PARTIAL DISCHARGE DETECTION METHOD AND PATTERN RECOGNITION USING FAST FOURIER TRANSFORM AND WAVELET ANALYSIS

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ABSTRACT: *Partial discharge causes deterioration to insulation and can lead to breakdown. The discharges usually small in magnitude and its occurrence cannot be avoided. It is important to detect the discharges prior to breakdown. Since the discharge is localized, therefore it is easier to locate using ultrasonic listening device called Ultraprobe 2000. The detection was made within ultrasonic range i.e. above 20kHz up to 100kHz. Within this range, the occurrence of the discharges is at early stage. Once the discharges become audible, the power system is possible to be affected by the discharges. The detection method was made for two types of partial discharges; external and internal discharges on a cable insulation. External discharge was created at a midway of RF Uniradio cable by exposing the braid to the air. Meanwhile for internal discharges, three pieces of Pure Wacker Silicon Rubber are sandwiched together and a small hole was pierced at the middle layer. The applied voltage was injected starting 5kV to 20kV for external discharges and 1kV to 6kV for internal discharges. Once the voltage is supplied to the test jigs, the discharges activity is observed and recorded in .wav format. The recorded signals are analyzed using Fast Fourier Transform and Wavelet Analysis techniques in order to obtain the information in time domain and frequency domain respectively. From these techniques, specific trends between the normal and faulty insulation conditions can be identified. Besides that, specific pattern for different type of discharges can also be recognized.*

1. INTRODUCTION

A partial discharge (PD) is one of the major factors in that causes electrical power breakdown. PD is electric discharges in insulating material that do not completely bridge the pair of electrodes in which the material is sandwiched in between. There are many 4 types of partials discharges i.e. internal, external (corona), electrical treeing and water treeing. Although the magnitude of partial discharges is usually small, they cause progressive deterioration and may lead to ultimate failure. In fact, the occurrence of the discharges is before the actual breakdown [1]. It is beneficial to detect its occurrence at the early stage to reduce the number of breakdown cases. There are two detection methods of partial discharges namely the electrical and non-electrical method. The non-electrical method can be classified into four basic forms of non-electrical phenomena that includes; a) chemical transformation, b) gas pressure, c) heat d) sound (also known as acoustical) and e) light.

This paper focuses on the detection technique of two types of PD namely the external (combination of surface and corona discharges) and internal discharges. The non-electrical (i.e. sound) is adopted as a detection technique since it is a non-destructive control test especially the ultrasonic technique. Amongst the many methods of sound detection, focused on the ultrasonic method to detect the presence of partial discharges has been found. The ultrasonic technique is more valuable compared to audible technique [1] since this technique is immune to electrical interference, in general [2]. The ultrasonic detection worked within range of 20 kHz up to 100 kHz. The advantage of the technique mentioned in this paper is the detection was made on a non-contact method and without physical contact between detecting device such as sensor is placed at the sample under test (SUT). Since there is no physical contact with any detecting devices, the detection can be made online; without having to shut down the power system. Two types of sample under test (SUT) that were used and they are a RF Uniradio cable and an insulating material namely Pure Wacker Silicon Rubber. With the aid of ultrasonic transducer known as Ultraprobe 2000 as the detection device, the system employed a physical signal conditioning that manipulates the sound into a signal that can be processed by computer using a specific format (*.doc* format). There are several of signal processing techniques used by other research for the same purpose [3 -13]. The signal processing techniques employed which is the Fast Fourier Transform (FFT) and Wavelet Analysis (WA) provided in the MATLAB Software. The FFT is used to identify the normal and faulty insulation conditions. Meanwhile, the WA is used for pattern recognition for both partial discharge types. The patterns obtained are compared with the patterns obtained by other researchers using different techniques [14, 15, 16].

2. RESEARCH METHODOLOGY

This subsection is divided in two main parts; the experimental set up and the signal processing techniques.

2.1 Experimental Rig and Procedures

The setup for the experiment consists of three parts; the high voltage (HV) source, the test jigs (PD sources) and the ultrasonic detection and measurement as illustrated in Fig. 1 and Fig. 2.

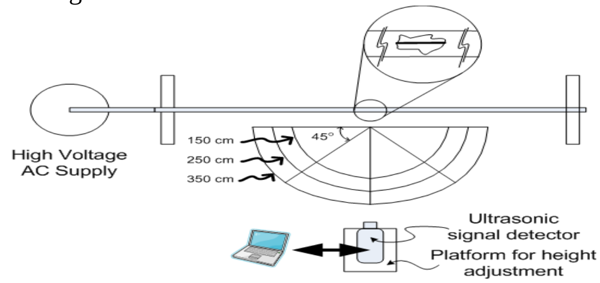

Fig.1 Equipment setup for external discharges.

