A NOVEL APPROACH TO PARTIAL DISCHARGE MONITORING

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ABSTRACT

On-line partial discharge (PD) monitoring has existed in some form since the early 1980s. It is the tool of choice to evaluate the health of the stator insulation on large rotating machines. However, analysis of partial discharge results remains difficult to most users and advanced interpretation is usually reserved for experts in the field.

While the hardware development has matured, it hasn't changed drastically over the last decade. The main trend in PD development over that period has been in the software area, mainly involving the use of post-processing to assist in pattern recognition. Multiple approaches and technologies have been presented in numerous papers by various groups worldwide. This paper will demonstrate a novel approach that automatically and in real-time classifies ultra-high frequency partial discharge pulses into representative patterns. The technology has been developed and patented by Eskom and commercialised for use on turbo generators by VibroSystM Inc. of Canada.
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1. INTRODUCTION

Stator winding failures are one of the most critical causes of generator forced outages on large turbo and hydro generating machines. Stator windings are subjected to high electromagnetic, thermal and mechanical stresses in the core and overhang regions. Good design, manufacturing and assembly are paramount to ensure reliable long-term operation. Knowledge of the stator insulation condition is critical to successful long-term operation. The various deterioration processes are mostly slow evolving. However, the corresponding failures are, for the most part, quite sudden and unfortunately, catastrophic.

Partial discharge detection is used to identify a number of anomalies in the insulation systems of high voltage equipment. Partial discharge is the indicator of choice which allows for an assessment of the health of the insulation. As the insulation ages and deteriorates, partial discharge activity will slowly increase. The total number of discharges, the total discharge current, the location of the discharge sites, the rate of change of the discharge activity as well as the size of the discharges produced gives an indication of the condition of the insulation.

This degradation of the insulation is caused by voids developing in the insulation itself, in between the insulation and the copper, on its surface inside the slot or within the overhangs. Monitoring of partial discharge consists of detecting PD activity, determining the various sources and finally trending their increase rate, if present. When performed correctly, this technology provides sufficient time to identify the problem, follow its evolution and more importantly, properly plan a timely intervention to apply corrective actions.

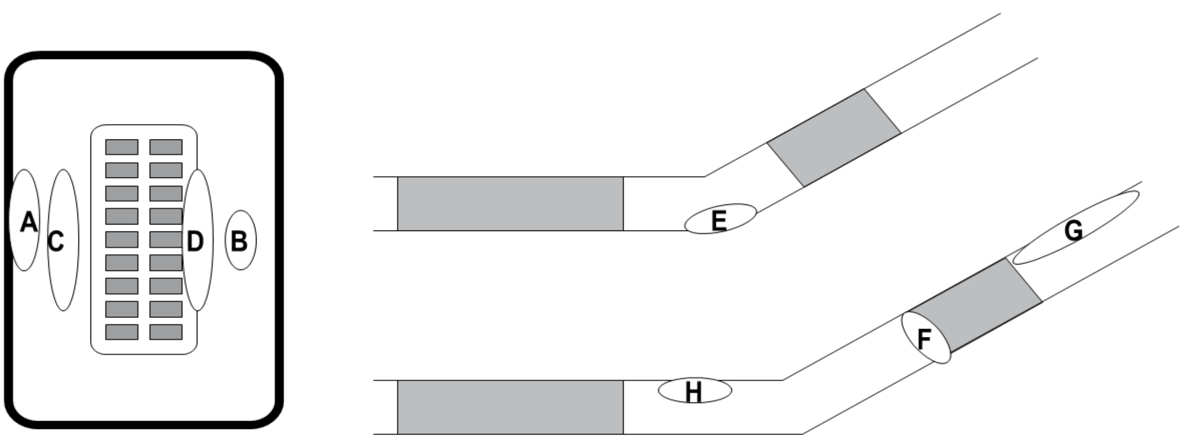
Off-line testing, although still a practical tool, does not reflect loading changes (VARs, temperature, vibration) and does not indicate individual faults. On the other hand, periodic on-line testing provides only sporadic snapshots of the insulation health under a limited range of load conditions, which does not indicate all possible individual faults. If any condition develops in the short term, only continuous on-line monitoring can properly detect and identify the problem. Continuous on-line monitoring provides a complete range of data under all operating loads and thermal conditions for analysis.

