PARTIAL DISCHARGE MEASUREMENTS AND DAMAGE TO HIGH VOLTAGE CABLES.

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INTRODUCTION

Aging cable networks are expensive to replace and can be costly to maintain. The costs tend to be large for failing and/or unreliable cables. Hence on-line partial discharge (PD) measurements have been used for some while to give engineering data about cable condition. The best data comes not from technical breakthroughs in measurement methods, but from extended experience of the PD methods and the relationship between the results and service performance.

This paper reports on the advances in measurements for on-line techniques, and the first sets of data from the failure of paper insulated cables. What the work shows is that the new PD methods are producing much more consistent results, with tools for noise immunity providing real benefits. The cable examinations show that times to failure will still be hard to predict, although those cables at risk are now fairly easy to identify.

TOOLS AND METHODS FOR ON-LINE TESTING

Methods for on line detection of PD in cables (and switchgear) have developed in two main directions in recent years. Firstly the reduction in noise from the typical on-line site. This is still an active area of research. The authors have pioneered the method of ‘event recognition’ which takes the complete waveform and separates the pulses into noise, PD events on the cable, and local PD events (1). Mostly the local PD events will arise from the switchgear.

Locating the PD pulses once they have been identified is actually a more important feature for the operational engineer. For the locations a transponder method has been employed to build up a ‘map’ of the PD events located along the cable. Figure 1 shows the idea behind the method. If a single cable circuit contains a PD site, then the two pulses launched at the PD site will travel to both ends of the circuit. An observer at one end might see an initial waveform such as in (figure 1). By placing a trigger unit and pulse generator at the remote end, (see figure 2), the initial waveform can be modified by the transponder so that PD pulses will trigger the remote pulse generator in the transponder and ‘tag’ the returning pulse. The pulse travel time of figure 1 can then be used to locate the origin of the PD site.

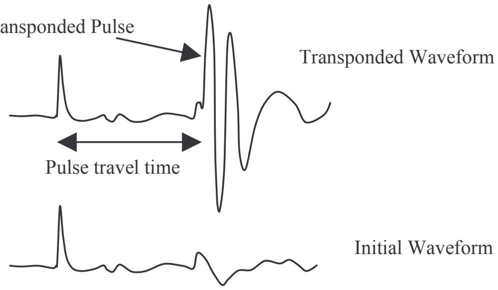

Figure 1 Locating PD pulses using transponded waveforms

An equivalent way of carrying out the on-line locations is to record complete cycles of PD data with a transponded pulse. This method was successfully tried several years ago, but the difficulty of communicating between substations with two PD recording devices has meant that the transponder mapping method was preferred.

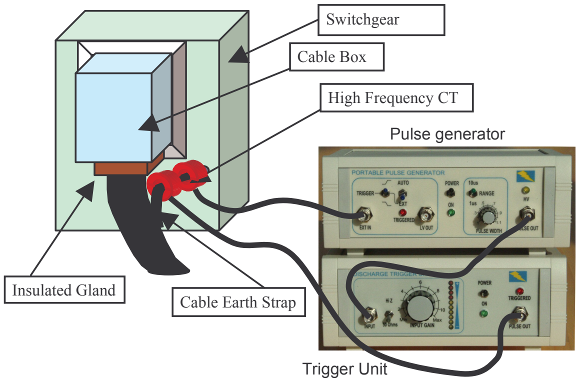

Figure 2 Transponder pulse detection and injection

For this set of tests, a particular circuit in EdF Energy was chosen to investigate the long term effects of PD activity. EdF Energy has many circuits being monitored for on-line PD activity, so the choice of circuit for further investigations was quite wide.

Figure 3 PD location equipment at the far end of the cable

Figure 3 shows the installation of the transponder equipment at the remote end of the circuit. The devices are battery operated and so can be used on those sites which have no local AC mains.

Using high frequency current transformers on the earth straps of the cables allows all phase/earth PD events to be located. However, in the special case of belted cables, this method does not detect phase/phase events. For this, each phase must have an HFCT. This can be quite difficult to achieve for traditional cable box arrangements, so in general only the phase/earth PD events are normally detected.

PD RESULTS FOR THE 11KV CIRCUIT

The circuit chosen was an 11kV PILC (Paper Insulated Lead Covered) cable of approximate length 1000m.