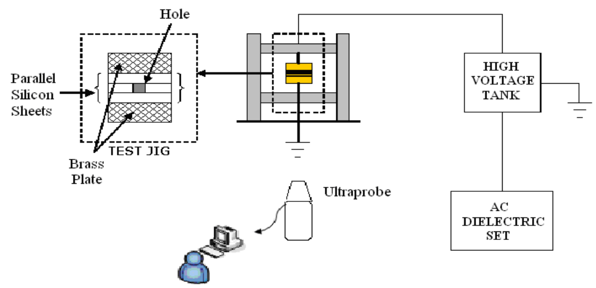

Fig.2 Equipment setup for internal discharges.

The HV source has AC Dielectric Test set and high voltage transformer (HV tank). The AC Dielectric Test is used to regulate the voltage and will immediately turn off if overvoltage. Meanwhile the HV tank is for step up or step down the voltage supply from the AC Dielectric Test set to the test jigs.

To create the partial discharge sources namely the internal and external discharges, different type of materials were used. For external discharge, arbitrarily length of RF Uniradio cable (UR No. M43) confirming to BS2316 is employed. At the midway of the cable, a small hole is created by puncturing a needle until exposed the braid of the cable insulation as in Fig. 3.

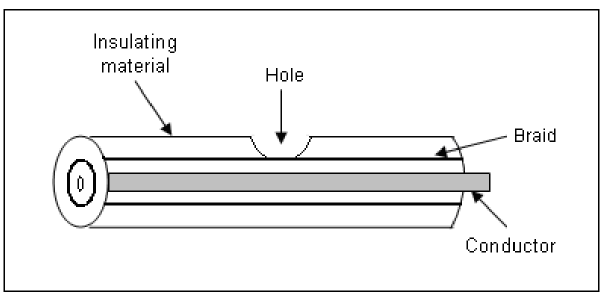

Fig.3 Creation of external discharges.

The hole must expose the braid to the air. The braid itself can act as a conductor and when the discharge from the air touches the braid, it will create discharges. To create the internal discharge, three sheets of pure Wacker Silicon rubber is used. These three sheets were sandwiched together with the middle sheet is created with small hole with chosen hole size 1 millimeters as in Fig.4.

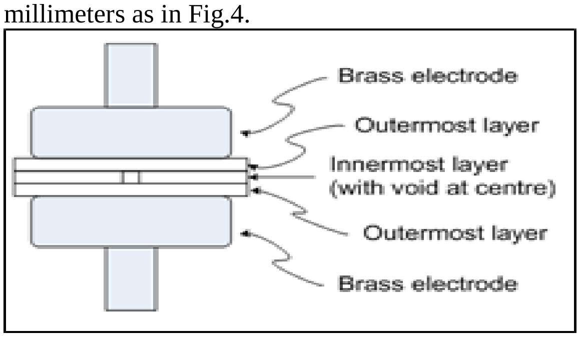

Fig.4 Creation of internal discharges.

For sample signal collection, the detection was made by the Ultraprobe 2000 and the signal was recorded using earphone and microphone that connected directly to the computer. The signal recorded and kept in *.wav* format using sound recorder provided in computer. For external discharge, the test jig is applied with 5kV up to 20kV voltage supply (in step of 2.5kV in each increment. For internal discharges, the supply voltages of values 1kV up to 6 kV (in 1kV increment) were injected. For each recording, 20000 data points was taken per recording. The overall process of the experimental procedure is illustrated in a form of block diagram as shown in Fig. 5.

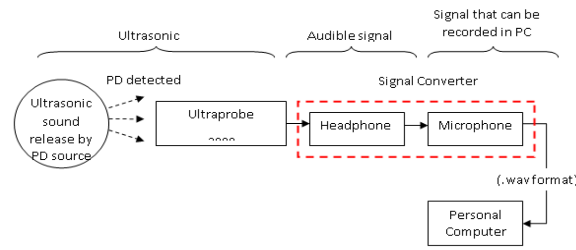

Fig.5 Block diagram of Signal Converter System.

