Pattern Recognition of Partial Discharge Signal in Gas Insulated Switchgear Apparatus using Visual and Cluster Analysis

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Abstract **-- This paper will describe the development of an acoustic Partial Discharge (PD) detection system to discriminate the defect sources and the dimension of the particles in a compressed SF_6 Gas Insulated Switchgear (GIS). Different types of material with different shaping will be used as artificial defects to induce PD in experimental works. PD measurements have been obtained under AC stress in a uniform electric field configuration. Discrimination and classification of the PD distributions of the studied defects are possible using the technique of visual and cluster analysis. The aim of visual analysis is to display the discharge signals in 3 dimensional forms to increase the visible strength. Cluster analysis is used to study and calculate the dissimilarity for the statistical parameters for different kinds of discharge sources and presents it in Dendogram.**

Index Terms **-- Acoustics, Clustering methods, Gas insulated switchgear, Partial discharges, Signal Processing, SF_6, Visualization.**

I. INTRODUCTION

GAS Insulated Switchgear (GIS) apparatus is well known to power engineers for its superior dielectric performance compared to the conventional air-insulated apparatus. It is only the presence of contaminating metallic particles in these apparatus that severely deteriorates their insulation strength. The particles cause Partial Discharge (PD), which if no suitable preventive action is taken can lead to breakdown. Therefore it is necessary to develop a particle detection system by which user can detect the presence of metallic or non-metallic particle in GIS more accurately before it causes enormous damage to the system and substantially loss in revenue.

There are various types of diagnostic methods available for the PD detection in GIS. Acoustic measurements applying externally located sensors are among the methods that are being explored. Their high sensitivity to the most common flaws, namely loose particles and discharges, makes acoustic methods promising for diagnosis of GIS [1].

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II. EXPERIMENTAL SETUP

All measurements were carried out in a model GIS as shown in Fig. 1 with system voltage of 14kV and gas pressure of 50kPa.

A. Acoustic PD Detection System

The PD measurement heavily depends on the detection instrument. On-line PD measurements based on digital systems have become attractive due to the versatility and flexibility of data acquisition and analysis at high speeds. A low cost computer-based acoustic PD detection system has been developed for real-time diagnostic as well as on-screen data analysis.

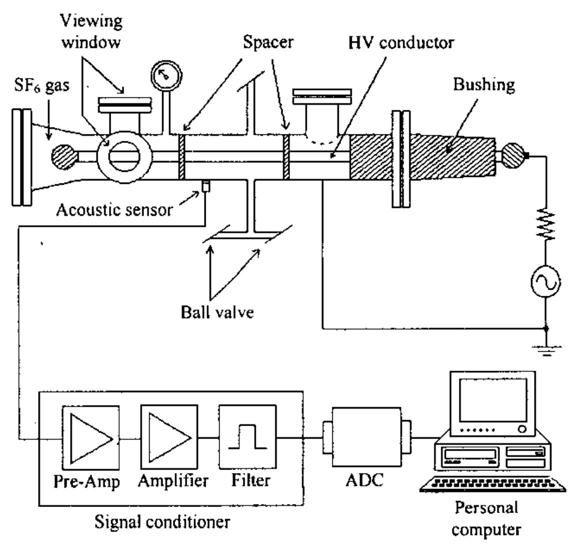

Fig. 1. Model GIS and Computer-based acoustic PD detection system.

B. Defect Characterization

The characteristic of the various types of defects running in GIS apparatus is required for the interpretation of the PD measurements and development of PD detection system. Defects in the insulation system may be left after the production and erection, and may also be produced during normal operation. Fig. 2 shows the most common defects that are taken into consideration, which are:

1) Free moving particle on the enclosure,
2) Protrusion on earth and live parts,
3) Corona on the electrode surface.

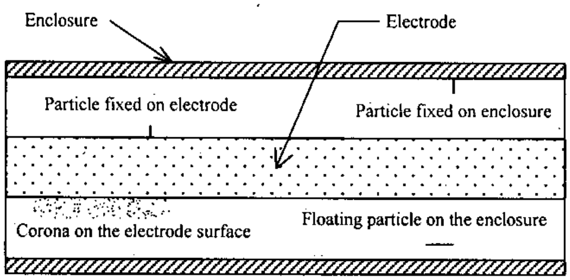

Fig. 2. Artificial defects for experimental works.

