DETECTION AND LOCATION OF PD IN MV CABLES IN ELECTRICALLY NOISY INDUSTRIAL ENVIRONMENTS

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ABSTRACT

The use of on-line methods to detect and localise partial discharge in underground cables has become increasingly common as coupling and signal processing techniques have improved. However, the use of on-line PD detection has often been limited in environments prone to high levels of conducted and radiated electrical noise such as industrial processing plants. The level of electrical noise interference in these environments can often exceed those of cable PD by more than an order of magnitude. The problem of reliable PD detection is compounded by the fact that the frequency components of the interference are often similar to those of partial discharge in cable.

In order to be effective, it is very important that a permanently installed PD monitoring system does not interpret such noise signals as discharge whilst reliably detecting genuine discharge when it occurs.

This paper describes the use of high resolution data acquisition and wavelet signal processing for the automated detection and quantification of PD in electrically noisy circuits.

A case study is presented from a steel processing plant in Taiwan where PD was detected in a 33kV XLPE cable and monitored for a period of several months until a planned outage could be arranged. The study shows how the PD wave shape can be analysed to accurately locate its source despite being superimposed on noise levels that are many times higher.

The discharge activity before and after a repair to the cable was carried out will be presented along with the results of a full analysis of the defect and discharge site.

INTRODUCTION

Partial Discharge (PD) monitoring and trending is becoming of increasingly important to Utilities and private networks needing to better understand the condition of their assets, to target maintenance and to increase network reliability. With advances in technology constantly improving the accuracy of PD detection and classification it is becoming an important tool for asset condition assessment in MV and HV cable systems.

PD DETECTION IN MV CABLES

Partial Discharge in underground cables is very often more difficult to accurately detect and locate than in other electrical assets such as associated switchgear. This is because the source of the activity can be up to several kilometres from the detecting sensor and high levels of noise can be induced in the cable earth.

Partial discharge activity in solid high voltage insulation induces small high frequency currents in the earth of the electrical system. These impulses travel through the equipment earth to the substation earth. In cables, detection of these signals relies on the cable sheath being isolated from the substation switchgear, such that the PD signals pass exclusively through the cable earth connection. Using a High Frequency Current Transformer (HFCT) they can be detected as they pass along the cable earth sheath where the HFCT is coupled.

Figure 1 below shows the coupling point of a HFCT sensor around the earth sheath of all three phases of an 11kV XLPE cable circuit.

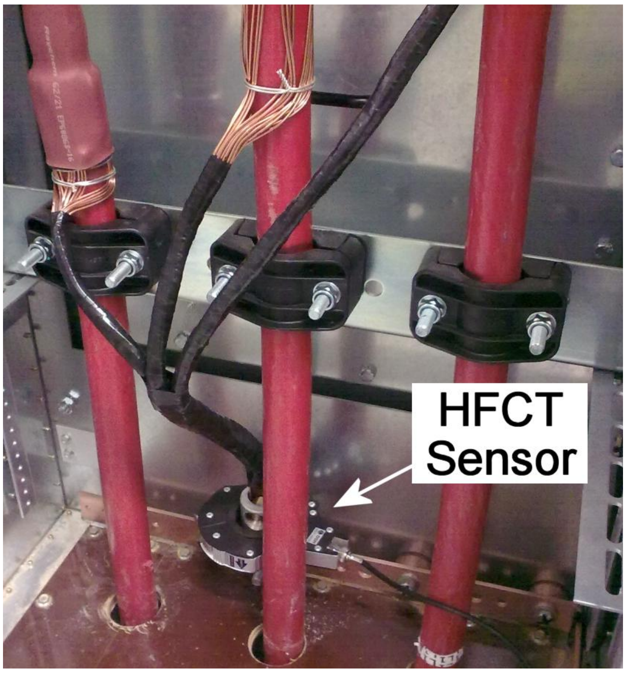

Figure 1: HFCT coupled to cable sheath

The HFCT is a passive transducer with a transfer function of approximately 5.0V/A and a fairly flat frequency response between 50kHz and 20Mhz.

Signals picked up by the HFCT are routed back to the PD monitor via a series of switching multiplexers and low loss coax cables, all shielded so as to minimise any radiated noise from the environment.

NOISE INTERFERENCE

Noise interference is induced in HV cables from radiated and conducted sources. Long cables are particularly prone to radiated interference from RF radio and communication sources. These noise sources are often in the form of modulated carrier waves. In industrial environments noise is very often introduced into the earthing system by large electrical plant, rotating machines, thyristor switching etc. These noise sources are generally in the form of transients often in regular patterns.

SIGNAL PROCESSING

There are a number of techniques that can be employed to process the raw signal to identify partial discharge.

Level Triggering

In quiet environments the background electrical noise induced in the earth sheath of the cable will be minimal and any Partial Discharge activity in the system will create pulses that are higher than the noise. Level Triggering above the noise would then be the simplest way to remove all signals other than the actual PD pulses.

In practice this approach is not practical as noise levels are rarely sufficiently low. If used the system will either only detect very high levels of PD or it is likely to incorrectly classify noise as PD.