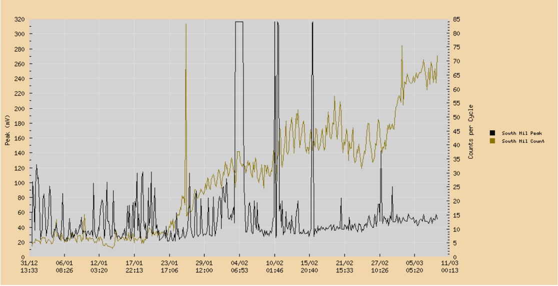

Figure 4 Monitoring results showing the rising PD activity

Figure 4 shows the rising PD activity on this circuit over a 12 week period. Notice the slow increase in overall peak values, and the characteristic increase in the number of PD events over the time.

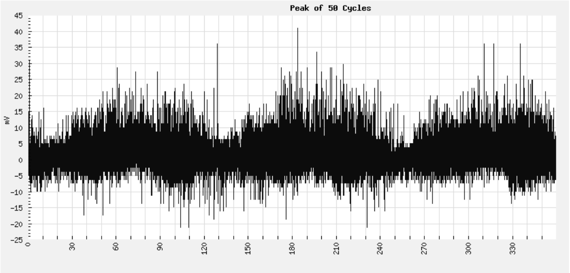

Figure 5 PD activity plotted in phase across a power cycle for 50 summed cycles.

Figure 5 shows the phase distribution of PD activity for the circuit measured over a power cycle, and summed for 50 individual cycles. The clear implication of figure 5 is the 3 phase nature of the PD activity. This is exactly the behavior expected for phase/earth PD events in a three phase belted cable.

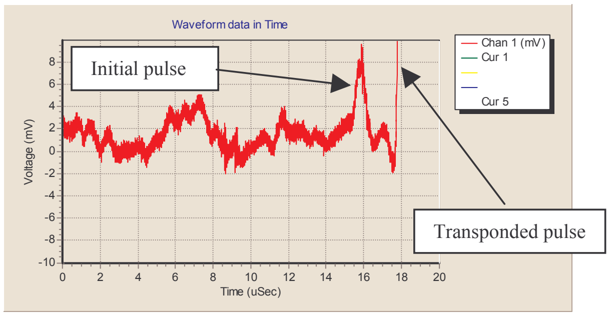

Figure 6 PD map from the remote end (transponder at the substation)

The waveforms which are used to draw the map are shown in figure 6. The figure shows the pulse which triggered the transponder, and the transponded pulses itself. The time difference between the two pulses is the same as the travel time between the PD site and the remote end of the cable.

The locations obtained from the transponder results are shown in figures 7 and 8

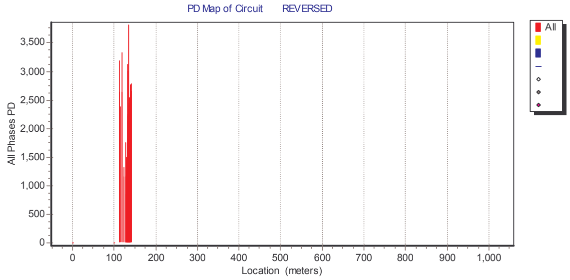

Figure 7 PD map from the remote end (transponder at the substation)

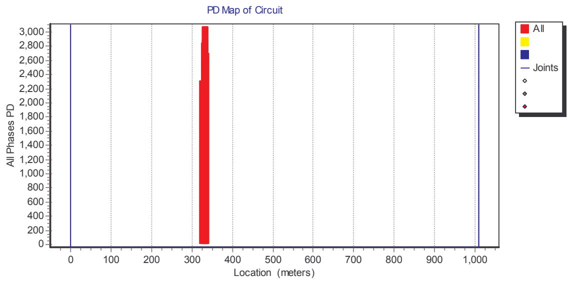

Figure 8 PD map from the substation end. (transponder at the remote end)

The PD map is reversed in figure 7 so that both the figures can be viewed as directly comparable. Notice that two different sites have been located from the two events. This is not uncommon when using transponders. It arises from the simple fact that the triggers tend to be from the largest PD events reaching each end. The attenuation is considerable over even moderate distances, and it is easy to miss smaller and longer pulses far from a PD site compared to the much larger (in recorded voltage but not necessarily charge) at a nearer site.