III. PD ANALYSIS

Reference [2] shows that the PD distributions (patterns) can be evaluated by correlating the PD pulses to the 50Hz or 60Hz sine wave. By measuring pulse distribution as a function of the phase angle it is possible to obtain information on the phenomena that cause these distribution [2]-[4]. Three phase-position distributions are processed:

1) The maximum pulse height distribution $H_{q\,max}(\varnothing)$,
2) The mean pulse height distribution $H_{qn}(\varnothing)$,
3) The pulse count distribution $H_n(\varnothing)$.

The combination of $H_{qn}(\varnothing)$ and $H_n(\varnothing)$ quantities can be displayed as a three-dimensional (3D) distribution having the advantage of visible strength. However, because of its complexity, $H_{qn}(\varnothing)$ and $H_n(\varnothing)$ are to be analysed separately in two-dimensional [3].

Statistical parameters that are used to evaluate the PD distributions are [2]:

1) Skewness, *Sk* – An indicator for the asymmetry of a distribution with respect to a normal distribution.
2) Kurtosis, *Ku* – An indicator for the deviation from the normal distribution.

IV. EXPERIMENTAL RESULTS

All the experimental results presented in this paper were obtained in the IVAT Laboratory at Universiti Teknologi Malaysia, using a model GIS. Along the experiments, metallic particles (Al, Cu) of different shaping are used as artificial defects to induce PD. Following is the defects of interest:

A. Protrusion on the Electrode.

A needle particle of copper (length = 25mm, dia.= 0.5mm) was attached on the surface of the electrode. Discharges generate acoustic signals that have to propagate through both gas and metal enclosure before they reach the sensor [1]. Fig. 3 shows the discharge pulses, which are correlated with the applied voltage [5] while Fig. 4 shows the phase-related distributions in 3D. Discharges appear mainly on the falling of the positive half cycle and rising of the negative half cycle. However, when the particle length is decrease, only discharges on the negative half cycle can be seen. The signal amplitude and number of pulses increases with the increase of particle dimension, applied voltage or gas pressure.

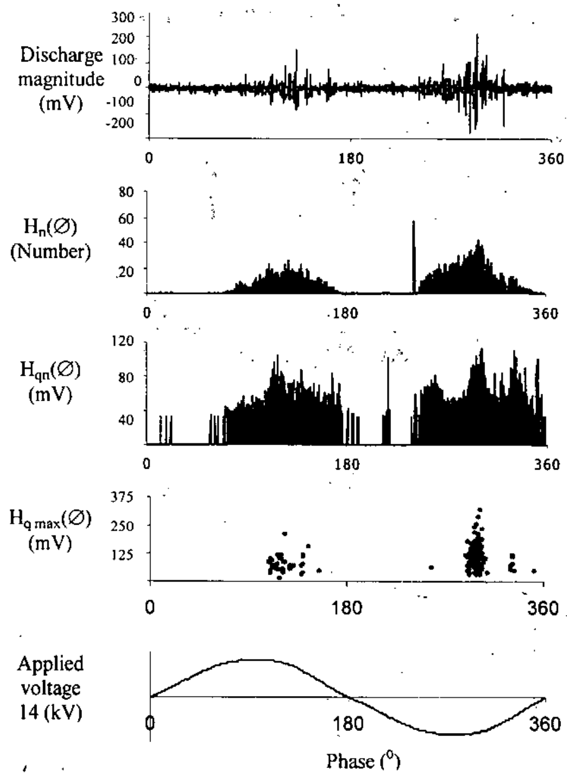

Fig. 3 Phase resolved quantities for discharge due to protrusion on the electrode.

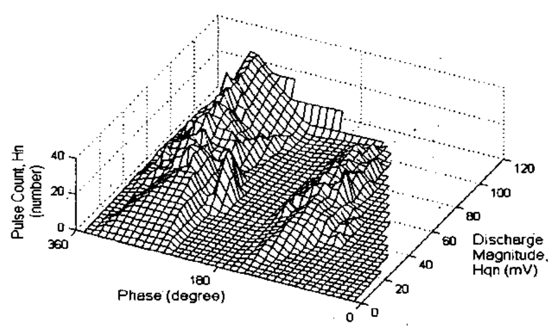

Fig. 4. 3D distribution for particle fixed on the electrode.

