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Denoising of partial discharge waveforms using multivariate wavelet method

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Abstract. The presence of Partial discharge (PD) in high voltage equipment is an indication of insulation defect or degradation in its insulation. The PD presence can be detected using an electromagnetic sensor, such as fractal sensor. The signals picked-up by the sensor then recorded using a digitizer or an oscilloscope. During the signals pick-up proses, the sensor will capture all the electromagnetic signals around the sensor. Thus, the sensor not only pick-up the PD signals but also unwanted signals or noises. The PD signals captured by the sensor might be buried in heavy noise that the PD signals might be unidentified. To recognize the PD signals de-noising process can be done. In this paper, discussed the denoising process by applying multivariate wavelet to the PD signals captured by using fractal sensor. Results show de-noising process can eliminated noises from PD waveforms even if the PD signals buried by noise signals.

Keywords: Partial discharge, fractal sensor, multivariate wavelet, insulation

1. Introduction

Partial discharge is a symptom of the degradation of the transformer insulation. If the partial discharge allowed to presence in long period of time thus grow overtime, the partial discharge can lead to the insulation breakdown and might cause transformer failure. Thus, partial discharge detection on transformer is a very essential.

Partial discharge detection on transformer can be done using varying method. Conventional method as defined by IEC standard 60270 is the most popular method used to detect PD in transformer. This method has mayor advantage compare to other method i.e. its ability to calibrate the measurement results. The IEC standard 60270 method results can convert to amount of pC generated by the PD sources. However, this method has a major drawback when applied in open area with high surround activity. As the conventional method works in frequency range up to 1 MHz [1], the surround electric field can interfere the measurement results. Thus, conventional is very risky to the noise signals around the transformer being test.

Partial discharge detection aforementioned in IEC standard 60270 classified as conventional method and other methods named as non-conventional. Non-conventional method such as DGA-dissolve gas analysis has proven accurate to detect the presence of PD inside the transformer tank. However, DGA has substantial disadvantage i.e. partial discharge can be detected only after some gas released by the PD source has built-up in the liquid isolation. The gas built-up, however, can take quite long time.

One of PD detection method developed lately is by detection the electromagnetic signals generated by the PD source. As the source to detect the PD events is electromagnetic signals generated by the PD events, this method is also called as ultra-high frequency (UHF) method. Though detection also can be arranged for lower frequency [2], such as 50 MHz ~200 MHz. Higher frequency used in UHF method provide advantage compare to a lower frequency one. This due to noise disruption relative lower. However, though electromagnetic PD detection has lower noise interferences the noise might still disrupt the PD signals thus error in PD detection can occur.

2. Detection of Partial Discharge Electromagnetic Signal

In the event of a discharge in transformer insulation, free electron charges which were initially at rest are accelerated and decelerated by an external force. The acceleration and deceleration processes produce a time varying electromagnetic field which radiates outward from the PD location.

A stationary charge has only electric field which is radiated radially. As the charge is in motion, electric field and magnetic field are produced. Assume the charge is initially at rest then accelerated. The electric field lines at any point in the direction of the path of the moving charge are entirely radial and must be continuous since they are produced by the same charge.

During the acceleration of the charge, the electric field lines are always updating its position. However, due to the time needed by the electric field lines to adjust, the lines will have disrupted the direction or become misaligned. This line disruption is known as a 'kink' which have both a static Coulomb field and an electric field which are perpendicular to each other. The transverse electric field produced by this process then causes radiation. The maximum radiation occurs along the line perpendicular to the direction of the acceleration. In the same direction with the acceleration there is no transverse electric field component produced, only a static Coulomb field thus no radiation occurs.

