RADIO FREQUENCY INTERFERENCE MEASUREMENTS AS A HV PLANT DIAGNOSTIC TOOL

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ABSTRACT

Partial Discharge (PD) tests provide an excellent method of assessing the condition of High Voltage (HV) plant under actual in-service conditions such as load and temperature. Such monitoring information, together with an understanding of the mechanism of PD allows for a more informed decision to be made about the condition of the insulation system. The use of Radio Frequency Interference (RFI) has gained increased acceptance as a front line non-invasive technique to assess the condition of individual HV electrical plant items as part of a substation surveillance program. This paper presents two case studies, one describing the surveillance of a 400 kV substation yard and the other RFI effectiveness in combination with DGA in diagnosing a fault.

INTRODUCTION

PD is evidence of dielectric breakdown of an insulation system and can lead to an electrical breakdown of the HV plant. PD is mainly caused by accelerated aging of insulation, manufacturing defects or installation related problems. The objective of PD measurements is to detect discharge at an early stage and make a proper evaluation.

HV plant 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 PD can provide early warning of insulation failure. This enables the engineer to take appropriate action and ensure the avoidance of unplanned outages, interruptions and loss of revenue.

PD plays a vital role in Doble Engineering Africa's condition assessment process. The condition assessment process comprises of two phases. The first phase is '*online'* where the unit is not removed from service for testing. The second phase is '*offline'* and is applied only to units that have been identified as high risk from the first phase, and provides a comprehensive analysis of the unit based on electrical tests.

The first phase consists of the assessment of the following:

a) DGA, oil quality indicators and furans
b) <u>PD detection using RFI</u> (this is where PD fits in the Condition Assessment Process)
c) Infrared Scanning
d) External Visual Inspection

There are currently four main PD techniques that are available.

a) DGA from oil sampling
b) Surveys using RFI
c) Electrical measurement of individual discharges using sensors
d) Acoustic measurements to locate the PD

This paper discuses the implementation of RFI measurements as a HV Plant Diagnostic Tool in detecting PD.

WHAT IS RFI?

RFI is a disturbance that affects an electrical circuit due to electromagnetic radiation emitted from an external source. RFI signals from discharge phenomena are characterized as broadband and impulsive with low repetition rates. Spectrum analysers and EMI scanning receivers are widely available and used in detection and measurement of RFI signals.

<u>Characteristics of RFI Emissions</u>

Surveillance of RFI emissions from PD 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 plant demonstrates that the discharges produce current pulses with rise times less than a nanosecond and therefore capable of exciting broadband signals in the VHF (30 to 300MHz) and UHF (300MHz to 3GHz) bands.

Detection Modes

The instrument used in both case studies discussed below has two detection modes: the Spectrum Analyser Mode and the Time Resolved Mode. In addition, the spectrum analyser mode has three separate detection techniques: the peak detection, the average detection and the separated peak.

Spectrum Analyser Mode

The 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, as this is common zone for PD activity, as discussed above. Further to the capture of RFI signals, the instrument has a gating time at which 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, is known as the resolution bandwidth 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

The frequency at which detection of RFI signals shows possible PD activity 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 a PD activity present, dependent on the physical characterization of the PD source and the degradation of insulation.

Practical Measuring

Figure 1 illustrates a typical baseline measurement. It will show the typical ambient frequency signature for the area where the 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.

Differing 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 also 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.