The site in figure 7 was chosen to exhume the cable and take it for examination. The locations were accurate to around 5m, so removal of 20m of cable would ensure that the PD site (or sites) would be adequately covered by removing a single length of cable centered on the PD site.

CABLE EXAMINATIONS

Some 20m of recovered cable was taken to a jointing school and destructively examined. Figure 9 shows the lead opened and the cores laid adjacent to each other. The carbon caused by the PD activity can be clearly seen along almost the whole length of the recovered cable.

Figure 9 exposed core and lead sheath of around 10m of cable

A close up of the carbonized core is seen in figure 10. The PD damage is very extensive under the lead sheath.

Figure 10 close up of outermost belt paper from PD site

In order to lend some semi quantitative methods to the cable examination, a scoring scheme was used so as to enable results to be plotted on a ‘scale’ of degradation. The scale used was as follows:-

0) Cable papers in ‘as manufactured’ state
1) Very light brown waxing
2) Darker waxing over larger area
3) Dark brown waxing covering a substantial area of the paper
4) Very dark brown waxing, or small spots of carbon
5) Trees, pinholes or areas of carbon

This scheme allows a degradation profile to be drawn through the cable insulation wall, providing that all the papers are removed and carefully examined in turn.

Figure 11 shows the degradation plot through the whole of the insulation wall. Core 1 was randomly chosen for this purpose, although clearly the two other cores would represent an equally valid cross section through the insulation. The first 10 papers are in the belt, and papers 11 to 33 are in the core.

The cable was identified from the marker tape as a Pirelli 1963, and was an 11kV MIND cable, lead covered and steel wire armored.

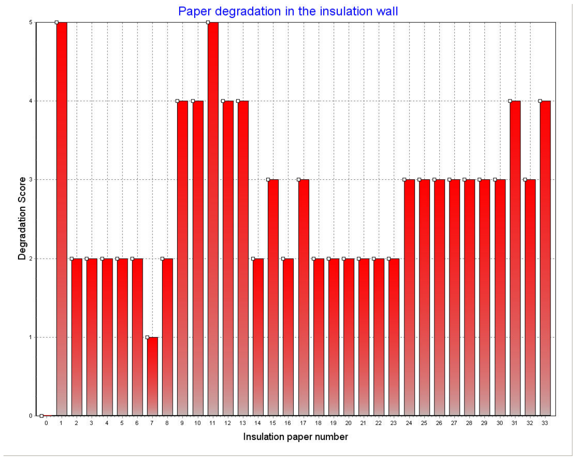

Figure 11 Degradation of the insulating papers in the core and belt Papers 1 to 10 are in the belt, all others are in the core.

The poor insulation quality at the outside of the core and the belt, do not continue all the way through the insulation. Whilst this cable is substantially deteriorated, it is certainly not in imminent danger of failure. Estimation of remaining life is very difficult, but failed cables have many papers with scores of 5 on this scale. This means that there may still be several years of service left in this cable before the degradation would result in failure in service. In this case it is debatable as to whether the cable would have been re-jointed. The wise engineer would probably have cut the cable back to clear the carbon from the belt.

CONCLUSIONS

The paper has presented some practical data on the results of PD damage to an 11kV PILC cable. The on-line methods which allow the section of cable to be identified represent a major advance in detection and location of PD on-line.

The remaining problem of the interpretation of the PD activity in terms of remaining service life is still to be determined. The results show that the cable is indeed badly damaged at the point of origin of the PD activity. However, this does not mean that the cable is in imminent risk of failure. Several years life may still be present in the remaining insulation. However, as regards the risk of failure, the PD method does give very good indicators as to those sections of cable which are likely to give poor service performance.

The failures of cables which have occurred following PD measurements, have all had larger PD activity than this case. It seems that further tests of this nature will probably be needed to establish the PD characteristics associated with the imminent failure of the PD sites. The magnitude must be large for failure, but the number of pulses per cycle seems to show more accurately when a cable might be nearer to service failure.

References

1 R.R. Mackinlay, M. Michel C.W.Walton "*Tools for partial discharge testing MV cables and plant"*18th CIRED, Turin 2005.