The basic diagram of the UHF PD detection method is shown in Figure 1. The main component to detect the PD signals is an antenna which acts as a sensor that picks up electromagnetic signals emitted by the PD sources. The sensor is connected to a measurement unit to show and record the PD signals. In cases when the PD signal is too small, an amplifier can be installed between the sensor and the measurement unit. Using an amplifier which has a specific operational frequency, the PD signals can be magnified whilst blocking the noise signals. In the UHF range, the noise mainly comes from known communication sources such as digital TV or mobile phone signals. Thus, using a specific amplifier which excludes known noise frequencies, a clear PD signal can be shown and recorded by the measurement unit.

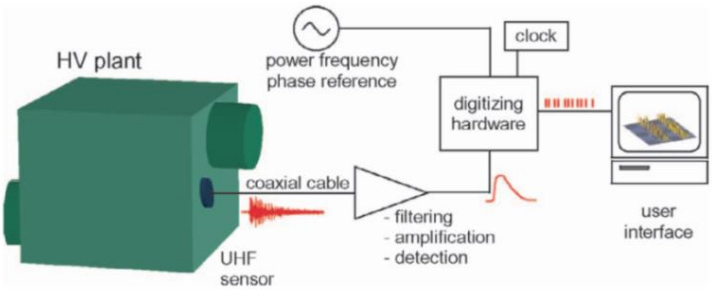


Figure 1: Typical UHF PD detection diagram [3].

2.1. Sensor to detect Partial Discharge on Transformer

The purpose of transformer monitoring extends from PD detection and recognition to PD localization. To be able to undertake UHF PD transformer monitoring, a sensor with capabilities to detect signals in the UHF frequency range is needed. For power transformer monitoring, the UHF sensor is inserted into the transformer tank to capture the electromagnetic waves emitted by the PD source. There are two ways of installing the sensor: via the oil drain valve [4] or the dielectric window [5]. The size of the oil drain valve imposes a constraint on the sensor dimension, while the dielectric window can be created with an appropriate size to accommodate the sensor. However, the placement of a dielectric window sensor needs an additional hole to be fabricated on the transformer tank. As for the oil valve sensor, this is not required because the sensor can be easily retrofitted into the transformer via the existing built-in oil drain valve [4].

Typically, the sensor is a monopole type. It can be inserted via the oil drain valve. The size of the sensor is usually limited by the diameter and length of the oil drain. A typical oil drain valve sensor size is 5 cm in diameter, and 10 cm in length [4]. The shape of the sensor can be a short monopole [4, 6], plate, zigzag or conical [4, 7] or any shape as long as it is able to be fitted to the drain valve. The sensitivity of this kind of sensor is affected by the depth of the sensor insertion [4]. The deeper the sensor is inserted, the higher the magnitude of the PD signals acquired. However, the sensor must not initiate breakdown due to the high electric stress at the tip of the sensor [5]. To reduce electric stress, the sensor can be encapsulated in some dielectric material [5].

For a dielectric window, the sensors usually have a planar shape [5]. The sensor can be a micro-strip sensor [8,9,10], log-spiral, spiral [5,11] or fractal [12]. This kind of sensor is usually etched on the surface of a dielectric material, using the same process as in making electronic printed circuit boards (PCB). The sensor is etched on the PCB with dimensions proportional to the working frequency of the sensor. In 37, the miniaturization of the microstrip UHF antenna was discussed by applying an impedance matching technique. This technique can reduce the antenna dimensions to 5x5 cm for example. However, even though the antenna works in UHF range, the bandwidth is very limited. To increase the bandwidth, [10] designed a microstrip antenna using sandwich substrate. As a result, the frequency range of the antenna has a very wide range from 30 MHz to 3000 MHz. However, to manufacture this microstrip antenna is not practical.

Most of the measuring arrangements are unbalanced systems, i.e. the input to the measuring system is a coaxial cable which consists of a live input and ground. While planar sensors are usually crafted as a balanced system, an unbalanced system is also possible, such as a circular or single arm log-spiral or spiral. Thus, to connect the sensor to the measuring system, a converter from balanced to unbalanced is needed. This connector forms part of the sensor and is called a balun.

In this paper, we use fractal sensor to detect the PD signals. As the sensor is an un-balance sensor type, the sensor connected directly to an oscilloscope via coaxial cable.