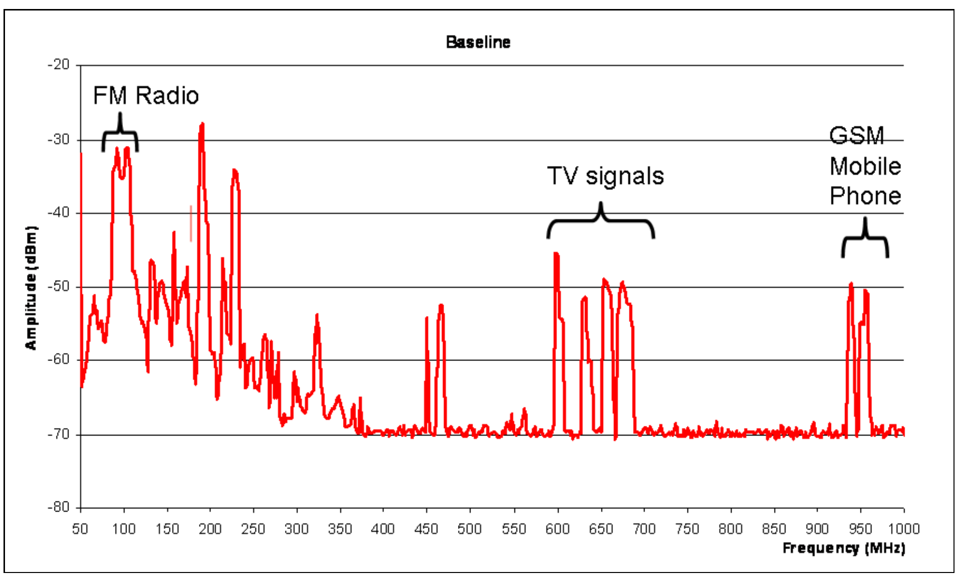

Figure 1: Typical baseline with telecommunication signals present

CASE STUDY 1: 400 KV SUBSTATION YARD SURVEILLANCE

RFI measurements were performed at a 400kV substation yard and an assessment thereafter performed to characterize any potential insulation degradation. The results obtained allow for future trending and therefore facilitate an assessment of individual HV plant over time.

Substation Site Detail

The substation discussed below has a capacity of 2000MW and was commissioned in 1995. An aerial photograph of the substation is shown in Figure 2 with the 400 kV yard encircled. The photograph illustrates both the size and complexity of the site.

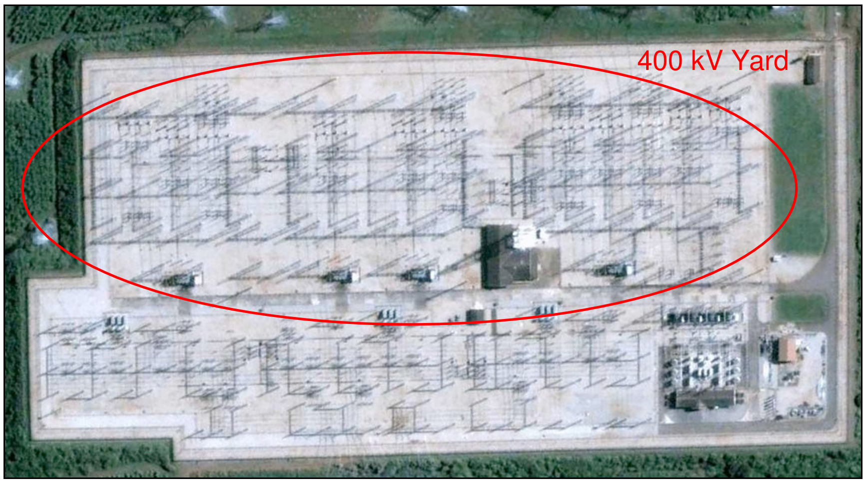

Figure 2: Aerial View of Substation ongoing RFI Surveillance

Substation Background RFI

Baseline measurements of peak and average mode (TRAC0281: A and TRAC0281: S) was taken adjacent to the entrance of the centrally located control building outside the 400kV yard enclosure. This established the ambient RFI profile for the site. Further two peak measurements (TRAC0298 and TRAC0313) were taken within the 400kV enclosure. This was considered as suitable baseline measurements and was used to establish comparisons for future observed RFI. See Figure 3.

The baseline measurements taken within the 400kV yard indicate a general increase in observed RFI in comparison with the ambient RFI at the control building. In particular a further uplift in RFI amplitude from 200MHz to 400MHz was observed which indicated an increase in detectable discharge activity. This increase was determined to be attributable to the level of pollution on the apparatus bushing insulators.