One of the major problems facing all current commercial partial discharge detectors is identifying and localising different patterns in these scatter plots. These different patterns have unique signatures associated with them. These signatures represent different faults or types of corona activity. However, using the presently available technologies, all the pulses that make up the scatter plot cannot be separated. As a result all of the pulses are displayed on the same scatter plot. If only one unique pattern is dominant, then it can be identified, but as soon as there are two or more patterns they interfere with each other. As any piece high voltage equipment will have multiple sources of partial discharge activity, accurate identification of fault location from the scatter plot is difficult and sometimes impossible. Up to now, no solution has been found to reliably localise the unique pulse signatures. The partial discharge equipment that is presented in this paper applies a novel method of signal processing that allows localisation and display of the various unique signatures that result from the pulses that the device is producing. The processing to classify the ultra-high frequency partial discharge pulses into representative patterns is performed in real time.

2. HOW AND WHERE DO PARTIAL DISCHARGES OCCUR?

Partial discharges are tiny electrical discharges which occur within voids inside high voltage insulation or on its surface. Figure 1 shows the main locations of discharge activity:

- Between the copper and the insulation (ground wall). (D)
- In the insulation (voids). (B and C)
- Between the insulation and the core iron (slot) (A)
- Surface of the winding, usually at the overhangs: (E) delamination at elbow, (F) bar-to-bar,(G) surface, (H) grading paint junction)



Typical stator bar (left) and end-winding (right) cross-sections
Figure 1

Discharges occur when the electrical stress exceeds the electrical breakdown strength of air, i.e., 3 kV/mm, which is much lower than the electrical breakdown strength of the solid insulation. Each discharge creates an electrical pulse. The larger the void, the greater the discharge and the pulse.

Voids and delamination inside the coil insulation are created by poor VPI, thermal cycling and load cycling or extended periods of operating beyond the rated temperature of the insulation. The partial discharges gradually erode the epoxy walls of the air pocket, making it larger and consequently generating larger partial discharge pulses. Voids are also created inside the slots between the insulation and the stator iron by the erosion from stator bar vibration and thermal cycling. As the void enlarges and the winding loses intimate contact with the stator laminations, partial discharges appear and further erode the groundwall insulation, which increases the PD activity. If the stress grading material is incorrectly applied at the slot exit, surface tracking may occur and this may eventually lead to sparking between the overhang winding and the stator core. This discharge activity will eventually erode the insulation surface. Poor spacing between the overhangs along with contamination can cause tracking and discharges on the surface of the overhangs. This may eventually lead to a flashover between adjacent overhangs. Finally, poor overhang support and bracing could result in excessive vibration which leads to insulation cracking, copper strand cracking and eventually major failures. Partial discharge activity is generated within these cracks and if identified correctly, can be used as an early warning indicator of this type of damage.

Each partial discharge has its own characteristics depending on its location. The pulses have extremely fast rise-time at the discharge origin, of approximately 1 to 5 nanoseconds. Partial discharges usually occur during the first and third quadrants of the AC cycle. Partial discharge pulses can have either negative or positive polarity. Negative partial discharges are produced in the positive cycle of the current waveform, and positive partial discharges are produced in the negative current waveform.

Partial discharges which occur within the stator section of the machine display three main areas of activity:

- Positive discharges << negative discharges
- Negative discharges << positive discharges
- Positive discharges == negative discharges

Each of these conditions indicate the general location of the discharges in reference to the copper, the insulation or the stator iron. If the negative discharges exceed the positive discharges, the discharges are considered to be closer to the copper, and are called groundwall discharges. If the positive discharges exceed the negative discharges, the discharges are considered closer to the stator iron, and are called slot discharges. If there is an even distribution of positive and negative discharges, the discharges are considered to be within the insulation, and are called internal or void discharges.