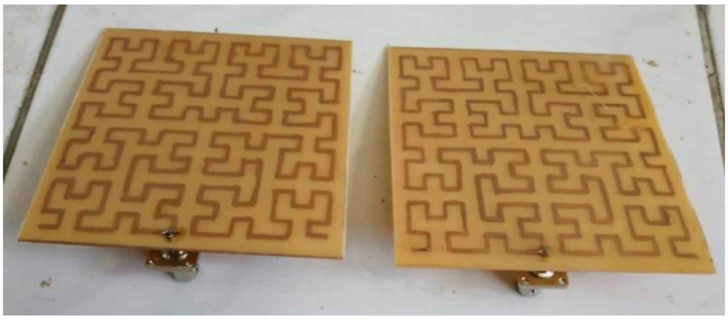


Figure 2. Fractal sensor in used in the experiment.

2.2. Fractal Sensor

In this paper discussed the using of fractal sensor to capture the partial discharge signals. The sensor has dimension of 5x5 cm. as shown in figure 2. The sensor built on single layer PCB with terminal connected to a BNC. The sensor VSWR is shown in Figure 3. As one can see the sensor VSWR shows good value at the designed frequency range as the VSWR value below 2 for the frequency up to 1000 MHz.

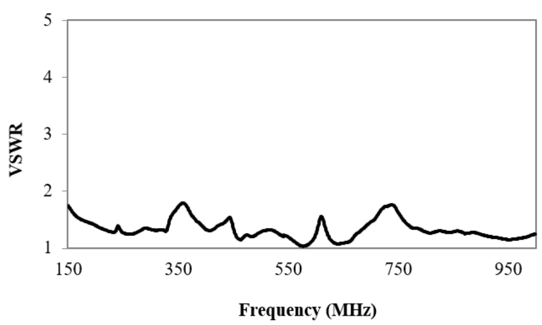


Figure 3. Fractal sensor VSWR up to 1000 MHz.

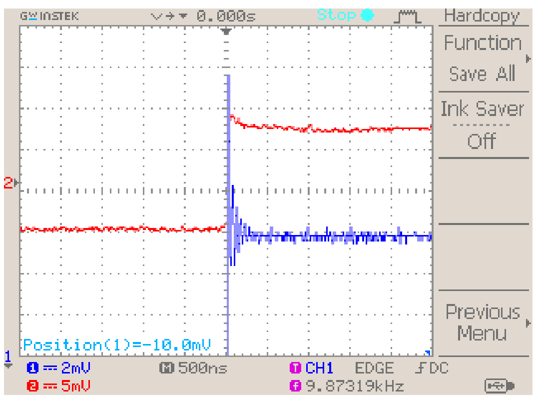


Figure 4: Sensor response to a step pulse.

2.3. Sensor Response to a Step Pulse

Partial discharge signals is a very short pulse that contain frequency up to a few GHz [13]. Thus, to test the sensor ability to detect the PD signal one can use a steep pulse which contain frequency in a wide range up to GHz. The step pulse response of the fractal sensor which use in the experiment shows in figure 4. The sensor shows ability to capture the step pulse signals generated in an TEM cell. So, the fractal sensor can be used to detect the partial discharge signals in the experiment.

3. Noise on Partial Discharge Signals

On-site partial discharge detection might encounter a very different scheme. The partial discharge detection on laboratory, within controlled environment, will encounter less noise or even eliminated. However, on-site partial discharge detection might encounter noise from the surrounding environment. Noise can be produced by varying sources and can be classified in two type i.e.: 1. continue noise produce by telecommunication system, thyristor switching and line transmission switching, and 2. thermal noise produce by the PD detection system itself. The noise can be swamped the PD signals, so the PD signals unable to recognize. To recognize the PD signals, denoising might needed.