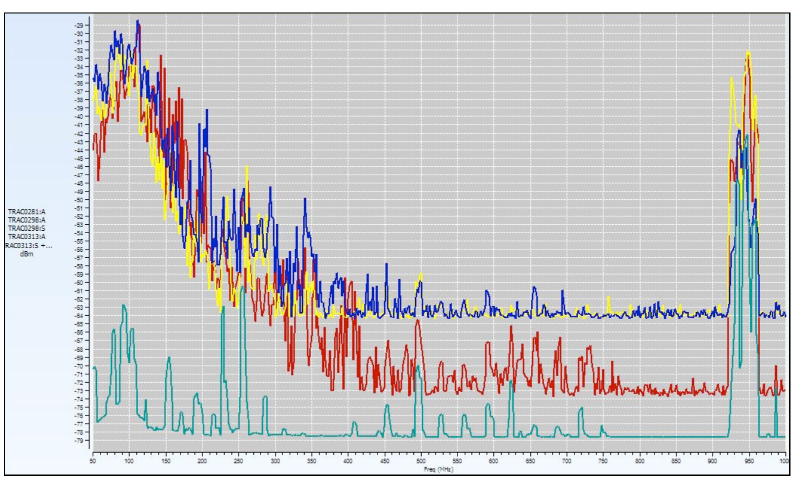

Figure 3: Baseline Measurements of RFI Surveillance

RFI Measurements – Central Section of 400kV Yard

RFI measurements performed in the central section of the yard showed a 10dB uplift at frequencies up to 200MHz in comparison to the baseline measurement. Again, this increase was attributable to the loud and audible levels of corona that are present across the site as well as to the level of pollution on the apparatus bushing insulators. When the measurement points were moved towards the vicinity of electrical circuit bay '<u>Capacitor 11</u>', a broadband uplift in RFI amplitude can be observed at frequencies between 200MHz and 620MHz. The broadband nature of the uplift and the frequency range in which it was observed highlight a potential site of insulation degradation. Observations at higher frequencies up to 900MHz provided further evidence to indicate the presence of a fault. The measured RFI emissions at these frequencies were highly attenuated with propagation and can be used for localisation. Analysis of RFI emissions recorded within the vicinity of circuit bay provided evidence that additional resources be used to locate and characterise the nature and severity of the degradation. See Figure 4.

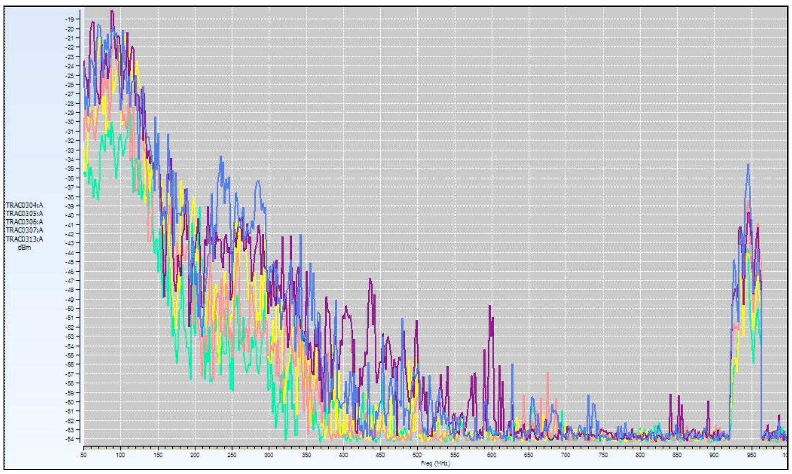

Figure 4: RFI Measurements in the Central Section

RFI Measurements – South Western Section of 400kV Yard

RFI measurements in the south western section of the yard and towards the vicinity of circuit bay '<u>Bus Coupler A</u>', showed a significant broadband uplift in RFI amplitude observed at all frequencies up to 700MHz. The broadband nature of the uplift and the frequency range in which it was observed highlighted a potential site of insulation degradation. There are observations of activity at higher frequencies up to 900MHz providing further evidence to indicate the presence of a fault. The measured RFI emissions at these frequencies are highly attenuated with propagation and would be used for localisation. This suspected fault was singled out in the remaining time for further monitoring in order to localise the location and characterize the nature and severity of the fault. See Figure 5.

