INFLUENCE OF NETWORK EVENTS ON PARTIAL DISCHARGE ACTIVITY AND CABLE HEALTH

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ABSTRACT

Medium Voltage distribution power networks are dynamic systems in a constant state of flux. Load varies according to customer demand and regular patterns (daily and weekly) are often observed. These gradual variations are occasionally punctuated by step changes caused by network reconfigurations or underground cable faults. Together with environmental influences (weather, soil condition etc.), these factors contribute to mechanically stress the cable network and impact directly on the health and condition of the cable insulation.

INTRODUCTION

With the technical support of IPEC Ltd, EDF Energy Networks is now extensively monitoring partial discharge (PD) on its medium voltage network (more than 1000 feeders are currently equipped with a variety of PD sensors). Over the past few years, a large number of partial discharge trends have been observed. These trends can only be fully understood and explained when correlated with network events such as switching, load, etc.

This paper looks at the correlation between these events and partial discharge activity in underground paper insulated cables. A number of real case studies are presented using selected data from the cable partial discharge monitoring system on the EDF Energy distribution network:

- The relationship between load, cable temperature and discharge activity is analysed over extended periods of time.
- The effect of network switching on “regular” partial discharge behaviour is also presented and linked to underground cable faults.
- Various other trends observed are shown and described.

Partial discharge activity is often studied in isolation. Work carried out by EDF Energy Networks and IPEC shows that in order to gain a better understanding of failure modes, and better predict failure, external factors must also be considered.

Finally, the association of distinct partial discharge patterns with network events and particular fault types, (paper/joint defect, pin holes, partial water penetration, etc) is discussed.

MONITORING SYSTEM

The ASM partial discharge monitors installed on the EDF Energy network use high frequency CT sensors coupled to the MV cable earth to detect PD online. The CT is a high frequency transducer designed specifically for picking up partial discharge signals in cables. It has a split core ferrite to allow retrospective fitting to earth straps without the need for disconnection, and is electrically screened to reduce noise interference.

The monitor acquires PD signals from the distributed PD sensors via a series of multiplexers. The analogue signals are processed and digitised by purpose built signal conditioning and acquisition electronics. An integrated PC then analyses the digitised signals, applying sophisticated noise reduction and partial discharge recognition algorithms. The data is stored in an on-board database until accessed by a central server.

Figure 1: ASM On-line partial discharge monitor

Data is sampled from each circuit at 100MSamples/sec, every 30 minutes giving a sufficiently high data resolution to accurately track variation in PD wave shapes, magnitudes and repetition rates over time.

Load and CB switching events

The load current is measured and recorded for every circuit on the network once a minute. Load files are then produced showing the average load over the previous 30 minutes for each circuit. Additionally, every circuit breaker (CB) switching operation (open and close) is recorded.

Central database and web site analysis

The monitoring system centralises data management by storing all data recorded by distributed PD monitors in a central database.

Data from each PD monitor is accessed by modem once every 24 hours or more frequently where connected by broadband. When monitors are contacted by the server all data recorded since last contact is downloaded and inserted into the central database. Similarly, load and circuit breaker switching data is automatically inserted into the database.

INCIDENCE OF MULTIPLE HV FAULTS

It has been observed by network operators and field engineers that once a cable experiences an HV fault, the likelihood of a subsequent fault on the same or a neighbouring circuit is increased over the following months.
This trend has been demonstrated by analysing the incidence and distribution of faults in the EDF Energy London area MV network.

The Network in this region comprises 151 primary substations with a total of 2672 outgoing circuits between 6.6kV and 33kV largely of PILC construction. In the first 11 months of 2008 there was one or more HV fault on 239 different underground cable circuits where the cause of the fault was recorded as being deterioration due to ageing or wear. This implies there was on average an 8.94% chance that any particular circuit would experience a fault of this type during the 11 month period.

From this, the probability of a circuit experiencing multiple faults can be calculated if the faults were independent and unrelated. However records show that almost 3.5 times as many circuits experienced 3 or more faults during the analysis period than would have been predicted if cable faults were independent.

