Partial discharge detection using RFI measurements

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In service high-voltage (HV) substation equipment is exposed to electrical, mechanical, and thermal stresses as well as environmental conditions. All of these stresses can act to accelerate the deterioration of the insulation and hence the electrical integrity of the HV equipment eventually leading to failure. Detection and measurement of partial discharge (PD) phenomena, which are asymptoms of insulation deterioration, can provide early warning of insulation failure.

Critical to this is the availability of accurate and cost effective surveillance tools. If those tools are non-invasive they can provide early recognition and location of possible sites of electrical degradation whilst components are still in service. Trending over time of the gathered PD data is essential to allow the rate and severity of degradation to be monitored. Maintenance can then be planned. Unplanned outages, interruptions, inevitable loss of revenue and penalties that are incurred as a result can then be avoided.

There are different techniques available to measure the partial discharges online: e.g. dissolved gas analysis (DGA) of oil, acoustic emission measurement and radio frequency interference scanning. This article discusses the use of radio frequency interference scanning (RFI) measurements, which is gaining increasing acceptance as a front line non-invasive technique to detect partial discharge on plant. The instruments for RFI measurements are typically hand held units as shown in Fig.1.

RFI signals from discharge activity are considered to be broadband and impulsive in nature with low repetition rates. Spectrum analysers and EMI scanning receivers are widely available and used in detection and measurement of RFI signals. However, their use for measuring low repetition rate broadband signals presents particular challenges for reliable and repeatable detection and measurement. The measurement process requires specific understanding of signal and instrument characteristics to ensure the RFI signals are accurately represented.

Surveillance of RFI emissions from PD phenomena involves the measurement of complex waveforms varying considerably and often erratically in amplitude and time. Research and practical measurement carried out on PD activity within oil-insulated HV equipment demonstrates that discharges produce current pulses with rise times less than 1 ns and therefore capable of exciting broadband signals in the VHF (30 to 300 MHz) and UHF (300 MHz to 3 GHz) bands. Other investigations in open-air insulation substations show that signals from PD and flashover occupy a frequency range up to 300 MHz.

Measurement technique

The instrument used (Doble PDS 100), has two different detection modes: Spectrum analyser mode and time resolved mode. Within the spectrum analyser mode, there are in addition three separate detection techniques; peak detection, average detection and separated peak and average detection.

Spectrum analyser mode

Spectrum analyser or frequency mode scans the frequencies detecting RFI signals, looking for PD activity. The area of interest is between 50 MHz and 1000 MHz. It is commonly known that the PD activity will be in this frequency range. Further to the capture of RFI signals, the instrument has a gating time of 40 ms, i.e. the instrument "looks" at two cycles before it moves on and "looks" at the next frequency window. This frequency window is set to 6 MHz, also known as the resolution bandwidth (RBW) of the instrument. By detecting the peak amplitude of the RFI signal, an RFI emission due to PD activity will be detected and presented.

Time resolved mode

After detection of an RFI signal shown as a possible PD activity, the given frequency can be set, and the time resolved mode will show the possible PD signal in a time plot, correlated to the power signal, in a time of 20 ms. A typical PD source will emit a pulse twice the power frequency, therefore the shown signal will have a time resolved plot. A smaller PD source might emit a signal only once in the power frequency, i.e. repeat itself every 20 ms. This implies that there will be one or two clusters of peak signals in this mode when there is PD activity present, dependent on the physical characterization of the PD source and the degradation of insulation.

Fig. 1: Doble PDS 100 used for RFI measurements.

Practical measuring

Fig. 2 illustrates a typical baseline reading taken prior to measurement on any HV equipment. A baseline reading will show the typical ambient frequency signature for the area where a substation is located. The frequency spectrum from 50 MHz to 1000 MHz consists of several different continuous signals like FM radio, mobile phones and other telecommunication sources.