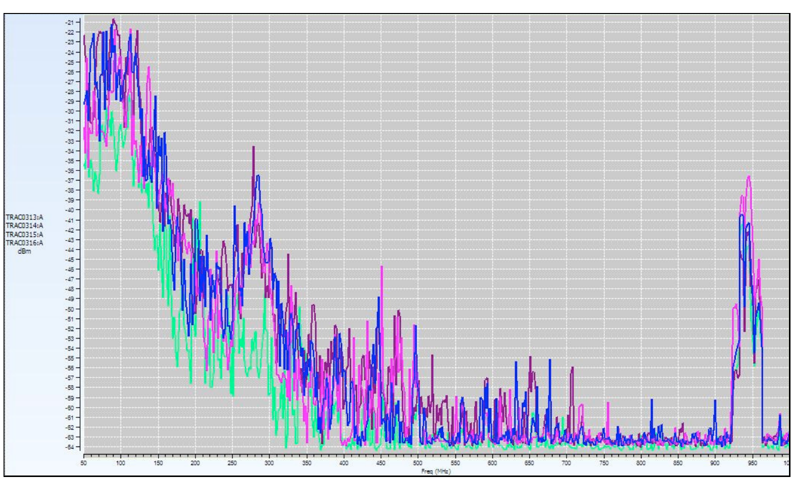

Figure 5: RFI Measurements in the South Western Section

Fault Location and Characterisation

RFI measurements taken along circuit bay 'Bus Coupler A' is provided in Figure 6. The comparison of RFI traces and the relative uplift in measured amplitude at the higher frequency ranges suggest the location to be close to the intersection of 'Busbar 2' and 'Bus Coupler A'. It can be observed from Figure 4 that the broadband nature of the RFI emissions extends up to 1000MHz. Using a spot frequency of approximately 900MHz, the source of RFI emissions was located and identified as Bus Coupler 2A Isolator - Blue Phase. See Figure 7.

