Review of Partial Discharge Signal Processing and Monitoring System using Virtual Instrument Software

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Abstract. Most of Partial Discharge (PD) processing systems have been developed using virtual instrument to analyse raw measured PD signal. However, some of researchers had neglected the denoising or recognition technique and only focussed on PD location estimation and vice versa This paper reviews an overview of denoising recognition techniques, denoising analysis, PD sensors, location methods and type of virtual instruments in published PD signal processing signal system. A perfect PD analysis system is more beneficial if both PD denoising and locating are applied in the system. Based on this review, the new design of PD signal processing system based on DWT denoising technique and RC sensor using LabVIEW Software for underground power cable using SCTM as PD location algorithm is proposed.

Keywords: Partial Discharge, De-noising, Denoising, Location, Processing System, Monitoring System, Statistical Analysis, Review.

1. Introduction
Rising demand in the power sector has spurred innovative thinking on monitoring HV power equipment online for reliable power sector operations. Most HV power equipment is made with insulation that protects the conductor and is resistant to HV. However, the insulation material condition may deteriorate as a result of PD activity being triggered and if left untreated will result in complete equipment failure. Therefore, the measurement, analysis and location of PD for HV power equipment is important to detect early stage PD events. Nevertheless, the PD signal that measured during the PD measurement usually comes with White Gaussian Noise (WGN) and Discrete Spectral Interference (DSI) noises signal. In order to obtain pure PD signal data, denoising process on the raw measured PD signal is a must. The perfect denoising technique is to extract noise and interference from the raw PD data without altering the pure structure of the PD signal [1], [2].

Detecting the location of PD fault in the power system can provide you with important information about the condition of the insulation material. PD fault need to be identified, located, and repaired before the total failure of the power plant. However, repetition of current pulse injection through power cable during PD fault detection can cause new damage
to the insulation. Accurate and optimal methods for determining the location of PDs in electrical equipment are important for equipment maintenance and PD source correction [3], [4], [5].

1.1. Denoising techniques of PD signal
In choosing type of denoising technique, the characteristics of PD signal need to be taken into account. Since the PD signals are non-stationary, irregular and non-periodic in nature, PD spectrum signal contains a sharp edge and a very short period transient impulse. Thus making it difficult to suppress the signal of the noise using conventional linear filters such as Fast Fourier Transform (FFT) thresholding [6], digital filtering like an Impulse Response (IIR) and Finite Impulse Response, (FIR) [7], and adaptive filtering [8]. The linear filters tend to remove or preserve the pure PD signal with the noise due to similar appearance in both spectrums. As for traditional FFT, all information related time data will lost during the process of denoising. To overwhelm this difficulty, non-linear method have been proposed and mainly based on Wavelet transform [9], [10]. The Discrete Wavelet Transform (DWT) has been commonly used as a powerful and well-known method for analyzing PD data in both time and frequency domains [11], [12].

[13] has stated that in recent years, great progress has been made towards PD processing methods based on DWT denoising technique. However, there are still many questions about this method. The most appropriate way to select wavelet family and to select quantity of decomposition level has not yet been validated. [13] advised that it is important to continue exploring this DWT technique in order to obtain validation on these issues. [13] had worked on the wavelet filters recognising as to find out the optimum performance of the DWT denoising technique on PD location and detection.

In the proposed work by [14], various mother wavelets of the DWT denoising technique are implemented to select the most compatible one with the Electroencephalogram (EEG) signal recorded from tele-serial addicted persons. In determining the efficiency of the denoising technique, the minimum Mean Square Error (MSE) and higher Signal to Noise Ratio (SNR) are chosen as a performance indicator in choosing a suitable mother wavelet. Supported by [9] who had extracted PD signal using DWT for on-line measurement, had reviewed that there are five parameters as PD denoising performance indicator in evaluating the denoising effect. There are MSE [15], SNR of de-noised signal [16], Cross Correlation (CC) [16], Time Cost (TC) [17] and Energy Loss (EL) [18] during denoising. The denoising effect is better when MSE and EL values are lower and SNR and CC values are higher.

Additionally, a performance method of an optimum threshold estimator for de-noising partial discharge signal using DWT technique that proposed by [19] is evaluated using four different performance indicators, namely SNR, MSE, CC Coefficient and Pulse Amplitude Distortion. From presented results of the analysis using those four parameters, the optimum denoising technique based on DWT could be analysed. [19] could concluded that the proposed method was consistently overtakes the existing method.