The analyses procedures involved two parts; the detection of the faulty insulation using Fast Fourier Transform (FFT) and pattern recognition using Wavelet Analysis (WA). For external discharge, direct approach is employed. Direct approach is a method of analyzing the signal directly without having to consider the preliminary procedure of the signals. This is due to the characteristics of this discharge itself; easily to detect by the Ultraprobe 2000. However, for internal discharge, indirect approach is employed. Since the discharge occurs in the insulating material, the detection was difficult to capture. The signal captured is affected by 'white noise' from the environment and the equipment. Therefore, a preliminary procedure must be made to obtain a clean sample signal before the actual analysis is done. During the experiment to capture the internal discharge, there are two condition must be undertaken. First, the signal was captured when the equipment is in off condition (surrounding). Second, when the equipment is in on condition (online). In preliminary procedure, the signal obtained from the second condition is eliminated with the signal obtained from the first condition (signal). The assumption made in this preliminary procedure is described below. This procedure is done in the MATLAB algorithm.

Assume that;

Offline signal (Equipment off-state) = Surrounding Noise

It can be stated that;

Online signal (Equipment on-state) = Offline signal + Equipment Noise = Background noise

Therefore;

Sample signal = (Signal + Online signal) – Online signal = Signal (Pure)

2.2 Signal Processing Procedure

This subsection describes the signal processing procedure using MATLAB software. The processing procedure are divided into two stages; Fast Fourier Transform (FFT) and Wavelet Analysis (WA). The FFT is used to detect the faulty insulation. With the aid of FFT, the specific frequency domain affected by the partial discharge can be identified. On the other hand, the WA is employed to overcome the drawback of the FFT. The WA able to detect at which time oscillation that the signal are affected by the discharges. Therefore WA will identify specific pattern for different type of partial discharge that occurs in insulation.

A. Fast Fourier Transform (FFT)

In FFT there are two main processes involved prior to the actual FFT process and they are; parameter selection and plots at various ranges. The FFT parameter selection must be considered to obtain the real value of FFT (real FFT), real value of absolute FFT (real |FFT|) or absolute values of real FFT values (|real FFT|). The reason of this test conducted is to see the effects on the signals when the values are being applied to the algorithm. The use of real value in this test is to let the signals be plot freely without any limitation and by having the absolute value, it will strip away the minus sign if the number is negative and to leave the number unchanged if it is nonnegative. In term of FFT plots, the range of the signals is varied arbitrarily in order to check whether the FFT plot varies in terms of the signal pattern, peak magnitudes and the frequencies if the range is changed.

In the actual analyses of FFT, the signals are applied with this algorithm are from both conditions; healthy and faulty with several apply voltages and this procedures applicable for both cases; external and internal discharges. From the plots obtained, each signal is observed carefully and closely for its characteristics and patterns of the signal. Any slight change or difference between the healthy and the faulty signals are recorded. The sample from the resulting FFT plot as in Fig. 6. By referring to the figure, there are two plots. The upper section is the raw signal (*.wav* format) plot and the lower section is the actual FFT plot. For the plot of raw signal, the *x*-axis is the number of data points of each signal. On the other hand, *y*-axis stands for the magnitude. Meanwhile for FFT plot, the *x*-axis will be the frequency and is being measured in Hertz. Similarly to the raw signal plot, *y*-axis indicates the magnitude of the signal.

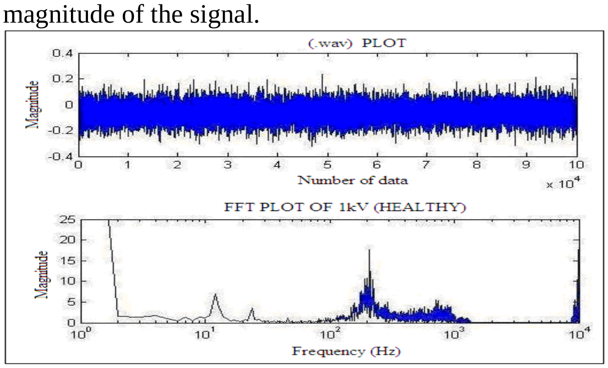

Fig.6 Plot of the FFT algorithm

B. Wavelet Analysis (WA)

This analysis employs time-localized oscillating function for analysis and to determine the mother wavelet. The set of wavelet function of a real mother wavelet is as follows:

$$\psi_{a,b}(t) = \frac{1}{\sqrt{a}}\psi\left(\frac{t-b}{a}\right) \qquad (1)$$

Where a and b is the scaling and shifting respectively and $\psi_{a,b}(t)$ is the wavelet basis.