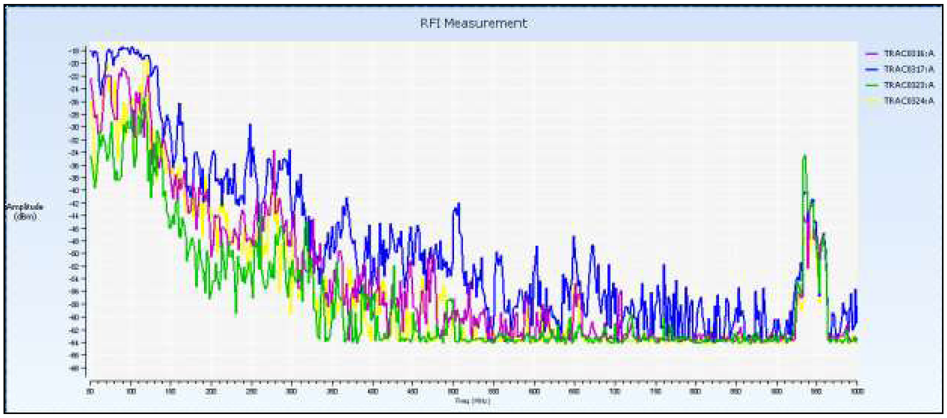

Figure 6: Localizing the RFI Measurements in the South Western Section

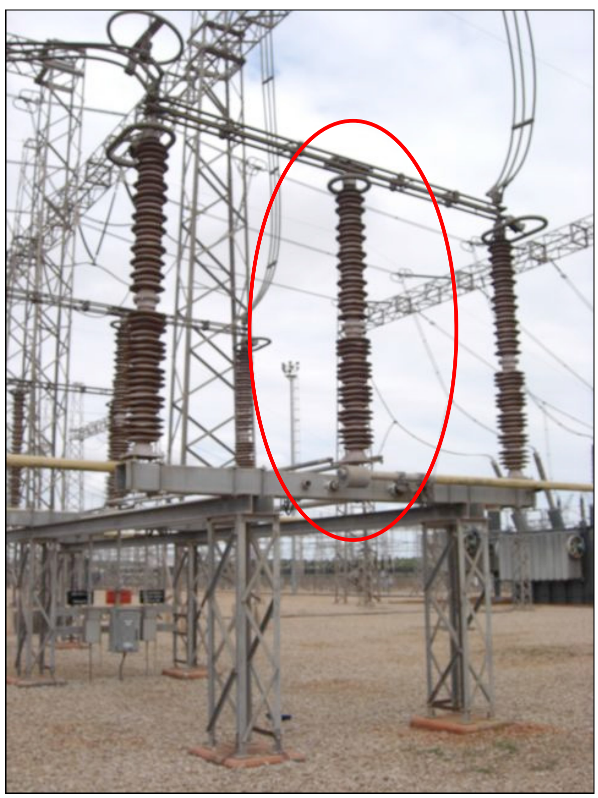

Figure 7: Busbar Coupler 2A Isolator -- Blue Phase

A further measurement of the suspect apparatus compared with the baseline measurement is plotted in Figure 8. Uplifts were again evident providing evidence that the apparatus is exhibiting significant signs of deterioration and that a fault condition exists.

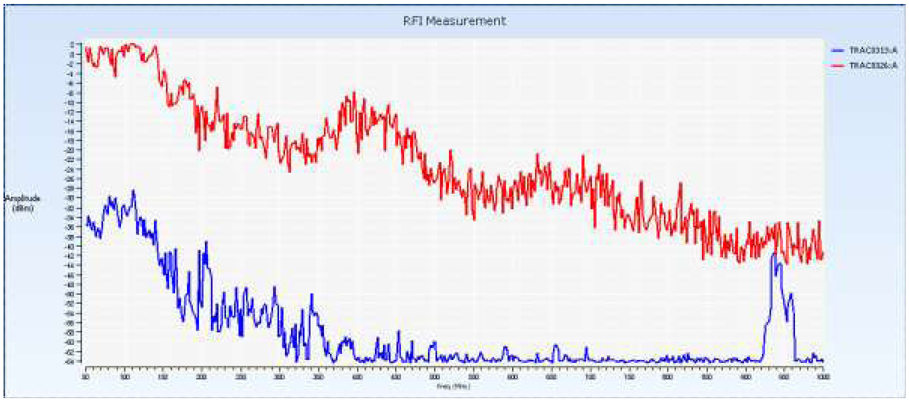

Figure 8: *RFI Measurements*

Time revolved measurements were then performed at a number of spot frequencies to characterise the source of RFI in terms of its pulsed behaviour. The observed discharge pattern is repeatable in behaviour, having symmetry over both half cycles. See Figure 9.

The time interval between each pulsed phenomena, within each half cycle, is consistent across multiple power cycles with little variation in amplitude. This pattern of pulses is consistent with a contact related fault.

