Lastest Development in Partial Discharge Testing

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INTRODUCTION

Failure of High Voltage insulation is the No 1 cause of High voltage system failures with IEEE statistics indicating that electrical insulation causes up to 90% of electrical failures of certain high voltage equipment. The application of Partial Discharge (PD) Testing to diagnose the condition of high voltage insulation has grown dramatically over the past few years. According to IEEE 400, the proven and effective way to establish an electrical preventative/ predictive maintenance program is by using PD testing.

As condition assessment has become an important aspect of PD testing, many users are now turning to online non intrusive PD testing. The main advantage of online PD testing is no equipment needs to be shut down and this is a great attraction to many plant owners as normal operation of the plant will not be affected.

However, there is usually much more interferences to content with while doing online testing. ***Electrical interference often gives a mis-interpretation to the final PD analysis if it is not effectively separated from PD signal. In fact, statistics have shown that almost 70 % of the mis-interpretation in PD diagnosis is due to these interferences and the remaining 30% is due to the limitations of the hardware being used.***

In recent years, there have been many important developments in the sensors and measuring instrumentation. Today, almost all the instrumentation uses digital technology that enables ultrawideband PD detection with the attractive advantages of noise separation and PD type identification. There have also been an emergence of software PD pulse pattern recognition tools that are very successfully implemented to separate PD from interferences and identifying the PD type.

In this paper, the authors will introduce an advanced PD system known as PDPAC™ using the highly sensitive Electromagnetic (EM) sensor to carry out PD testing with out having the equipment to be shut down. Various applications and photographs of using this system for different high voltage equipment are also briefly illustrated..

In addition, it also touches on the most important aspect of PD analysis which is the removal of unwanted interferences from site data. The key feature of this system lies with the **PDFusion™** *software which consists of powerful PD pulse recognition tools specially designed for more effective PD pulse discrimination and noise reduction.*

Finally, based on extensive PD site investigations carried out over the past few years, a few typical case studies are also presented with the identified faults using PDPAC™ interpretation methods.

Hardware

The instrumentation (Fig 1) consists of a high speed digitizer (Sampling rate up to 100MS/s) interfaced to a laptop for acquisition of signal. The high sampling rate is necessary for acquisition of each single PD or noise pulse for PD pulse discrimination. Apart from snap shot mode, it is also capable of operating in short term monitoring mode to log the PD trend over a period of time.

Figure 1 : PDPAC™ System

Sensor

The sensor being used is an electromagnetic (EM) sensor. The principle of detection lies in the sensing of electromagnetic waves emitted by faulty equipment with insulation defects. It is a non invasive sensor and do not require any equipment to shut down while carrying out PD measurement. In addition, there is also no physical electrical contact between the sensor and the equipment and thus it is a very safe sensor to use.

Of all the non intrusive sensors, EM sensor is by far the most sensitive sensor used for PD testing. The typical bandwidth can be up to 300MHz or higher. With a high bandwidth, it can capture PD pulse shape in greater details compared to conventional sensor having bandwidth less than 40MHz (typical). In addition, it is also extremely sensitive and can detect PD discharges as low as 100 µV with embedded amplification. With high bandwidth and sensitivity, it can detect not only external discharges (surface, corona etc) but also weak internal discharges (cavity).This is far superior compared to conventional sensors with lower sensitivities (1000 µV and above) which most of time fails to detect weak internal discharges.

With these unique characteristics, EM sensor can generally be used for almost any type of high voltage equipment.

The various applications of EM sensor are described below:

-Detecting PD during injection test.

-Detecting PD in cable. (Figure 2)

-Detecting PD in oil. (Figure 5)

-Detecting PD in HV motors, generators. (Figure 4)

-Detecting PD in switchgear. (Figure 3)

-Detecting PD in transformer (oil or dry). (Figure5)

Figure 2 : Overhead cable PD test

Figure 3 : Switchgear panel PD test

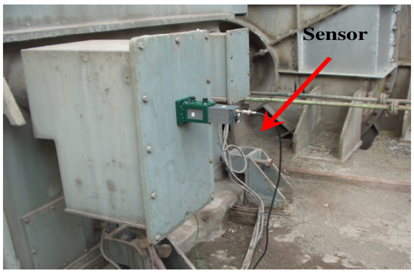

Figure 4 : Motor Cable Box PD test

Figure 5 : Oil type transformer PD test

Electrical Interferences (Noise)

Electrical interferences (noise) remain one of the most challenging task even till today with both advancement in hardware and software development.