B. Protrusion on the Enclosure.

Copper metallic particle (length = 25mm, dia.= 0.5mm) was attached on the inner surface of the GIS chamber. If the electric field at the tip of the needle type particle exceeds the withstand level of the gas, discharges could be observed. Discharges occurred only at the positive half cycle for smaller dimension particles but on both positive and negative half cycle when particle length increase as shown in Fig. 5 and its 3D distribution in Fig. 6.

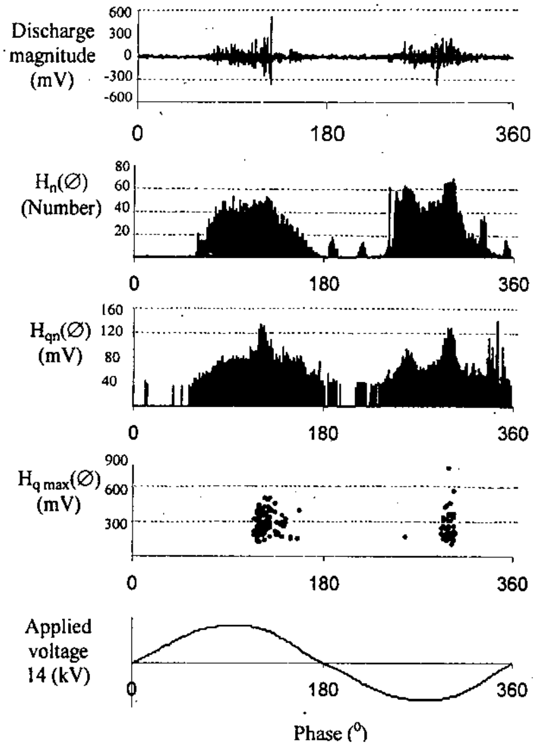

Fig. 5. Phase resolved quantities for discharge due to protrusion on the enclosure.

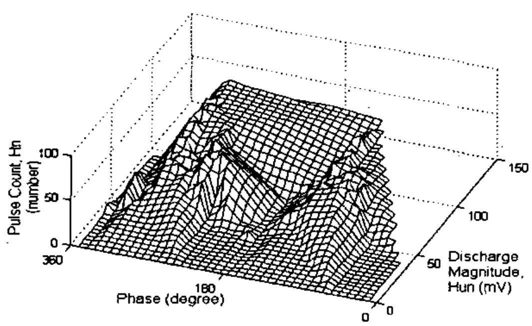

Fig. 6. 3D distribution for particle fixed on the enclosure.

C. Free moving particle on the Enclosure.

At operating voltage, if a free moving particle inside GIS chamber acquired enough energy it will be lifted off and bouncing on the enclosure surface. When the particle hits the GIS enclosure, this results in excitation of an acoustic wave propagating along the chamber and can be picked up either with an AE sensor or an accelerometer [6].

For this investigation, a wire particle of copper (length = 25mm, dia.= 0.5mm) was left on the GIS enclosure. The discharge pulses appeared in both positive and negative half cycle of the applied voltage as shown in Fig. 7 and Fig. 8. However, larger signal always dominate at the positive half cycle.

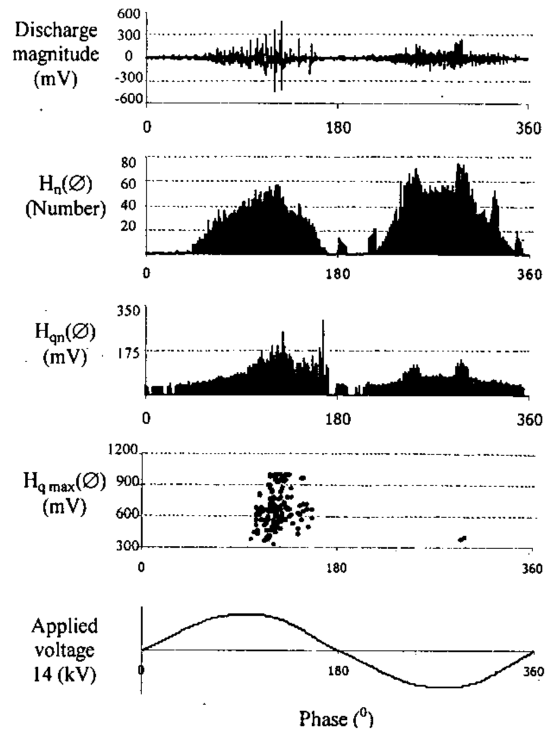

Fig. 7. Phase resolved quantities for discharge due to free moving particle on the enclosure.