1.2. Locating PD fault
Detecting the location of PD fault in the power system can provide you with important information about the condition of the insulation material. PD fault need to be identified, located, and repaired before the total failure of the power plant. However, repetition of current pulse injection through power cable during PD fault detection can cause new damage to the insulation. Accurate and optimal methods for determining the location of PDs in electrical equipment are important for equipment maintenance and PD source correction [3]–[5].

Electric detection is the most commonly used method for PD detection in underground power cables compared to acoustic, optical and chemical detection because of its capable to capture
more accurate PD signals. However, the electrical detection method is suffering with Electromagnetic Interference (EMI) signal which sourced from the DSI during the measuring process. Nonetheless, it is proven that this EMI can be suppressed from the measured signal by using the DWT as denoising technique [20]–[22] Current sensor is one of the sensors for the electrical detection method. Issue of low sensitivity and low bandwidth of PD sensors are a major concern for early stage PD detection [23]. However, researchers had found that RC sensor has the potential to replace other PD sensors in detecting PD fault location on underground cables due to its characteristics of light weight, good linearity, no core saturation effect, wide range of frequencies, has a high installation flexibility, strong non-interference capabilities, and operational safety at low [24], [25].

PD measurement technique for PD location are basically divided into single-end, double-end and multi-end techniques. Multi-end PD measurement technique had better accuracy than double-end and single-end PD measurement techniques [26]. CC process was added into the multi-end PD location technique in order to minimize the error of estimated time different in the PD location technique and named as Multi-End Cross Correlation (MEC) [22]. Segmented correlation technique is a new developed technique proposed in PD location technique in order to massively reduce the program execution time during the PD fault location estimation process. [22]. Trimmed mean data filtering technique is one of statistical analysis techniques that help in reducing the percentage error of the PD location algorithm [27]. Thus, both segmented correlation technique and trimmed mean data filtering technique had been combined in a new location algorithm which named as Segmented Correlation Trimmed Mean (SCTM) Data algorithm. The new SCTM algorithm using MATLAB that able to estimate the PD location faster even in noisy environments since the CC process only need to be performed on the selected PD signals in the segment. Contrary, for MEC algorithm, the CC process need to go through on the whole measured signals [5].

1.3. Published Researches of PD Signal Processing System

As a review study, several published results on previous PD signal processing system are presented in this section as shown in Table 1. The information is essential to clarify the effectiveness of proposing new PD signal processing system compared to conventional method in order to develop a virtual instrumental system that can denoise, analyse and locate the measured PD signal from measurement data effectively. The major drawbacks of each developed PD analysis are highlighted.

As can be seen in Table 1, most of the researchers preferred to use LabVIEW software as a virtual instrument platform of PD analysis system. [28] stated that the LabVIEW platform is more widely used as a programming tool than MATLAB, C++, Delphi because LabVIEW uses a more user-friendly and easy-to-use graphical programming language. In addition, it also incorporates many easy-to-use subroutine processing signals for later development. For example, FFT and DWT transformations are large and complex programs when using different programming languages. But by using LabVIEW, they appear just like the sophisticated interfaced icon modules [28].