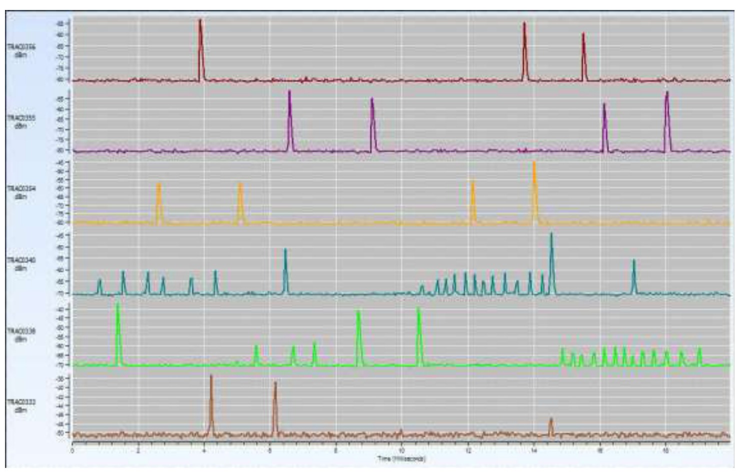

Figure 9: *Time Resolved RFI Measurements*

CASE STUDY 2: VALUE OFF RFI MEASUREMENTS IN COMBINATION WITH DGA

DGA was performed for a local utility during Phase 1 of their Condition Assessment Process. The unit was a 132/33 kV, 45 MVA transformer that was manufactured in 1970. The science behind DGA is that certain gases are produced at certain temperatures. These gases are generated by heat as a result of current flow, partial discharge, hot spots, etc.

DGA Analysis

The DGA signature showed significantly high levels of acetylene throughout the DGA history. This is shown in Figure 10. Acetylene, usually produced around 700℃, usually indicates a high energy dielectric fault. However the presence of such a dielectric fault occurring over a long period is not a logical analysis. However, recently developed DGA signatures provided us with two possible fault diagnoses for such DGA results.

The two possible diagnoses are:

Possible Fault #1

A difference or floating potential type fault. The possible causes for this type of fault are typically sparking or arcing between bad connections of different or floating potential, discharge in winding clamping bolts or between clamping parts/structure or a floating stress shield between the windings

OR

Possible Fault #2

A gas communication between the tapchanger compartment and the main tank, or between the respective conservators, most probably being that of a leaking barrier board between the main and tapchanger tanks.

To enable the distinction to be made between a floating potential and a communication related fault, this transformer was an excellent candidate for RFI measurements.

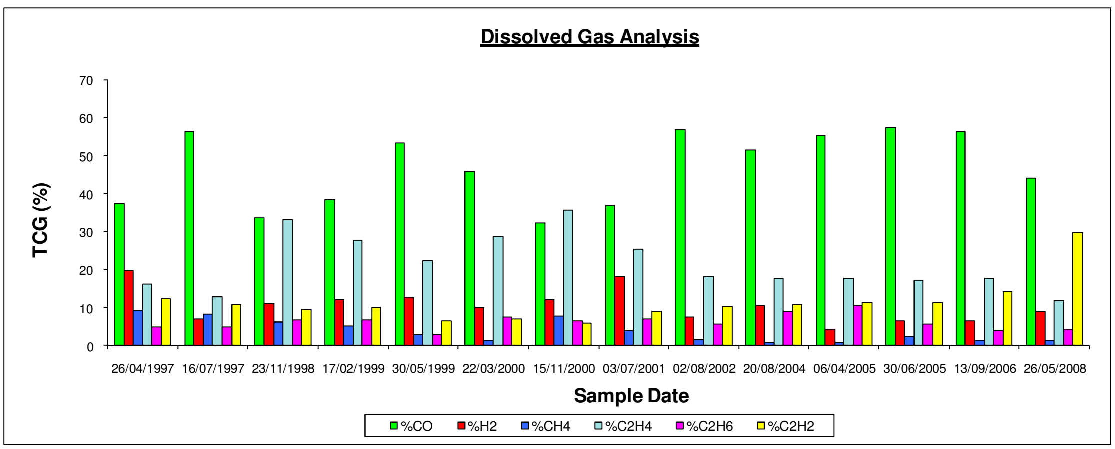

Figure 10: DGA signature showing acetylene throughout transformer history

RFI measurement

RFI measurements performed around transformer showed a significant broadband uplift in RFI amplitude observed at all frequencies up to 800MHz. At approximately 380MHz the amplitude peaks at -38dB. This substantial uplift in dB scan showed a definite rise in amplitude in the RFI measurement when compared to the baseline measurement. This confirmed the discharge activity. See Figure 11.