Based on inspection statistics as well as research surveys conducted worldwide, 60 % of the site area inspected actually contains low to moderate noise while 40% contains moderate to high noise. These statistics figures are not constant and they are still increasing due to invention of modern electrical and electronics equipment which greatly increase the noise content in the measured data.

Generally PD analysis is quite straight forward if the environment contains low level of industrial noise as the noise can be easily removed by some simple and established digital signal processing and filtering techniques. However this is not true for moderate to high noise environment. PD analysis will become extremely complex and very often PD analysis accuracy (without efficient noise removal) will drop significantly with the increase in noise content. With this reasoning, this also explains why PD analysis sometimes works very well while other times it just gives false indication. Most importantly, noise must first be effectively removed from the measured data for effective PD analysis.

Main problem of industrial noise

With the large number of different type of noise present today, there are hardly any "Fixed" noise separation technique or techniques that can be used all the time under different site condition." Very often, this will lead to misinterpretation of PD analysis if inadequate or wrong techniques are used.

Therefore, the best solution is not to rely only on fixed techniques but rather an adaptive "selection of the best combination of noise separation techniques" for efficient PD denoising.

PDFusion™ with Hybrid Methodology

With the above limitations in mind, **PDFusion™** adopting new techniques of noise removal is designed specially to tackle noise problems in PD analysis.

PDFusion™ software adopts an innovative 'Hybrid Methodology' in which mulitple powerful noise separation techniques are fused together for superior noise removal.

Some of these techniques described are already widely used in both research and industries and are implemented for their known efficiency in noise removal for PD analysis.

These techniques and their associated strengths are :

- Phase resolved time domain analysis.
  Good for removing random, non continuous noise.

- Pattern Recognition analysis.
  Good for removing continuous and spurious noise.

- Statistical parameters analysis.
  Good for removing PD alike noise.

- Wavelet-based Multi-Resolution Signal analysis. Good for identifying PD embedded in noise.

PDFusion™ Denoising with Hybrid Methodology

Figure 6 below shows the raw data collected using the PDPAC™. This data is collected from a very noisy environment in a power plant. At first glance, one will think whether is this a (i) Noise data or (ii) PD data? In this case, it is difficult to judge whether this is a PD or noise data without proper software denoising tools. To add to the challenge, it will even be more difficult to analyze if the data consists of both PD data and more than one type of noise sources.