PILC CABLES

As the load on a circuit increases, the conductor temperature will increase accordingly. This will heat up the cable insulation at a rate dependant on the cable type and its surrounding environment. Studies have shown that there is a direct correlation between the load on a circuit and its temperature where the average temperature lags the load in time due to the thermal mass and thermal conductivity of the cable.

Partial discharge and insulation temperature

Age related faults in paper insulated cables are very often associated with voids and moisture ingress, both of which are key factors in the development of partial discharge activity. Under normal conditions voids are filled by insulating oil preventing the on-set of PD. However as oil migrates during load cycling, these voids can become depleted of the impregnating oil allowing PD to initiate. Under high load conditions the oil viscosity and density is low and the oil pressure in the cable high. This high pressure and oil mobility forces the oil into any cavities reducing the number and size of potential PD sites. When the load is reduced, the oil cools increasing its density and viscosity and leaving low pressure in the cable and allowing voids to open up [1].

RELATIONSHIP BETWEEN LOAD AND PD

Analysis of the PD and load data shows that approximately 60% of circuits that regularly exhibit partial discharge activity do so in a manner that is directly related to the loading on that circuit.

Variation in Peak and Count

Partial discharge activity is commonly measured in terms of its Peak (the highest PD seen during a measurement period) and Count (the number of PD that exceed in magnitude a given threshold). In combination Peak and Count are good indicators of PD activity levels.

Figure 2 shows PD activity (Count) varying in relation to load over an 8 day period.

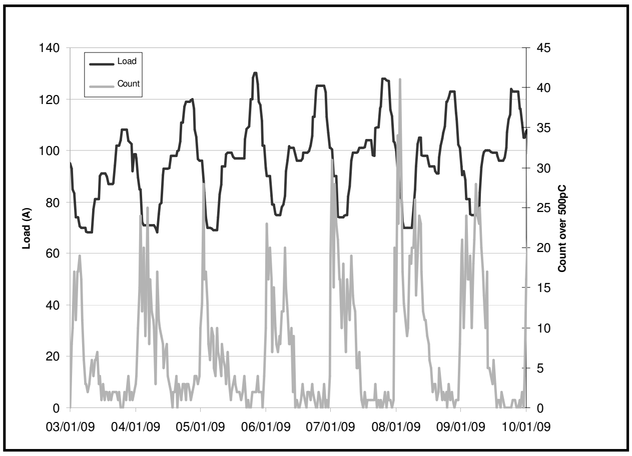

Figure 2 : Variation in Count with load

It can be seen that the PD site is only active when the load reduces and the cable temperature falls.

Although many circuits show peak and count increasing and decreasing together with load, others show them behaving independently with respect to load. A number of circuits show Peak varying significantly but Count very little, suggesting that PD sites are remaining active throughout the loading cycle but the PD are changing in magnitude as the temperature changes.

Other circuits show Peak remaining stable with only Count varying significantly with load suggesting that sites become more active or new PD sites initiate as the temperature changes.

Positive and negative relationships

Load related PD patterns fall broadly into two groups; those with positive and those with negative relationships with load. An analysis of circuits exhibiting load related activity levels has shown that 83% of circuits studied had a negative relationship where PD activity increased when load decreased, albeit with a time lag due to the thermal response of the cable.

Figure 3 shows an example of a positive relationship where activity increases when the cable temperature increases.

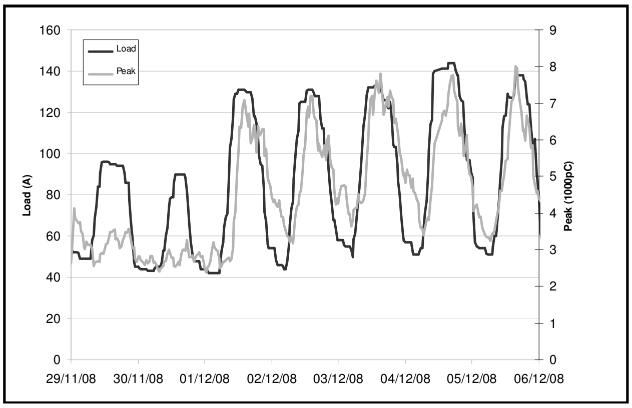

Figure 3: Positive relationship between Load & Peak

The example shown in figure 4 shows a negative relationship between load and Count where activity increases when the cable temperature reduces.

