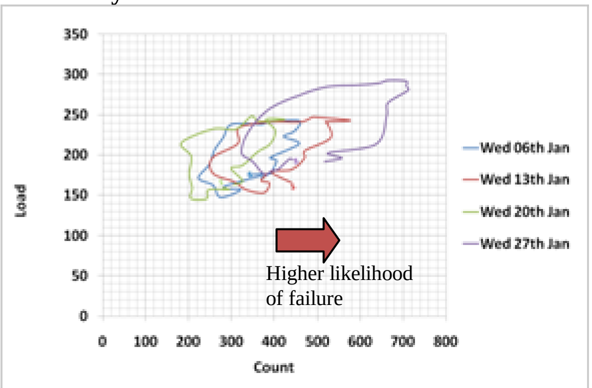
Load and pd count shows a typical systematic dependency over the studied period (01/07/2009- 27/01/2010). Hysteresis analysis was used to observe this dependency over time. Figure 7 shows a 24 hour hysteresis of count against load. Labels on the graph represent the hour in which the data was recorded. The count number after a 24 hour period does not return exactly to the starting point (non elastic hysteresis). This could be due to the number of discharges developing further during the period or the cable not fully cooling during the weekly load cycle.

Figure 7 Load Count Hysteresis – one day



The hysteresis loop has been observed to shift throughout several daily cycles. The direction of movement could be another indicator to monitor the criticality of discharges. Hysteresis loops for four Wednesdays in Jan 2010 are shown in Figure 8. All the loops are generally moving towards the right indicating an increase in the number of discharges and an increased likelihood of failure. There is a decline in the number of discharges on 20th of January which is also seen in Figure 6.

Figure 8 Load Count Hysteresis – Four Wednesdays in January 2010



Measures for load hysteresis

The shape, area and displacement of the load – pd count hysteresis loop are indicators of load related pd activity. The following parameters have been used to quantify these parameters:

Aspect Ratio

Aspect ratio is an indicator to define the shape of the hysteresis curve:

Aspect Ratio= (Max Count-Min Count)/ (Max Load-Min Load)

If aspect ratio is close to one, then the shape of the hysteresis is close to a circle. If the value of aspect ratio is more than one the hysteresis loop is inclined to elongate along the count axis and if the aspect ratio is less than one then the hysteresis loop tends to elongate along the load axis.

Position Displacement

Hysteresis loop location can be measured by defining Position Displacement:

$$X = (\text{Max Count} + \text{Min Count})/2$$

$$Y = (\text{Max Load} + \text{Min Load})/2$$

The overall trend in the gradient (positive or negative) of the displacement line is an indicator of pd load correlation.

Area

The area enclosed by hysteresis loops can be calculated using the following method:

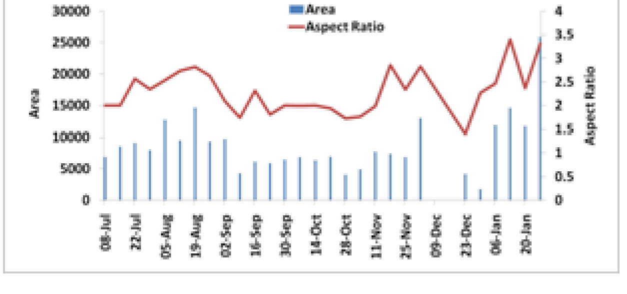
$$\text{Area} = 0.5 \sum (x\Delta y - y\Delta x)$$

Where (x1,y1), (x2,y2), (x3,y3), ..., (xn,yn),(x1,y1) are the coordinates of an enclosed polygon.

Parameter Evolution

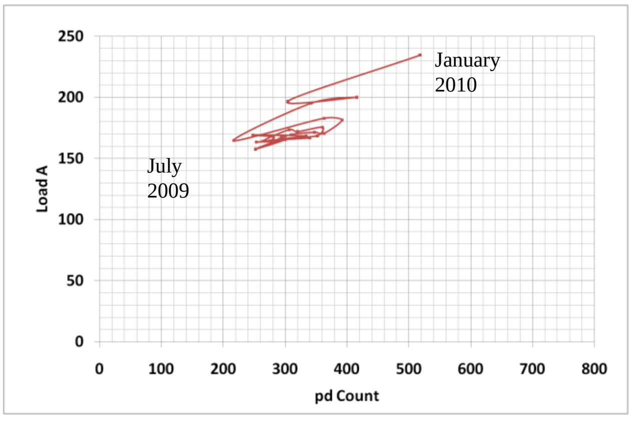
The long term evolution of the hysteresis area and the aspect ratios at for the North London Substation for all Wednesdays from August 2009 until January 2010 is shown in Figure 9, (data is missing for 9/12/09 and 16/12/09 due to a hardware issue).

Figure 9, Evolution of hysteresis area and aspect ratio



The evolution of the displacement of the hysteresis loop is shown in Figure 10. It can be seen that following the Christmas period of low load (Figure 6) the hysteresis area, aspect ratio and displacement have a positive trend and are above the previous average corresponding to the increase in pd activity.

Figure 10 Evolution of displacement of hysteresis loop



Conclusions

Indicators for assessing development of pd activity when it is associated with load and hence assessing criticality factors have been identified as:

- the position displacement of the load – pd count hysteresis loop
- the area of the load – pd count hysteresis loop
- the aspect ratio of the load – pd count hysteresis loop

SUMMARY

This paper has described the recent developments in the development and installation of precedence detection to accurately locate discharging switchgear panels.

A generic model has been developed to assess the criticality of switchgear discharges with respect to the environment which can be refined to be applicable to different types of switchgear and pd events. The strong correlations obtained suggest that control of the substation environment could lead to prevention of discharge and hence improve the health of the assets.

The importance of understanding the load pd relationship and the use of hysteresis techniques to determine relationships between pd and load and enhance criticality assessment for both cables and switchgear has been discussed.

REFERENCES

[1] Cliff Walton, Sarah Carter, Matthieu Michel, Carl Eastham, 2009, "Avoidance of MV Switchgear Failure Case Studies of On-Line Condition Monitoring", *CIRED*

[2] Neil Davies, Darren Jones, Testing Distribution Switchgear for Partial Discharge in the Laboratory and the

Field, IEEE 2008.