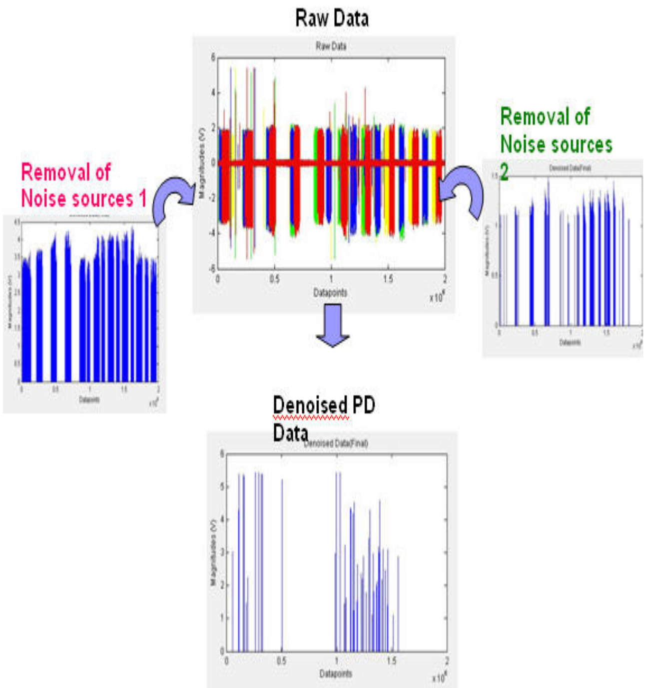

Figure 6 : **PDFusion™** Denoising with Hybrid Methodology

In the above illustration using **PDFusion™** , the raw data is effectively segregated into PD and noise data after denoising. Here, two different types of high frequency noise sources (Noise source 1 and Noise source 2) are removed and PD signal is effectively extracted. As you can see, it is very important to remove all sources of noise as removing just one noise source will still result in large error in PD analysis. Therefore, for any accurate PD analysis, ideally noise should be totally eliminated if not removed as much as possible. In this example using Hybrid Methodology, a combination of denoising techniques are actually implemented concurrently for denoising. With this new combination, large number of different type of noise are effectively removed. With that, PD analysis can be implemented very accurately in almost any kind of noise environment.

PDFusion™ Identification Illustration

Indentification of PD type is only possible with high sampling rate in which the data is collected. With a high sampling rate, single pulse shape can be captured in greater details and analyzed using single pulse analysis.

For different types of PD, there will be a unique pulse shape patterns corresponding to their PD type. Figure 7 below shows the different type of PD.

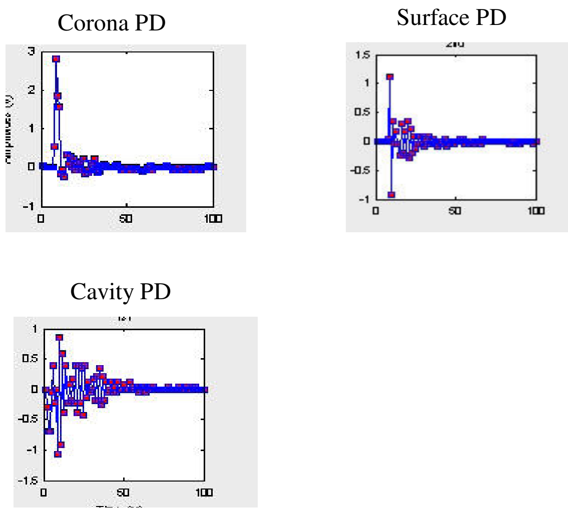

Figure 7 : Pulse pattern of different PD type

By knowing the PD type (Corona, Cavity or Surface PD), it will provide very beneficial information to the plant owner to plan their rectification and servicing works based on the type of PD found.

TYPICAL CASE STUDIES

- **PDFusion™** software is put to test on two different high voltage equipment (transformer and switchgear) under different noise condition. The denoising is carried out using :

- (i) Without Hybrid Methodology.
  This involves using only 1 tool (Pattern Recognition analysis) to do the denoising. This tool is chosen mainly because it is the most established and widely used tool for denoising nowadays.

(ii) With Hybrid Methodology.
This involves using a combination of all the denoising tools as described earlier.

Case 1: Case Study on transformer

The Partial Discharge Testing was carried out for Company 'A' on 5th Nov 2009. The equipment is a cast resin dry type transformer rated at 11kV/415V. The transformer is located in air conditioned environment at 27°C. Before denoising, the raw PD data is polluted with some amount of noise and interferences. Figure 8 shows the PD Distribution Graphs "Without Hybrid Methodology" before and after denoising while Fig 9 shows the PD Distribution Graphs "With Hybrid Methodology" applied.

Without Hybrid Methodology (Fig 8)

After denoising, , the average and maximum PD amplitudes are 0.581 V and 0.816 V respectively. The total number of pulses is 87. Under PD severity guildlines, this constitutes a "Minor PD" condition which indicates some form of insulation defects and requires servicing attention.

With Hybrid Methodology (Fig 9)

After denoising, , the average and maximum PD amplitudes are 0.615 V and 0.681 V respectively. The total number of pulses is 16. Under PD severity guildlines, this constitutes a "Borderline" condition. . In this case, "Borderline" severity simply means that the equipment is in the early stage of PD defects and exhibit very little PD activities.