Differentiation between telecommunication signals and signals due to PD activity, is easily explained by the behaviour of the two different signals. Telecommunication signals are often narrow banded and will be shown on the instrument screen at any time and place. TV signals as shown in Fig. 2 are typically narrow banded signals. RFI signals due to PD are wide banded, and the amplitude of the signal will be strong close to the PD source and the RFI signal will attenuate when the distance to the PD source increases.

Case study 1: Correlation between DGA and RFI measurements

A South African, 132/ 33 kV, 45 MVA transformer manufactured in 1970 showed

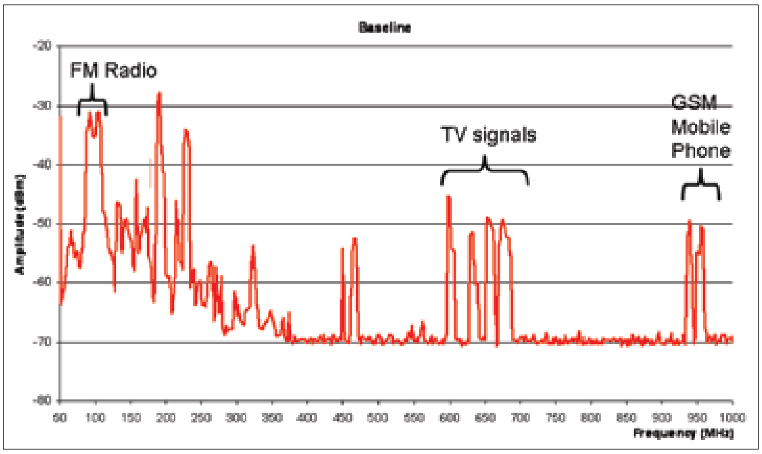

Fig. 2: Typical baseline with telecommunication signals present.

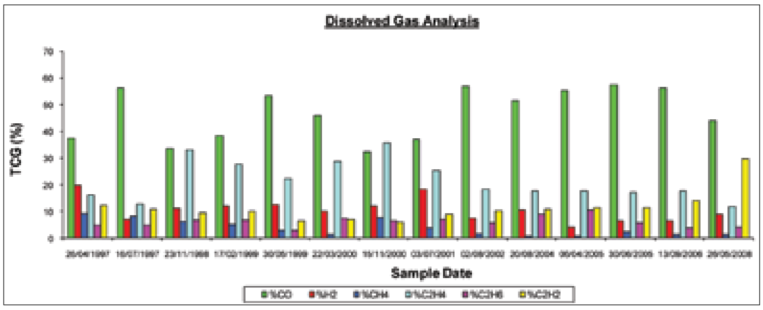

Fig. 3: DGA signature.

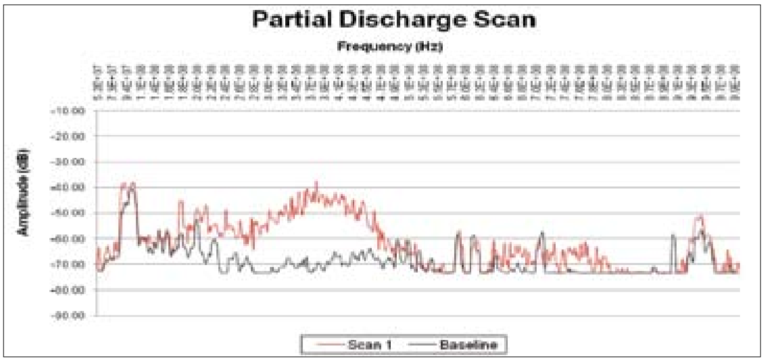

Fig. 4: RFI measurement of PD activity.

high levels of acetylene throughout the transformer DGA history. This DGA signature is typically the result of two types of faults i.e. a floating potential type fault or a leaking barrier board between the main tank and tap-changer. This type of DGA signature, as shown in Fig. 3, makes the transformer an excellent candidate for PD measurements.

The PD scan (Fig. 4) showed a definite rise in amplitude in the RFI scan compared to the baseline (in black). This confirmed the floating potential type fault.