If the function is shifted, then for each shift, or correlation, the output would be as follows:

$$W_x(a,b) = \langle x, \psi_{a,b} \rangle \qquad (2)$$

The WA is breaking up of signal into shifted and scaled versions of original (mother) wavelet. There are two types of analysis can be performed; (i) *temporal analysis* which used with contracted, high frequency version of prototype wavelet (ii) *frequency analysis* that performed with dilated, low frequency version of the same wavelet.

The process of performing WA begins with decomposition process of the sample signal. Decomposition involves the filtering process using different cut off frequencies. The filters types used in this process is Low Pass Filter (LPF) and High Pass Filter (HPF). The LPF is used to analyze the low frequency component and HPF is used for analyzing the high frequency component of the signal. The sample signal that undergoes a decomposition process shows in Fig. 7.

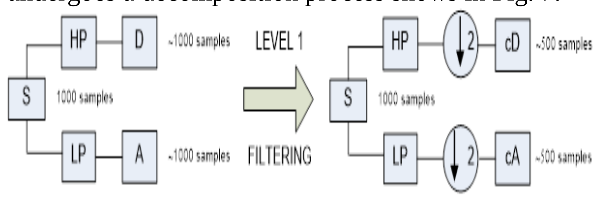

Fig.7 Basic flowchart of decomposition

The decomposition will result in an approximation information from LPF and detail information from HPF at each level of decomposition. The low-frequency content is important since it provides the signal its identity and high-frequency content, impart flavor or nuance. In WA, decomposition (which involved filtering) and reconstruction, the word approximation and details is mentioned. The approximations are the high-scale, low-frequency components of the signal and detail are low-scale, high frequency components. The measure of the amount of detail information in each signal (resolution) is changed by filtering operations. Meanwhile, the scale of the signal is changed by subsampling; upsampling and downsampling. Downsampling of a signal corresponds to reducing the sampling rate, or removing some of the samples of signal. In simple words, downsampling by two refers to dropping every other sample of the signal and at the same time the downsampling by the factor of n reduces the number of samples in the signal n times as Fig. 8.

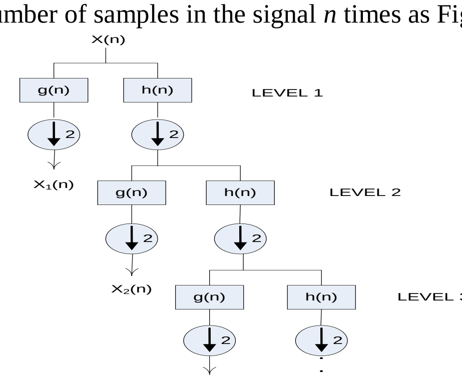

Fig. 8 Decomposition Tree

From the resulting signal from the decomposition process, the process of reconstruction to the signal is undertaken using upsampling as shown in Fig. 9. For upsampling, signals relate to the increasing of the signals' sampling rate by adding new sample. By upsampling a signal by the factor of *n*, this will increased the number of samples in the signal by a factor of *n*. Upsampling technique is employed in the process of signal reconstruction as in Fig. 10. This process is for signal restoration process to ensure that the signal generated from this process is similar to the original signal but with 'clean' signal content.

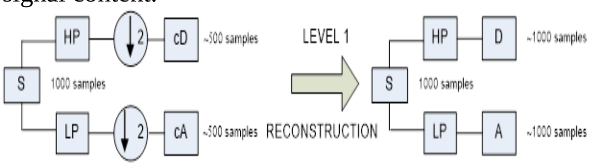

Fig. 9 Basic flowchart of reconstruction

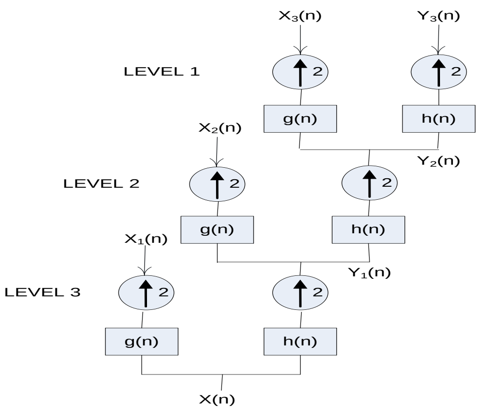

Fig. 10 Reconstruction Tree

3. RESULTS

3.1 Fast Fourier Transform

The purpose of this comparison is to differentiate as well as locate the occurrence of discharges in the insulating material. The analysis was made by observing the peak magnitudes and the frequency range that the peak magnitudes lie on that determine the frequency and apply voltage affected by the discharges. By observing the patterns of the healthy and faulty signals, the pattern itself may determine which signal is healthy and faulty.