Frequency Gating

Although near its source discharge pulses are very high frequency, when detected at the end of an HV cable the frequency components have are typically in the range 0.5MHz and 5MHz. This makes it possible to use Frequency Gating to eliminate signals that fall outside this bracket and class those within it as PD.

This approach can be effective in environments where the only noise sources are either very low frequency or very high frequency. However in practice many electrical interference noise sources have high magnitude levels in this frequency band and these are not eliminated leading to false positives.

Noise Channel Gating

If a sensor can be positioned such that it will detect background noise but not PD on the plant being monitored then it can be used as a 'noise channel' to gate out in the time domain all corresponding signals on the PD monitoring channels. This method is effective if a suitable noise channel can be set up but this is difficult and unreliable. It can be used to discriminate against some types of noise interference during switchgear PD detection but it is of very little value in cable PD detection.

High resolution sampling and Signal Processing

By digitally sampling and recording PD signals from the sensors, powerful processing algorithms can be applied to the data to identify the PD. In order to do this effectively signals should be sampled at sufficiently high resolution and for PD in cables a sampling rate of at least 100MSamples/sec is required. If small PD are to be detected in high noise levels, a good dynamic range is necessary and the sampling voltage resolution should be at least 12 bits.

Sampling at such a high resolution gives rise to a lot of sampled data for every power cycle and the challenge is to reliably identify the very small portions of this data that include partial discharge. Wavelet analysis is a powerful tool for identifying PD pulses in very large data sets [1] and has been used by IPEC in the development of a PD recognition and classification algorithm, DeCIFer for this purpose. The output of the wavelet analysis includes transients resulting from PD and noise sources so a rule based expert system is then used to classify pulses as either noise or PD and quantify those that are identified as PD.

CASE STUDY

Introduction

In 2009 IPEC installed a permanent substation monitoring system to monitor for Partial Discharge on 54 33kV feeder circuits of the largest steel manufacturing plant in Taiwan. The Advanced Substation Monitor (ASM) installed was running the DeCIFer algorithm to eliminate background noise and identify and classify any PD on the monitored assets. The 33kV system consists of XLPE cables fed from GIS switchgear at the primary substation, where the monitoring system and transducers were installed.

Noise

As with many industrial sites, this steel plant has high levels of induced electrical noise, frequently saturating the signals coming from the sensors.

Some of this raw data was extracted as an example, and is shown in Figure 2 below.

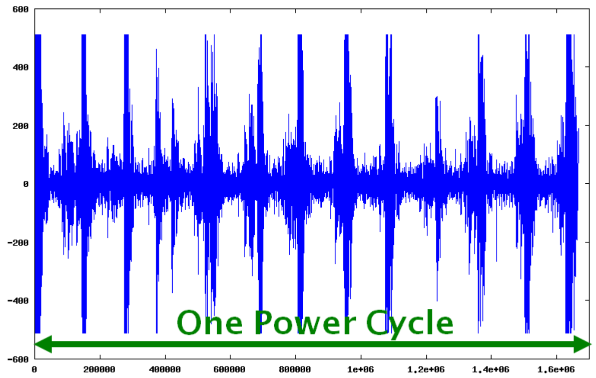

Figure 2: High noise levels detected by HFCT sensor (Vertical scale ±600mV)

PD Detected

Following installation one particular circuit was classified as having high levels of Partial Discharge activity. Each asset is automatically categorised as having a Criticality rating between 0 and 100. Figure 3 below is the summary bar graph of the Criticality scores across the substation.

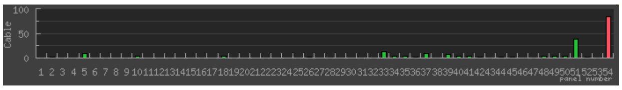

Figure 3: Feeder circuit Criticalities

This high level of PD detected prompted further investigation. Figure 2, used to demonstrate the high noise levels, was taken from the circuit with the high PD. The DeCIFer algorithm had detected a significant PD that was much smaller than the surrounding noise and of a similar frequency (figure 3).

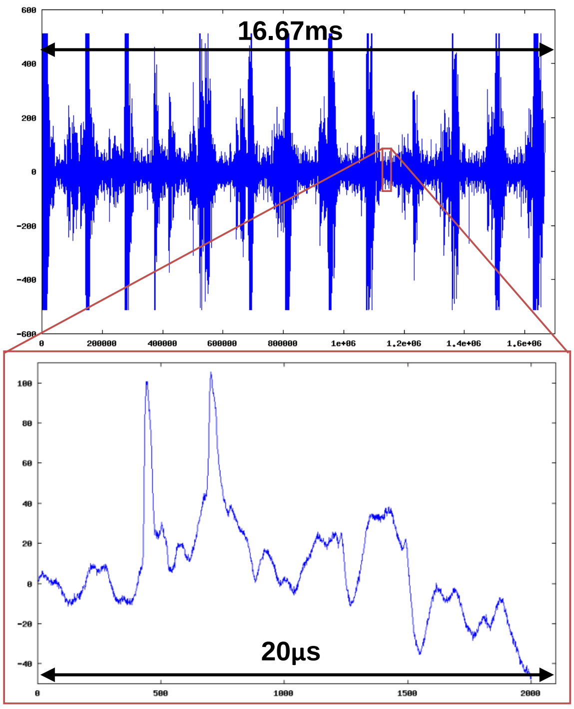

Figure 4: PD in relation to surrounding noise

It can be seen from the difference in scales above that the Partial Discharge was hidden within the surrounding prominent noise on the circuit. Also the main frequency of the noise is similar to that of the PD detected.