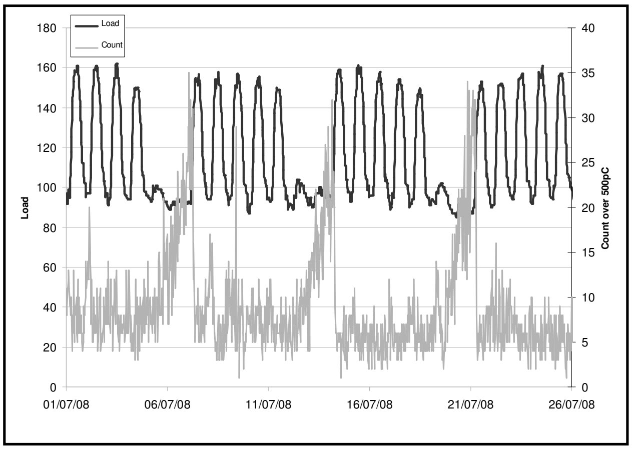

Figure 4: Negative relationship between Load & Count

In this example, it can be seen that the load is varying between approximately 100A and 160A over the 24 hour loading cycle on week days and remaining low at about 100A over the weekend. It is evident that only at weekends is the cable cooling sufficiently for the PD activity to increase significantly.

Relative behaviours of Peak & Count

It has been observed that in cases where Peak and Count both have either a positive or negative relationship with load, they very often correlate with load variation in different ways. For instance, the example shown in figure 5 shows the variation in Peak and Count for a circuit over a 24 hour period during which time the load decreases over night.

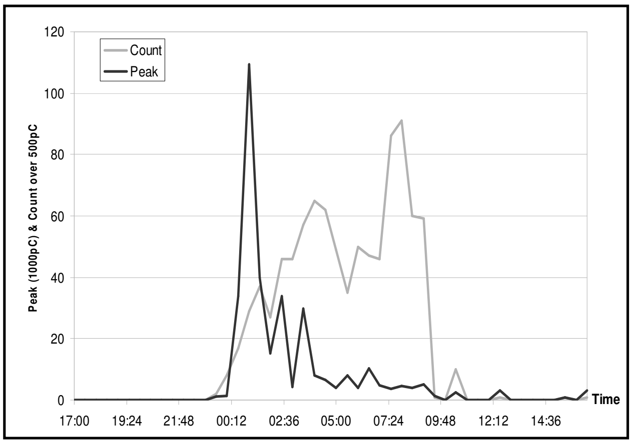

Figure 5 : Peak & Count over 24 hours

It can be seen from the graph that as the cable cools down PD activity initiates. At the onset of the activity, the partial discharge peak is very high but Count is low. As the cable continues to cool down and the oil mobility and oil pressure decrease, the Peak reduces significantly and the Count steadily increases suggesting gradual temperature related change in the nature of the PD site.

IMPACT OF NETWORK SWITCHING

The distribution of load within a ring is often altered through necessity as a result of a fault elsewhere on the network, maintenance work being carried out etc. PD monitoring data has shown that such changes, resulting in an increase or reduction of load, can have an impact on the condition of a circuit.

Load reduction increasing PD levels

Figure 6 shows PD Peak and load over a 3 week period where the base load on the circuit is reduced by approximately 40%.

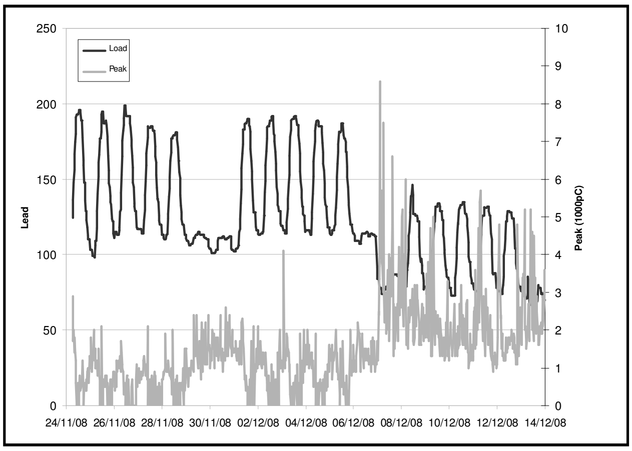

Figure 6: Positive relationship between load & Peak

It can clearly be seen that the PD activity significantly increases as the load is reduced and the cable temperature decreases.