A. External Discharge

In the FFT plot obtained, the peak magnitude section is observed. The section where the highest magnitude of the peak that a certain signal able to achieve is observed and the frequency of the peak is recorded. For healthy signal, the peak will lies at the lower frequency range. Meanwhile, for the case of faulty signal, the peak magnitude is again observed. From the peak magnitude, the frequency range can be determined and for the case of faulty signal, the peak lies at the higher frequency range as shown in Fig.11.

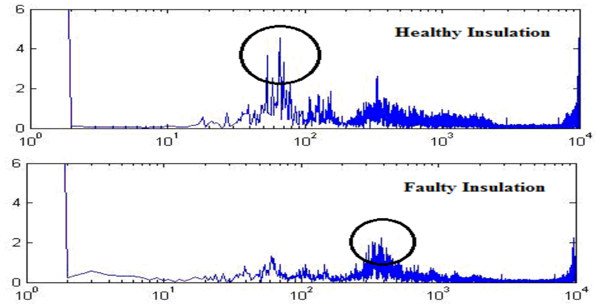

Fig. 11 Comparison between FFT plots for healthy and faulty insulation condition (External discharge)

B. Internal Discharge

For the case of internal discharge, the existence of kink at the FFT plots is considered. The kink is the slope or curve that exists at the FFT plot as shown in Fig. 12. The existence of the kink is to indicate the seriousness of the internal discharges (void) that may affect the insulation. If the insulation material can withstand with the void size, then the kink cannot be seen in the FFT plot. If the kink size increases, then that particular void size can be considered as fully affected the insulation and during the testing, the discharges have becoming audible.

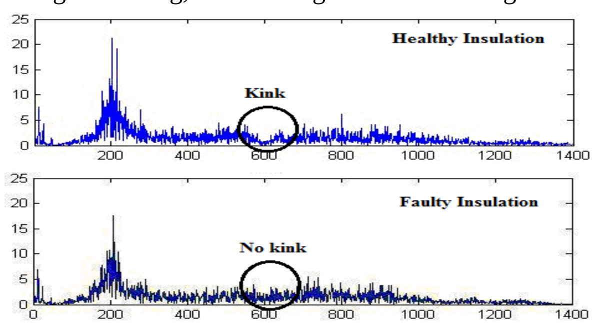

Fig. 12 Comparison between FFT plots for healthy and faulty insulation condition (Internal discharge)

3.2 Wavelet Analysis

Prior to this analysis, the mother wavelet for external and internal discharges needed to be identified. Several of mother wavelet type and the number of level were tested by trial and error. For external discharge, Daubechies of level 7 (Db7) is said to be mostly close to the original signal. Meanwhile, for internal discharge, Symlet of level 3 (Sym3) is closely match with the original signal.

A. External discharge

The resulting signal in faulty condition is shown in Fig. 13. When comparing the original faulty signal with the signal that is being applied with selected mother wavelet, it can be seen that the signal with applied mother followed most of the patterns changes that happened in the original faulty signal although at some points the signal with applied mother can be seen slightly shifted from the original signal. This shows that the signal with applied mother is capable of providing enough information and able to represent the original faulty signal.

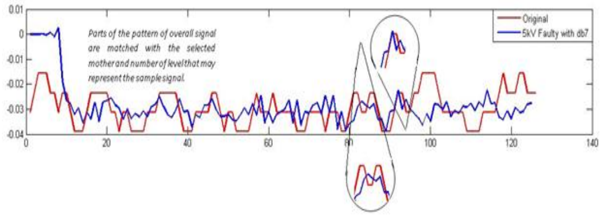

Fig. 13 Observation and comparison of the relation of signals (External discharge)

B. Internal discharge

The selected mother wavelet and the number of level (Symlet 3) were applied to the faulty signals with various values of applied voltage. From the resulting signals shown in Fig. 14, although at some part (highlighted) of the signal, the patterns did not perfectly match the signals and slightly shifted, the selected mother and its level was found valid to be applied on the faulty signals.