During the first quadrant of the exiting waveform, the copper-insulation interface becomes a cathode, resulting in the release of more free electrons at this interface and a dominance of negative discharges. During the third quadrant of the exiting waveform, the stator iron-insulation interface becomes the cathode, resulting in the release of more free electrons at this interface and a dominance of positive discharges. During both the first and third quadrants, the insulation is the cathode, resulting in equal distribution of negative and positive discharges in both quadrants.

Partial discharges in the overhang area generally occur in both the first and third quadrants and usually contain equal amounts of negative and positive discharges, but this is not always the case. If these discharges are generated between two different phases, they normally display a 30° or 60° phase shift.

3. NEW APPROACH

Most PD monitoring instruments presently available are based on detection of multiple resonant peaks of both polarities. This produces readings that tend to be symmetrical in both the positive and negative sections of the half cycle. This “echo” or “mirror” effect makes analysis and interpretation difficult, especially when different sources of PD activity are superimposed on the scatter plot.

A number of existing PD instruments use a noise suppression or cancellation technique to separate PD activity from the system side out and only keep PD activity from inside the machine. This is usually done by utilising two points of detection and subsequent digital processing. However some techniques also eliminate some valuable PD activity from inside the machine.

One of the major problems facing all current commercial partial discharge detectors is identifying and localising different patterns in these scatter plots. These different patterns have unique signatures associated with them. These signatures represent different faults or types of corona activity. However, using the presently available technologies, all the pulses that make up the scatter plot cannot be separated. As a result all of the pulses are displayed on the same scatter plot. If only one unique pattern is dominant, then it can be identified, but as soon as there are two or more patterns they interfere with each other. As any piece high voltage equipment will have multiple sources of partial discharge activity, accurate identification of fault location from the scatter plot is difficult and sometimes impossible. Up to now, no solution has been found to reliably localise the unique pulse signatures.

EMI detection is another method of displaying partial discharge information. Up to now the acquisition units have been either selective frequency volt meters, which are very expensive or complex or AM radio type receivers, which are very simple and crude. The technique is not normally included in a partial discharge detection system and the units are applied separately.

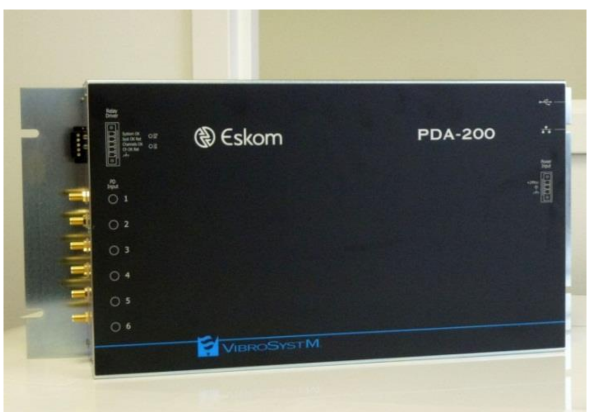
In designing a new PD monitoring system, the goal was 1) to have a system that would eliminate the “echo” effect by picking up only the original pulse peak of the right polarity, 2) eliminate noise using a single point of detection, 3) implement fault diagnostics through automatic PD pattern matching (PDPR), and 4) complement the system with the addition of electro-magnetic interference (EMI) detection.

The new technology is the result of 15 years of development at ESKOM, and 9 years of development in partnership with VibroSystM of Canada.