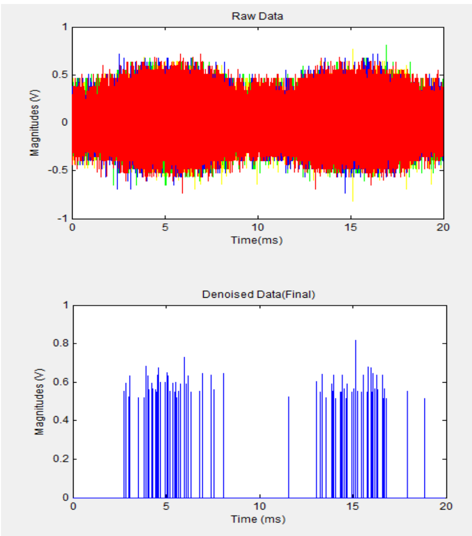

Fig 8 : PD Distribution Plot (Without Hybrid Methodology)

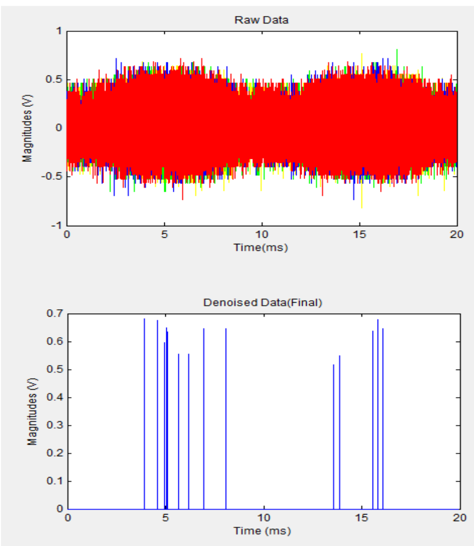

Fig 9 : PD Distribution Plot (With Hybrid Methodology)

Further analysis also identify corona discharge PD as highly dominant.

As this is a "Borderline" case and also corona PD, no immediate shut down is actually required. Customer is instead advised to service the transformer only if there is already a planned maintenance schedule in place thus avoiding unnecessary shutdown monetary losses. Otherwise, the customer is advised to monitor them again in 3 to 6 months time to check the rate of PD degradation.

Inference

Upon planned servicing, no cable puncture, surface tracking or any abnormalities are observed. Therefore, this is clearly not a "Minor PD" condition that requires immediate servicing. Instead, it is just a case of early stage PD (Borderline case) where visual inspection shows that some little patches of white powdery residue are actually present on the HV joints and cables of the transformer as shown in Fig 10 and 11. This also concludes that analysis using "Hybrid Methodology" actually provides a better interpretation on the severity level (Borderline case) based on the defects found.

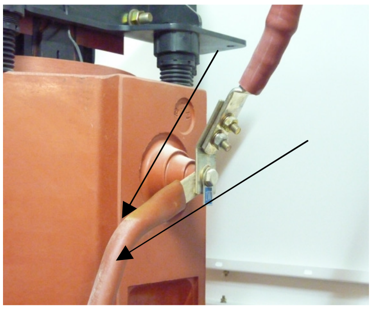

Fig 10: White powdery residue (Corona discharge) along the cable of dry type transformer

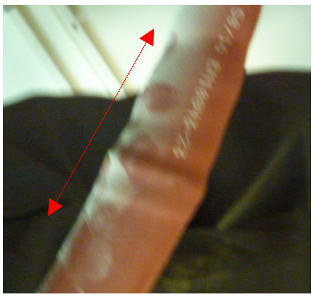

Fig 11: Zoom up view of Corona discharge along the cable

In the planned servicing schedule, the contaminated surface was cleaned and there was very little PD ("Normal" severity under PD guildlines) detected after analysis.

Case 2: Case Study on Switchgear

The PD testing was carried out for Company 'B' on 27th April 2009. The 11 kV rated equipment is metalclad vacuum switchgear. It is located in extremely noisy environment and in addition it is also interconnected to motor.

Figure 12 shows the PD Distribution Graphs before and after denoising "Without Hybrid Methodology" while Fig 13 shows the PD Distribution Graphs "With Hybrid Methodology" applied. Before denoising, the raw data is heavily polluted with large amount of noise and interferences.

Without Hybrid methodology (Fig 12)

After denoising, the average and maximum PD amplitudes are 0.64 V and 1.19 V respectively. The total number of pulses is 91. Under PD severity guildlines, this constitutes a "Minor PD" condition which indicates some form of insulation defects and requires servicing attention.