As a result of the correlation between the DGA and PD results an internal inspection was performed. The inspection revealed a winding clamping bolt sparking fault, thereby confirming the floating potential fault. This is shown in Fig. 5.

Case study 2: Correlation between EMI and RFI measurements

A South African, 275/88/11 kV, 250 MVA transformer manufactured in 1984 was known to have a discharge type fault previously indicated by dissolved gas analysis (DGA). RFI measurements (using the Doble PDS 100) and EMI measurements (using a high frequency current probe) were performed to establish correlation between the measurements.

RFI measurements were taken around the periphery of the transformer. The frequency trace exhibits a discrete appearance as pulses are accumulated. Short bursts of pulse accumulation are interspersed with long intervals of no or low energy activity. Triangulation of the higher frequencies locates the source of propagation in the

Fig. 5: The source of the PD from winding clamping bolt.

vicinity of the HV B phase. The frequency traces are shown in Fig. 6. The blue trace is the peak baseline measurement; and the red trace is the RFI measurement at the source of the PD. Observing the RFI at 900 MHz for a period of time in spot frequency mode sees the measured peak amplitude reaching -45 dB at the location. This mode also confirms the burst nature of the pulse sequence.

The conducted EMI was measured at the HV neutral at the point on connection to the earthing arrangement. This is shown in Fig. 7. The measurement is also subjected to significant attenuation through the HV neutral connection and requires an extended observation time to arrive. In the time revolved mode both the RFI and conducted EMI measurement show similar measured pulse behaviour. However, the pulsed activity is more easily captured and more of the lower energy pulses are detected.

Partial discharge activity is indicated by both the measured RFI emissions and conducted EMI on this transformer. For each the pattern of discharge is characterized by very short burst activity interspersed by intervals of no or low energy activity. There is a strong correlation between the RFI and conducted EMI measurement.

Case study 3: PDS100 detects and locate sources of PD in a substation

An RFI emissions survey was carried out on an entire 400 kV substation in South Africa and measurements of RFI emissions were recorded at various survey locations for future trending. During the RFI emissions survey a strong source of PD was triangulated to bus coupler isolator.

Fig. 9 illustrates measurements of RFI emissions taken at the suspect apparatus (trace in RED) and compared with the baseline measurement (trace in BLUE) for that section of the substation. Uplifts of 60 dB and 30 dB are evident at spot frequencies 400 MHz and 1000 MHz respectively, providing evidence that this apparatus is exhibiting significant signs of deterioration and that a fault condition exits.

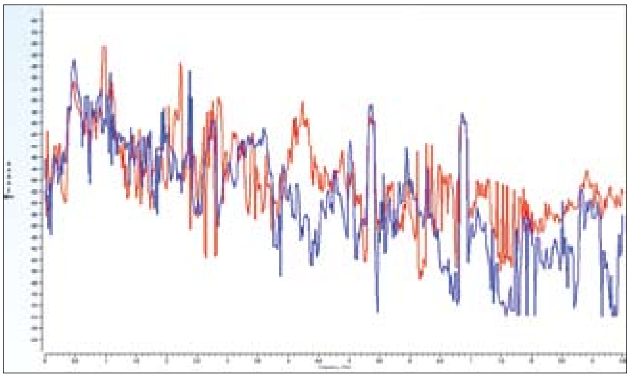

Fig. 6: RFI scan.

Fig. 7: Position of HFCT measurements.

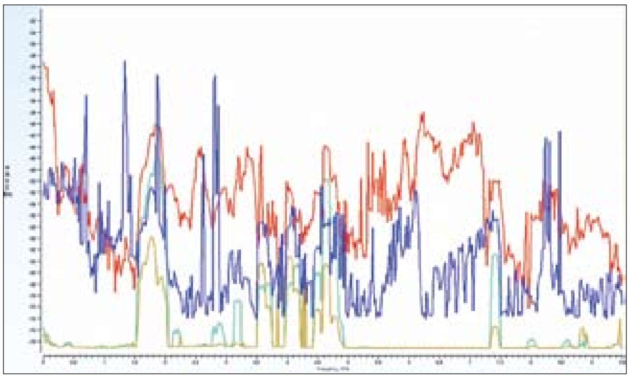

Fig.8: HFCT measurements on neutral/earth strap.