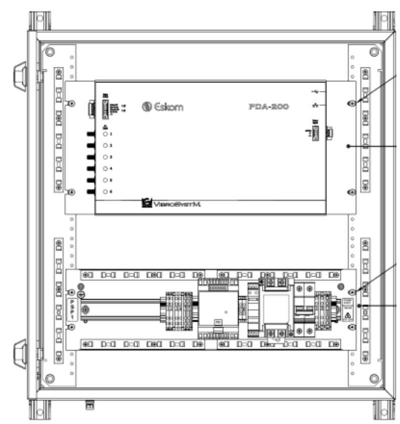
3.1. PD detector

The new system is based on a patented partial discharge identification system which makes use of advances in electronics and processing. It employed a ultra-wide frequency bandwidth of 150 kHz to 250 MHz. Advanced signal processing ensures that it always detects the dominant partial discharge. The system displays only the first peak associated with the partial discharge and no overshoots are displayed. All unwanted low frequency artefacts are removed from the signal. The instrument has a dynamic range of approximately 70 dB allowing continued acquisition of PD signals in the range from 2.5 mV to 10 Volts.

The utility has standardised on 80 pF coupling capacitors. However the instrument readily accepts a wide range of existing bus couplers. Only one coupler per phase, connected to the generator side, is required per machine. However, up to 6 couplers can be connected to the PDA-200 acquisition unit, which makes it compatible with numerous existing 2 couplers per phase installations. As shown in fig. 2 and 3, the acquisition unit is rack-mounted in a wall-mount enclosure near the generator. Each of the acquisition units of the power station are connected to a central system controller via a fibre-optic Ethernet network, and each power station can be accessed remotely by engineers across an existing TCP/IP network. This allows for remote monitoring, analysis and supervision.



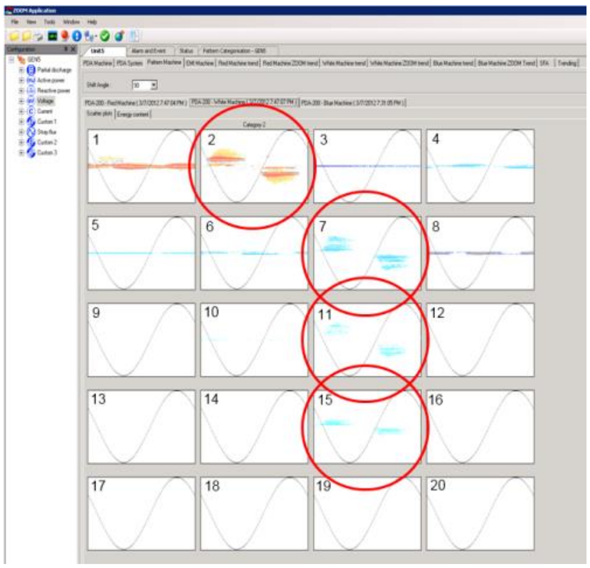
Acquisition Unit.
Figure 2



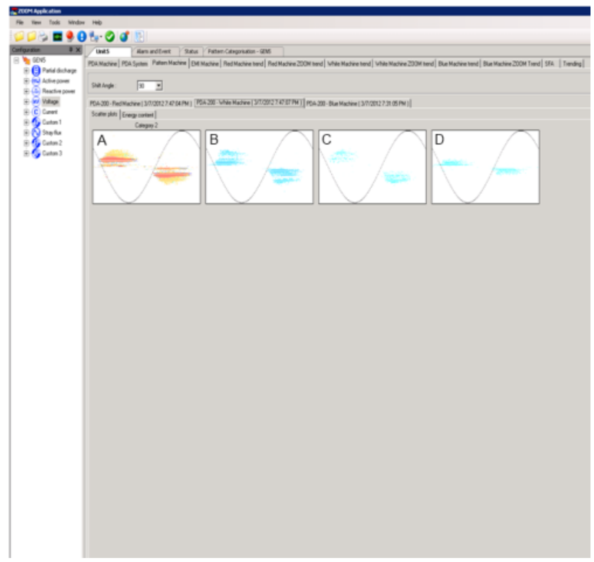
Acquisition unit inside the wall-mount enclosure
Figure 3

3.2. Fault diagnostic

The software uses a unique and patented PD pattern matching system to categorise different sources of PD activity. It compares critical information from each PD pulse to determine the matching criteria (category) and then builds a separate scatter plot for each category. The scatter plots display a selectable number of points on a FIFO basis. This makes it easy to select only the relevant fault scatter plots and to hide non applicable ones. This is illustrated in figures 4 and 5. The fault diagnostic process is done in real-time at ultra-high frequency rates with no user intervention.