By looking at this example it is clear that the alternative methods of detection described earlier would have failed to detect the source of discharge on this circuit.

Noise levels like this are often found in heavy industry plants, where high electrical noise with a wide frequency band will be present; emphasising the need for sophisticated noise rejection techniques when conducting electrically sensitive testing or monitoring.

Defect Location

PD detected on this circuit was investigated by IPEC Data Analysts. It was found the discharge had a regular and clear reflection. An example of this reflection taken from the data analysis web front end is shown in figure 5 below.

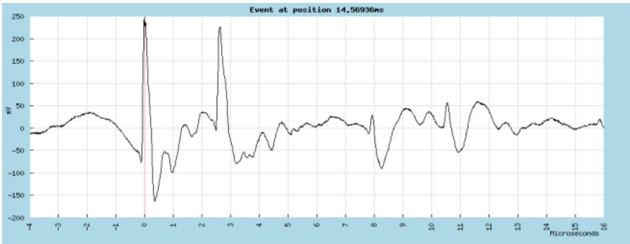

Figure 5: PD as displayed on web front end

The wave shape above shows the original PD pulse, followed by a reflection. By looking at many wave shapes acquired by the ASM system it was seen that this reflection occurred in every segment.

Normally when a defect is an on-line cable map for PD source location is conducted. Cable mapping uses Time Domain Reflectometry (TDR) to locate the source of a Partial Discharge based on the differences in arrival time of a PD pulse and that of the reflected PD pulse from the far end of the cable. As the PD reflections on cable circuits are often not as strong as seen in this case, a trigger unit is used at the far end of the cable to inject a pulse when the PD is detected. In this case however, with a clear reflection, the cable mapping technique can be used without the need to install extra equipment in the customer site.

High resolution data was downloaded from the ASM monitoring device and processed through on-line cable mapping software.

The PD was identified as being within a section of cable 0.7% of the overall cable length which was 700m. Customer records showed a straight joint within this 5m region and, as joints are commonly the weak points in MV circuits, this was suspected to be the source of the discharge.

Planned replacement work was conducted to remove the suspect joint. This was shipped to an independent laboratory in the UK for analysis.

The investigation into the condition of the cable joint found evidence of significant PD activity. This was seen on the inner wall of the screen insulating sleeve, adjacent to the change in the diameter of the conductor.

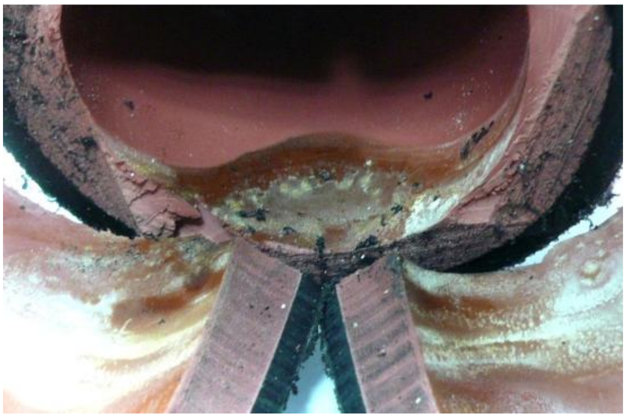

Figure 6: Evidence of PD found

"Due to poor workmanship during the making of the joint, when the red and black insulating sleeves were shrunk over the insulating tubing, excessive use of mastic prevented full insulator shrinkage leaving a small gap at the position at the change in diameter. At working voltage this gap allowed discharge to occur which would have continued until failure" [2]

Upon re-energisation of the circuit no Partial Discharge was detected, closing the loop and confirming that the Partial Discharge had been detected and removed. In industrial networks the cost of an outage can be significant, it was confirmed by the customer that this failure could have cost hundreds of thousands of dollars in lost production.

CONCLUSION

The range of techniques available to effectively detect partial discharge in cables depends on the network voltage, structure and environment in which it is to operate. Networks with high electrically induced noise, such as process plant networks, make detection of PD significantly more difficult.

Wavelet analysis techniques used in the DeCIFer algorithm have proven to be effective in these environments where other techniques may prove unsuccessful.

REFERENCES

[1] Mingyou Hu, 1998, "A new technique for extracting partial discharge signals in on-line monitoring with wavelet analysis", Proc of 1998 Int Sym on Elec Ins Matls, 677-680.

[2] ERA Technology, Cobham Technical Services, 2009 "Examination of 33kV Cable Joint", Report Number:2009-0614, Project Number: 7F0574101