With Hybrid methodology (Fig 13)

After denoising, the average and maximum PD amplitudes are 0.68 V and 0.805 V respectively. The total number of pulses is 4. Under PD severity guildlines, this constitutes a "Normal" condition which states that the equipment is in good condition.

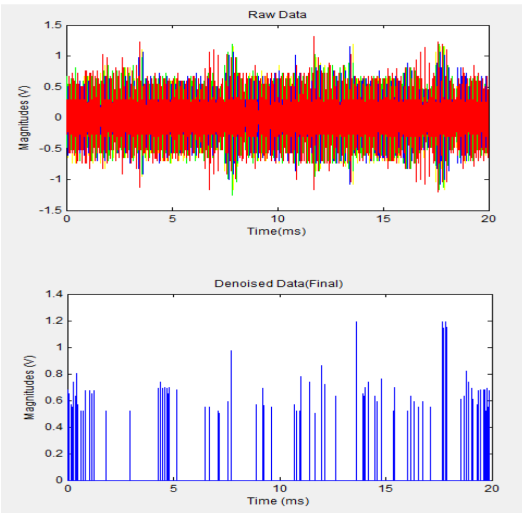

Fig 12 : PD Distribution Plot (Without Hybrid Methodology)

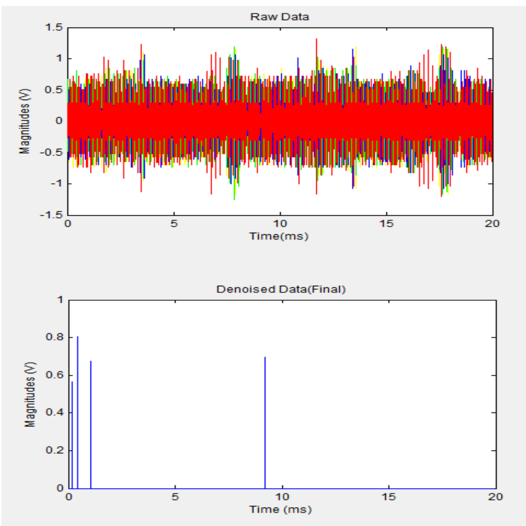

Fig 13 : PD Distribution Plot (With Hybrid Methodology)

Since this is a "Normal" case, no further action is needed by the customer to service the equipment that requires immediate shutdown. Customer is instead advised to service the transformer only if there is already a planned yearly maintenance or calibration schedule in place.

Inference

During its year end planned servicing and maintenance, this switchgear is shut down and thoroughly checked for any abnormalities (surface tracking, corona and cavity etc). No visible defects were actually seen and further electrical test results are all normal. This clearly reflects a 'Normal' condition and although the noise level is very high in this case, analysis using Hybrid Methodology is still capable of providing a very accurate PD analysis and interpretation.

CONCLUSION

To move PD testing from the domain of the expert to plant engineer is highly desirable. Plant owners who are mainly non specialists would like to do their PD analysis and interpretation in the most simple and reliable way possible. Due to these requirements, PDPAC™ is specially designed to be a safe and simple intelligent tool in asset management process in identifying the developing degradation process in operating HV equipment.

Very often, online PD site testing requires different digital post processing in order to suppress new unknown kind of interference effectively. To overcome these interferences, **PDFusion™** software (Hybrid Methodology denoising) with constant updates from university and industry R & D work is specially designed to effectively eliminate noise and dramatically inproving the accuracy of the PD analysis. Two case studies are also presented in this paper to illustrate the effectiveness of **PDFusion™** software on different high voltage equipment located in noisy environment.

And with these cutting edge technologies and capabilities, PDPAC™ has established itself to be a well equipped system with the following niche advantages: (i) To detect PD in the early stages (ii) To effectively remove interferences from noisy environment (iii) To determine the PD type. With that, the authors believe that PDPAC™ system has definitely move a considerable technological step forward in making more reliable PD analysis and interpretation.

About Hoestar Group

Hoestar Inspection International Pte Ltd is a leading specialist company providing one stop condition inspection services for our customers in Singapore and Asean regions for the past 20 years.

Hoestar PD Technology Pte Ltd is an innovative research based company that specializes in developing new and reliable electrical technologies.

For more information, please visit www.hoestarinsp.com.sg