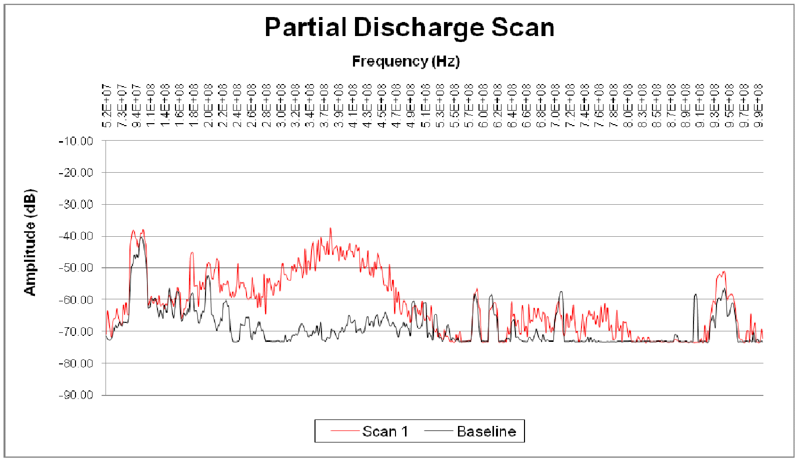

Figure 11: *RFI measurement of PD activity*

Internal Inspection

With both the DGA and RFI analysis pointing toward a discharge type fault, the go-ahead to perform an internal inspection was granted. The inspection revealed a winding clamping bolt sparking fault, thereby confirming the floating potential fault as described above. See Figure 12.

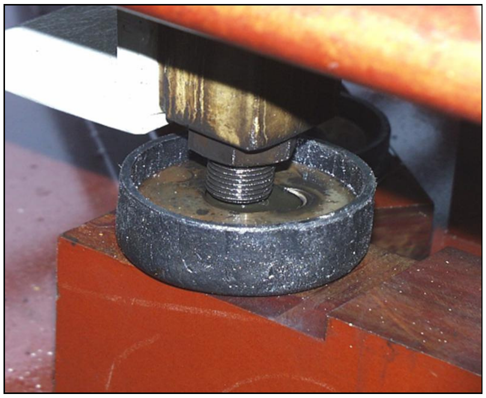

Figure 12: *The source of the PD from Winding Clamping Bolt*

CONCLUSIONS

RFI is a quick and simple method to detect PD which makes it an ideal tool for a condition based maintenance program. An entire substation can be surveyed and analyzed, with results recorded to allow future trending to enable assessment of individual HV plant over time.

RFI provides Engineers with a diagnostic tool to aid in effective analysis and identification of failures thereby ensuring the implementation of appropriate maintenance interventions. Risk assessment can easily be made based on level and frequency of PD activity.

As opportunities for offline diagnostic tests are rare and limited, it is essential to obtain as much information from online tests. RFI monitoring offers a routine non-invasive and cost-effective surveillance technique that complements and provides added value to other well established condition monitoring techniques such as DGA signatures.

The two case studies presented in this paper demonstrate the ability of RFI as a substation surveillance tool to assist in the effective discrimination and recognition of potential sites of insulation deterioration. In addition in conjunction with DGA it enables good calculated decisions to be made by the asset manager.

Finally, in view of the increasing costs of transformer forced outages and unexpected failures it is imperative to utilize the appropriate diagnostic test techniques such as RFI, which has proven to be reliable and cost effective to the company.

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BIOGRAPHY

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Kamendren Govender graduated from the University of Natal in 2006 with BSc in Electrical Engineering. Upon graduating he worked as a Candidate Engineer in Durban Electricity. In 2008 he joined Doble Africa as an Engineer. He is predominantly involved in transformer condition assessment work for the utilities in Africa.