Load increase leading to fault

The example shown in figure 7 is Peak and load data over a 5 week period from a circuit that faulted following an increase in its base load of approximately 40%.

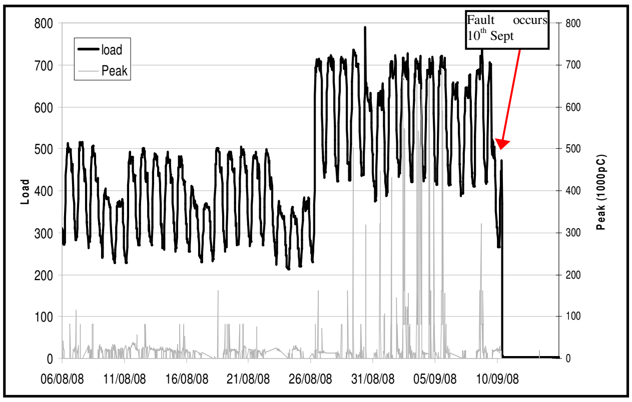

Figure 7: Cable fault following load increase

It can be seen that following the increase in load on the circuit, high levels of partial discharge initiate. Approximately 2 weeks after the step change in load, the circuit experienced a fault.

FAULT INITIATING PD

In addition to switching and load changes affecting PD activity, there is evidence that faults can be the cause the initiation of active PD site. Figure 8 shows an example where a circuit experienced a fault that was due to third party damage to the cable.

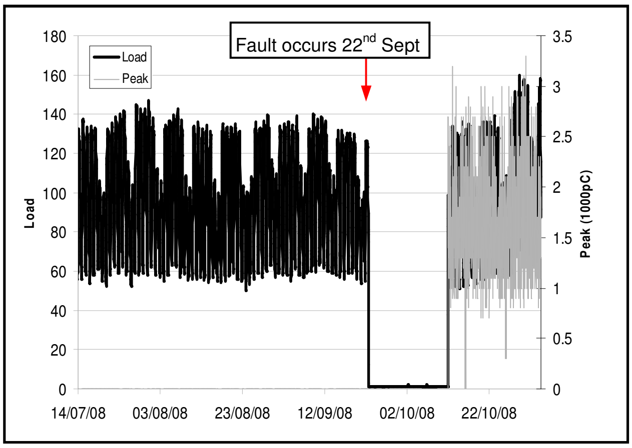

Figure 8: Fault initiating PD

The graph shows data for a 17 week period. It can be seen that the fault occurs and load is at zero while a repair is carried out. When the load is restored, a highly active PD site initiates.

As an increasing number of cases such as this are detected, it can be assumed that the fault conditions are physically damaging the cable and increasing the likelihood of failure.

CONCLUSION

It has been shown that multiple faults occur on circuits significantly more often than overall fault rates would predict.
This increase in likelihood of failure can be accounted for partly by the fact that a circuit that has previously experienced a fault is more prone to failure due to its general condition and partly by the impact of previous faults. As the age, physical state and working conditions of the network are relatively evenly spread across the network, it can be assumed that a large proportion of these 'causal' failures can be put down to the impact of the previous fault.

It has been shown that partial discharge activity is more likely to occur in cables under low load conditions as the insulating oil becomes more viscous, the oil pressure drops and voids and cavities open up in the cable insulation.

Work is continuing, investigating the physical nature of the different defects that are caused by these network events.

REFERENCES

[1] N Ahmed, N Srinivas, 2001, *"Can the operating conditions of the cable system effect the data of the field PD testing*", Annual Report, Conference on Electrical Insulation and Dielectric Phenomena, 311-314