Categorization allows easy identification of relevant PD sources
Figure 4



Only relevant categories are displayed after applying rules to hide non applicable plots
Figure 5

Table 1 summarizes the categories displayed in fig. 4 of which four categories were selected in fig. 5.

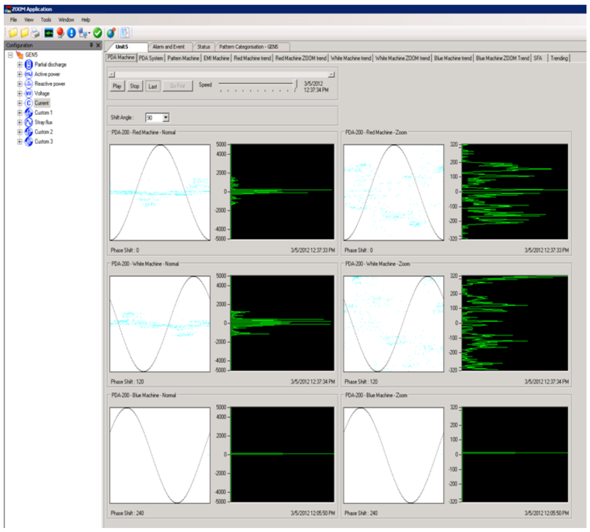
Table 1
Discriminating partial discharge categories

No.	*Type*	*Description*
1, 4, 6, 8	Cross-coupled signals	n/a
2	**Void discharges**	Some distance from the coupler
3, 5	Noise signals	n/a
7	**Delamination discharges**	Close to the coupler
9, 10, 12, 13, 14, 16 – 20	Spurious signals	n/a
11	**Slot discharges**	Closer still to the coupler
15	**Void discharges**	Between A and B discharges

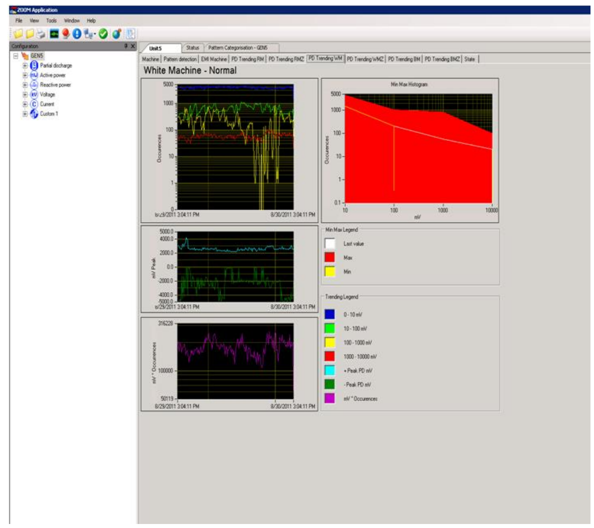
Through this process of pattern identification scatter plots that were created by noise pulses can be uniquely identified and then hidden from view. As a result noise can be eliminated using a system that only has a single point of signal detection, rather than the two or more points of signal detection normally employed to eliminate noise. Currently, the software only classifies and numbers each category and scatter plots that are identified as being generated by noise or other unwanted signals have to be hidden manually. The next stage of development will allow for automated pattern recognition, which will

A) remove noise, cross-coupled or spurious signals, and B) allow for automatic identification of the fault associated with each category.

The software also provides more traditional scatter plots per phase an example of which is displayed in figure 6, and trending plots per phase of occurrences, mV peak, min/max histogram and mV vs. occurrences an example of which is displayed in figure 7.