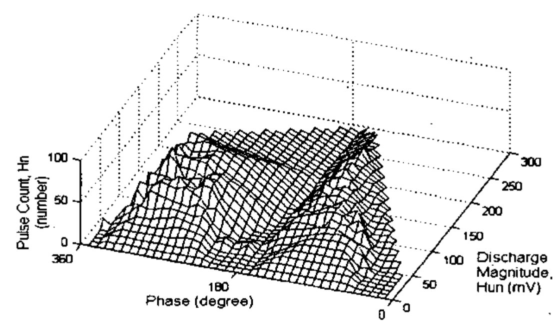

Fig. 8. 3D distribution for free moving particle on the enclosure.

D. Corona on the Electrode surface.

Corona will occur due to roughness of the electrode surface. In this case, a flat metallic plate was put inside the GIS so that gap between electrode and the enclosure will decrease and discharges due to corona on the electrode surface can be detected. Fig. 9 shows the discharges caused by corona on the electrode surface and its phase-resolved quantities, while Fig. 10 shows its 3D distribution. Discharges seemed alike to signals cause by protrusion on the electrode with lower magnitude.

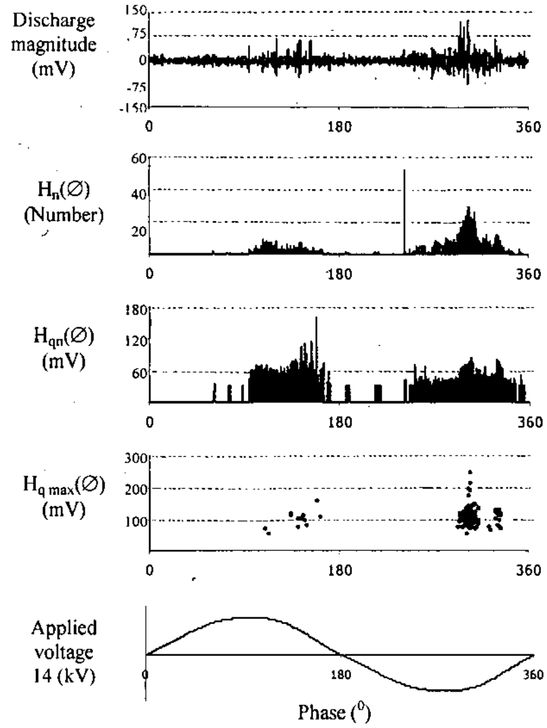

Fig. 9. Phase resolved quantities for discharge due to corona on the electrode surface.

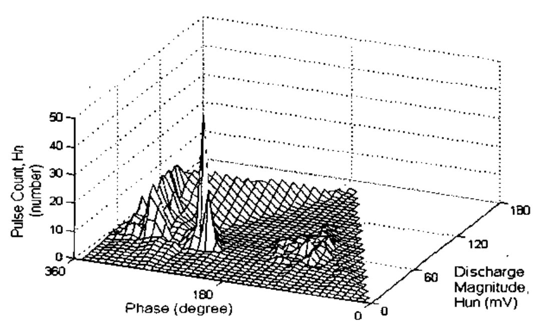

Fig. 10. 3D distribution for corona on the electrode surface.

V. STATISTICAL ANALYSIS

Visual inspection gave us a preliminary result of defects sources trapped in a GIS system. However, visual analysis depends on human eyes and different point of view may leads to inaccurate hypothesis. Therefore, more systematic method such as cluster analysis shall be introduced. Using this method, discrimination between possible clusters can be achieved. The patterns are represented by fingerprints (see Fig. 7), and this method examines the distances between all fingerprints. The result of the analysis is a tree structure, which illustrates the relationships between individual fingerprints (see Fig. 8). The percentage scale at the bottom shows the dissimilarity between fingerprints that were analysed together. By cutting such a tree at a certain percentage level, the fingerprints can be divided into several clusters [7].