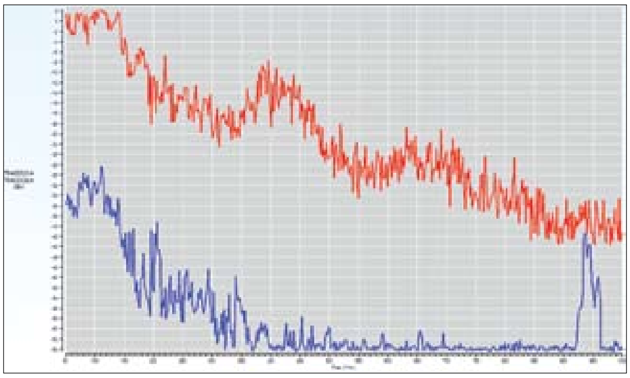

Fig. 9: RFI measurements.

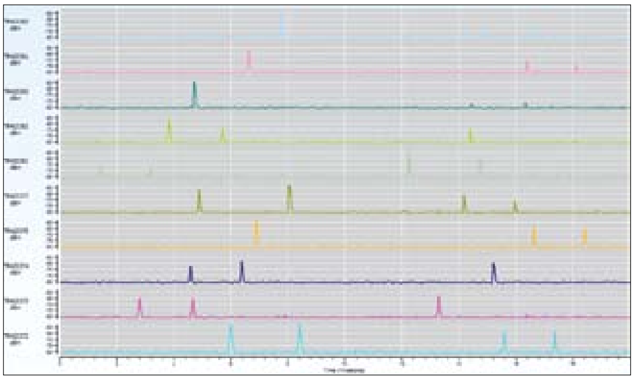

Fig. 10: Time resolved RFI measurements.

Time revolved measurements taken at a number of spot frequencies further characterise the source of RFI in terms of its pulsed behaviour. See Fig. 10.

The observed discharge pattern is repeatable in behaviour, having symmetry over both half cycles. The time interval between each pulsed phenomena, within each half cycle, is consistent across multiple power cycles with little variation in amplitude. The pattern of pulses is consistent with a contact related fault. Discharges such as this occur in advance of the voltage peaks.

Exploiting the high levels of attenuation observed at these frequencies, provides a very effective means of triangulating the source of the RFI and hence the site of degradation. Using a spot frequency of 900 MHz, the source of the RFI emissions was located and identified as bus coupler isolator – phase blue. See Fig. 11.

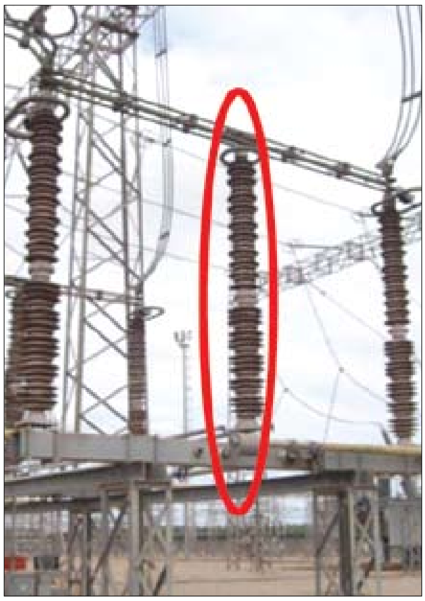

Fig. 11: The location of the PD source from the blue phase isolator.

Conclusion

The Doble PDS100 is an RFI emission surveying and mapping tool that is designed for use in a live substation. Without the need for special connections, the unit can detect partial discharge in just a few seconds thus making it an ideal tool for a condition based maintenance program. Whole substations can be surveyed and analysed. The results are recorded to allow future trending and therefore facilitate an assessment of individual HV apparatus insulation over time. The PDS100 is the perfect tool to detect and locate sources of PD.

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