As an overview, most of PD analysis systems using virtual instrument have been developed to analyse raw measured PD signal. However, some of researchers had neglected the denoising or recognition technique and only focussed on PD location estimation and vice versa. For example, [29], [7], [28], [30], [31], [32], [33], [34], [35] and [36] had provided PD denoising technique in their PD analysis systems using virtual instrument without completing them with the tools of PD fault location estimation system. In term of performance analysis of denoising technique, only [37] and [34] had included the Particle Swarm Optimization (PSO), MNE and SNR respectively as the performance indicator in order to find optimum parameter setup for of the denoising technique. On the other hand, [38] and [39] only considered PD fault location estimation in the system without implementing the PD denoising process. Therefore,
Comparatively, the PD analysis system in [37], which was well developed for transformers application with optimum DWT denoising technique based on PSO performance estimator, is able to include Time of Arrival (TOA) as the PD location algorithm. However, this system only applicable for PD in transformer respective analysis. In addition, the performance of the PD location system could be more efficient if the SCTM data filtering technique is applied as PD location algorithm similar to [40]. The PD sensor that had been used by [37] is Piezoelectric Acoustic Sensors. However, acoustic sensors are not suitable for PD detection in underground cables. Therefore, it is advantageous if the concept of PD analysis system in [37] can also be applied in PD measurement of underground power cable by using PD electrical detection type such as RC sensor as in [36]. While in [34], the PD denoising system was based on well performed DWT technique and analyzed by MSE and SNR. However, the PD denoising system only applied for imitated PD signal via simulation as a modelling system only. It has been made clear that the PD data acquisition, PD recognition, and PD fault location estimation are essential in order to design high efficiency PD signal processing system. Therefore, based on these gaps as shown in Table 2, a novel PD signal processing system using LabVIEW Software based on DWT denoising technique and RC sensor with SCTM as PD location algorithm is proposed to improve the accuracy in detecting PD using LabVIEW software for underground power cable.
| Reference | Type of Test Object | Denoising / Recognition Technique | Denoising Analysis | PD Sensor | Locating Method | Virtual Instrument |
|-----------|---------------------|-----------------------------------|--------------------|-----------|----------------|------------------|
| [29]      | Transformer         | Phase Sensitive Detection (PSD)   | N/A                | Ultra-High Frequency (UHF) | N/A          | National Instruments Measurement Studio |
| [7]       | Transformer         | Lock-In Amplifier (LIA)           | N/A                | Lightning Impulse (LI) Test | N/A          | LabVIEW |
| [28]      | Gas Insulated Switchgear (GIS) | DWT | N/A | Ultra-High Frequency (UHF) | N/A | LabVIEW |
| [38]      | Gas Insulated Switchgear (GIS) | N/A | N/A | Ultra-High Frequency (UHF), High-Frequency Current Transformer (HFCT), Acoustic Emission (AE), Power Frequency Signal. | Multiple-channel detection of UHF & Ultrasonic signals | LabVIEW |
| [30]      | Transformer         | Equivalent Time-frequency Method, FFT | N/A | High-Frequency Current Transformer (HFCT) | N/A | LabVIEW |
| [39]      | Gas Insulated Switchgear (GIS) | N/A | N/A | Ultra-High Frequency (UHF) | TDA | LabVIEW |
| [31]      | Underground power cable | FFT | N/A | Rogowski Coil | N/A | LabVIEW |
| [37]      | Transformer         | DWT | Particle Swarm Optimization (PSO) | Piezoelectric Acoustic Sensors | Time of Arrival (TOA) | LabVIEW, Matlab |
| [32]      | Capacitor Unit      | N/A | N/A | Piezoelectric Acoustic Sensors | N/A | LabVIEW |
| [32]      | Rotating Machine    | FPGA | N/A | PXI system (PCI | N/A | Unclarified |
| Reference | Underground power cable | DWT | MNE/SNR/CC | Rogowski Coil | Segmented Correlation-Trimmed Mean Data Filtering Technique | LabVIEW |
|-----------|-------------------------|-----|------------|---------------|-------------------------------------------------------------|---------|
| [29]      | -                       | -   | -          | -             | -                                                           |         |
| [7]       | -                       | -   | -          | -             | -                                                           | X       |
| [28]      | -                       | -   | -          | -             | -                                                           | X       |
| [28]      | -                       | -   | -          | -             | -                                                           | X       |
| [38]      | -                       | -   | -          | -             | -                                                           | X       |
| [30]      | -                       | -   | -          | -             | -                                                           | X       |
| [39]      | -                       | -   | -          | -             | -                                                           | X       |
| [31]      | X                       | -   | -          | X             | -                                                           | X       |
| [37]      | -                       | X   | -          | -             | -                                                           | X       |
| [32]      | -                       | -   | -          | -             | -                                                           | X       |
| [32]      | -                       | -   | -          | -             | -                                                           |         |
| [33]      | -                       | -   | -          | -             | -                                                           | X       |
| [34]      | -                       | X   | X          | -             | -                                                           | X       |
| [35]      | -                       | -   | -          | -             | -                                                           | X       |
2. Conclusion
This paper had discussed the PD in general. The current issues of the PD also had been discussed briefly including the presence of noises in measured PD signal as one of objective problems. This paper also had discussed briefly several PD denoising techniques and has established that DWT denoising technique is an excellent technique where capable to define the noises and PD signal in both time and frequency domains at the same time. Analysis performance of PD denoising technique based on MSE and NSR is also deliberated and proposed as well-performed method in determine the performance of denoising technique. Furthermore, review on PD location methods are also discussed and had proved that PD location based on SCTM data filtering technique is superior in withstand high noise signal in the PD signal and able to estimate the exact PD fault location faster compared to conventional algorithm. In this paper, several other developed PD processing systems had been discussed as a study reference to propose partial discharge signal processing system based on DWT denoising technique and RC sensor using LabVIEW Software for underground power cable. in order to design high efficiency PD signal processing system. From the research gaps of the reviewed papers, some of the principles, methods, and equations had been used as references for this research.

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