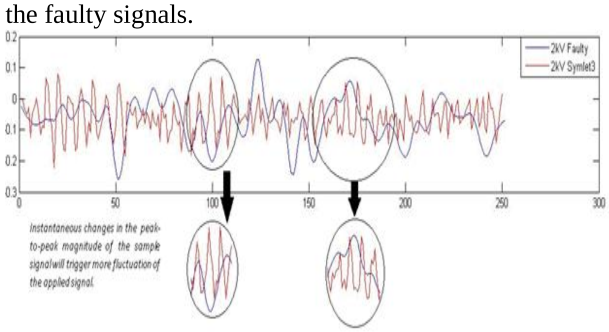

Fig. 14 Observation and comparison of the relation of signals (Internal discharge)

3.3 Pattern Recognition

Based on the overall results obtained from this research), the ultrasonic waveform is different to one another depending on the type of dielectric used as a sample and this had been proved by other researcher. As a result, the ultrasonic waveform can be used for discharges pattern identification. For the case of external discharge, the discharges attenuate fast and therefore the signals' pattern become as shown in Fig. 15.

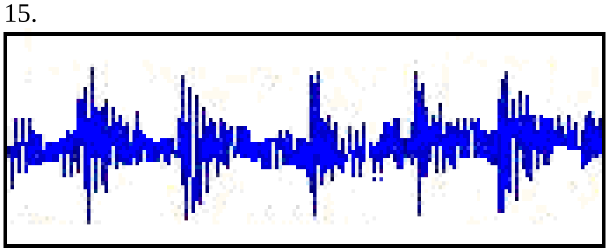

Fig. 15 Signature of external discharges

This is due to PD located at the point where the insulating material and the equivalent resistance pressure are stronger. On the other hand, for the case of internal discharge, the PD occurred in void and the equivalent resistance pressure is weaker, so the waveform attenuates slowly as in Fig. 16.

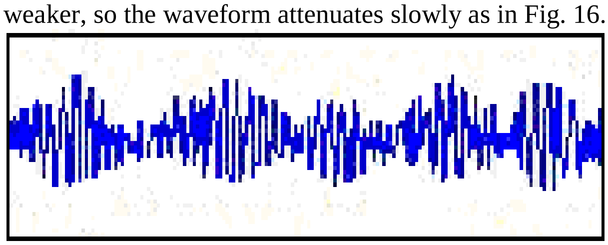

Fig. 16 Signature of internal discharges

4. DISCUSSIONS

With the aid of FFT as one of the analysis tool employed in this research, the location of the peak magnitude of a signal can determine signal is healthy or faulty. For the case of external discharges, by observing the FFT plots, when the peak magnitudes lie at the lower frequency; in this case 20 to 200 Hz, this indicates that the signal is in healthy condition. On the other hand, if the signal lies within higher frequency; 200 to 2000 Hz, it shows that it is a faulty signal. From the *.wav* plot of the faulty signal, the thumbprint of the PD beginning to be audible (at 12.5 kV) is when the constant band of the *.wav* plot developed to a 'herring bone' pattern. Based on the analysis done on the internal discharges, it concludes that the existence of 'kink' shows the difference between external and internal discharges that occurs in the insulation. Larger the size voids have peak magnitude at lower voltages, with exception for the void size 3 mm. It can be said that the larger the void size, the peak magnitude will be at lower frequency as evident at 4 kV, just before they become audible (at 5 kV).

In wavelet analysis, decomposition of a signal by downsampling, facilitate the selection mother wavelet and the number of level. In mother wavelet selection, the signal produced by the external discharges adopted Daubechies as the mother wavelet and seven (db7) as the number of level. Symlet with number of level 3 (sym3) is selected as mother for the internal discharges. The selection was made depending on the sample signals used. The pattern of the signal with applied mother that matches the patterns of the original signal within range or patterns shifted not more than double; in this case 10 points, then it can be selected as suitable mother wavelet. Daubechies is chosen as mother wavelet when the signal has the properties such as compactness, limited duration, orthogonality and asymmetry. Symlet is usually applied to signal that has a sinusoidal waveform.

5. CONTRIBUTION TO KNOWLEDGE

Reconstructing the decomposed signal with the up sampling technique help to restore the signal with much improved the original signal. The restored signals capable of differentiate between the healthy and faulty signals as well as the different types of PD. With WA, the results in FFT are validated.

6. CONCLUSION

In conclusion, the Fast Fourier Transform and Wavelet Analysis able to locate and detect the faulty insulation where the partial discharge occurrence is said to affect the power system and this may lead to ultimate system breakdown. By FFT, the frequency component affected by the discharges is clearly identified. Meanwhile, with the aid of Wavelet Analysis, the filtering process can be done to the signals obtained by using down sampling process. In addition, the up sampling process able to reconstruct and improve the signals by eliminating the unwanted distortion or noises.

7. ACKNOWLEDGEMENTS

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