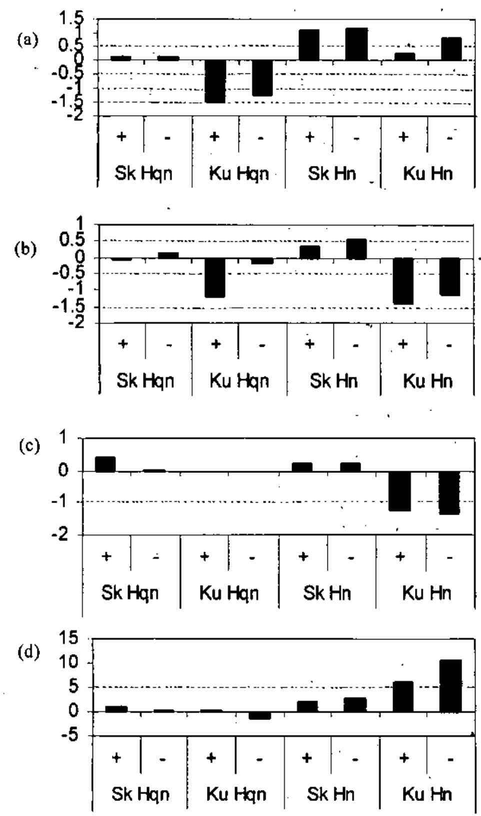

Fig. 7. Fingerprints for both H_{qn} ($\varnothing$) and H_n ($\varnothing$) distributions of the investigated cases: (a) Protrusion on the electrode surface, (b) Protrusion on the enclosure surface, (c) Free moving particle on the enclosure surface, and (d) Corona on the electrode surface.

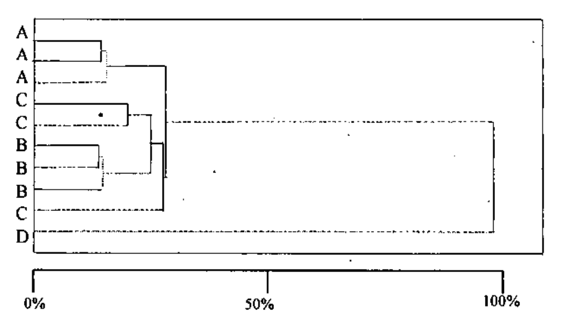

Fig. 8. Cluster analysis as applied to fingerprints of all measurements as discussed in this study: Protrusion on the electrode surface (A), Protrusion on the enclosure surface (B), Free moving particle on the enclosure surface (C), and Corona on the electrode surface (D).

With the cluster method, three different clusters can be observed. Cluster 1 consists measurements of protrusion on the electrode surface. Cluster 2 is a combination of protrusion on the enclosure surface and free moving particle on the enclosure surface. Cluster 3 consists measurements of Corona on the electrode surface.

In cluster 2, the dissimilarity percentage among the protrusion and free moving particle on the enclosure surface was low. This can be understood as both defects are placed upon the same location i.e. on the enclosure surface. Classification of cluster 1 and 2 help to discriminate the discharges sources between sources from electrode or enclosure.

According to the dendogram, corona was distinguished as a totally different cluster from cluster 1 and 2. This may because corona discharging is more stable and the pulses distribute more equally along the phase axis. Also, corona discharges are continuous and exist at the whole voltage cycle but with lower amplitude compared to other defects.

Cluster analysis is useful for comparison for an unknown discharges source with the laboratory data. It can be used to study the similarity level between this unknown sources with a collection of known situation. If it produces a high similarity level or being grouped together with a particular known discharge sources, then the unknown sources can be identify. However, the result of such recognition process strongly depends on the test measurement conditions at which the reference data are obtained, the number of measurements used to represent a defect and on the way the data bank is organized.

VI. CONCLUSION

GIS is usually tested for discharges using conventional discharge detection. Due to the increasing automation of PD measurements in recent years, computer-aided evaluation has been performed along this research. With the development of an acoustic PD detection system, stochastic PD signal processing can be performed easily using a digital tool.

In the study of the PD pattern characteristics, 4 common defects were investigated. The following conclusions can be made based on the this study:

1) The acoustic technique is suitable for PD detection and identifying of the defect in GIS.

2) Analysis of $H_{qn}(\varnothing)$ and $H_n(\varnothing)$ distributions using statistical operators provide valuable information about the shape of the distributions. This will then create fingerprints of a discharge type.

3) The method offers possibilities for defects quantification and consequently risks assessment of a GIS. However, the certainty is still low.

VII. ACKNOWLEDGEMENT

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VII. REFERENCES

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