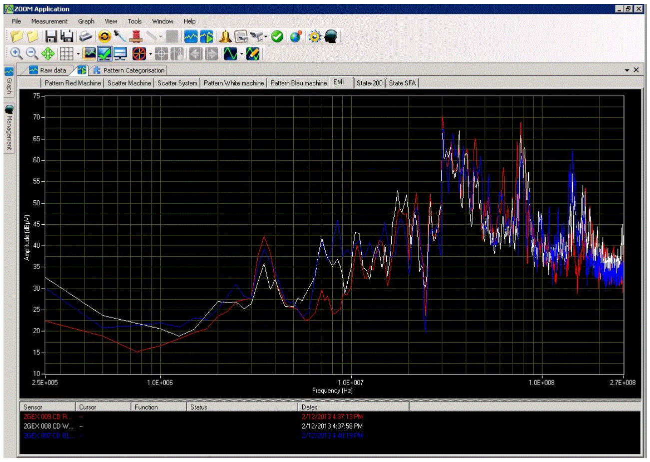
Scatter plots (white) at full scale and zoomed scale, as well as corresponding summary plots (black) for each
Figure 6



Trending plots of occurrences, mV peak, min/max histogram and mV vs. occurrences
Figure 7

3.3. Electro-Magnetic Interference (EMI) detector

Using the signals from the same coupling capacitors, and in parallel with the partial discharge acquisition the system gathers and displays EMI data. This system uses a patented sampling methodology. It focuses on particular frequency bands that are characteristic of group of faults in specific equipment. All unwanted low frequency artefacts are removed from the signal. The EMI displays are generated using algorithms that employ very low computational time. As a result it can provide on-line and near real-time EMI performance on all three phases simultaneously.



Electro-magnetic interference (EMI) plot
Figure 8

4. IMPLEMENTATION

Implementation of this new system started in 2012. Two Units have been deployed. A further 75 units have been completed and plans are in place to provide the final 12 units. It is intended to install all 89 units before 2015.

CONCLUSION

A new partial discharge device has been presented that is designed for automated pattern recognition and fault diagnostics of partial discharges. Early results have proven the effectiveness of the processing method to correctly identify the sources of PD activity without requiring the assistance of experts for interpretation.

Data has just begun to be recorded and analysed with this new technology. The early results are presented in this paper. These results have shown that this novel approach has very effectively achieved the goals of 1) to have a system that would eliminate the “echo” effect by picking up only the original pulse peak of the right polarity, 2) eliminate noise using a single point of detection, 3) implement fault diagnostics through automatic PD pattern matching (PDPR), and 4) complement the system with the addition of electro-magnetic interference (EMI) detection.

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BIOGRAPHY

Dr Simon Higgins Ph.D., M.Sc., B.Sc., CEng, MIEE

Dr Simon Higgins is the Eskom Holdings Corporate Specialist for Condition Monitoring. He was awarded his B.Sc, M.Sc. and Ph.D. from the University of the Witwatersrand in South Africa. Dr Higgins has headed up the Eskom condition monitoring research program. Through this program a number of condition monitoring systems to be applied to the power industry have been developed. These include partial discharge and EMI systems to be applied to generators and transformer, stray flux, and shaft monitoring products to be applied to generators as well as fault diagnostic and equipment health grading systems for generators, transformers, boilers and turbines. The equipment developed through this program has been granted 5 patents. A number of the products developed through this program have either been or are in the process of being commercialised with various commercial partners.

Mr. André Tétreault

Mr. André Tétreault has been with VibroSystM since 1995, starting out as a field technician. He then worked in the technical support area and software development. Now, as Director of the Tests and Diagnostics Division, he is responsible for machine data analysis. He travels all over the world sharing his experiences and expertise through training sessions on machine behaviour for power utilities and mining companies worldwide.

Mr. Tétreault, a graduate of computer technology, is a member of IEEE and a member of CIGRÉ A1 committee (Rotating machines). Throughout his career, he has contributed to several CIGRÉ, EPRI and IEEE papers and conferences on machine behaviour. His hands-on experience in the installation and commissioning of monitoring systems, as well as over 10 years' experience in analysing results, has given him a wealth of knowledge in regards to large rotating machines, including hydro-generators, turbo-generators, as well as SAG Mills and Ball mills.