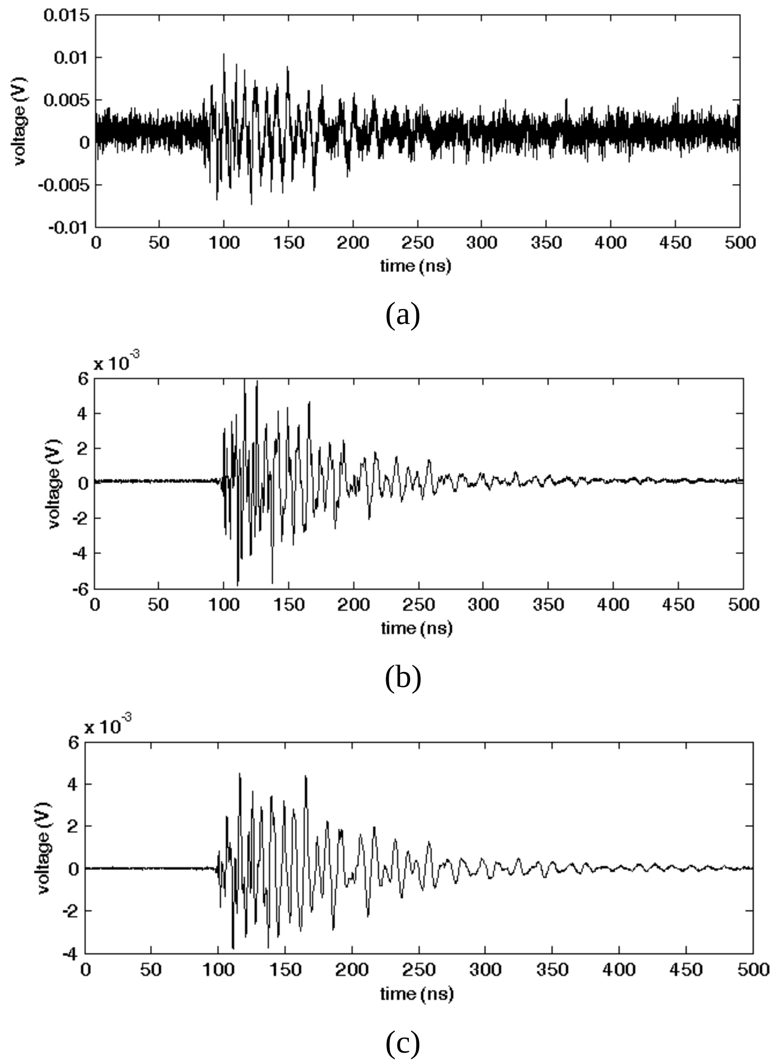


Figure 5 : Typical denoising result using multivariate wavelet method (a) original waveform, (b) denoising using threshold value, and (c) final result after applying PCA component analysis [15].

3.1. Denoising process

A free noise of partial discharge waveforms can be achieved by applied denoising process to a noisy partial discharge waveform. In this paper, discussed the using of wavelet multivariate [14] to denoise the partial discharge waveforms. The method based on regression model:

$$X(t) = f(t) + \varepsilon(t),\ t = 1,\ldots,n. \quad (1)$$

where:

$(X(t))_{1\leq t\leq n}$ = observed waveforms
f = denoised waveforms
$\varepsilon(t)_{1\leq t\leq n}$ = Gaussian white noise with unknown variance value σ^2

The multivariate denoising procedure is done in two steps. First, the original waveform is arranged by using wavelet transform, and then by using applying multivariate thresholding the waveform is denoised. Second, principal component analysis (PCA) is used to improve the denoising results. Figure 5 [15] shows typical wavelet multivariate denoising results in two steps procedures.

4. Experiment Setup

Figure 6 shows the experiment diagram. The partial discharge source is a surface discharge type. The sensor installed near the PD source i.e. at distance around 20 cm. The sensor connected to an oscilloscope to record the PD waveforms. The recorded data than copied to a PC, for further analysis. Input voltage controlled using a voltage regulator. The input voltage increased unti the PD generated by the PD source.

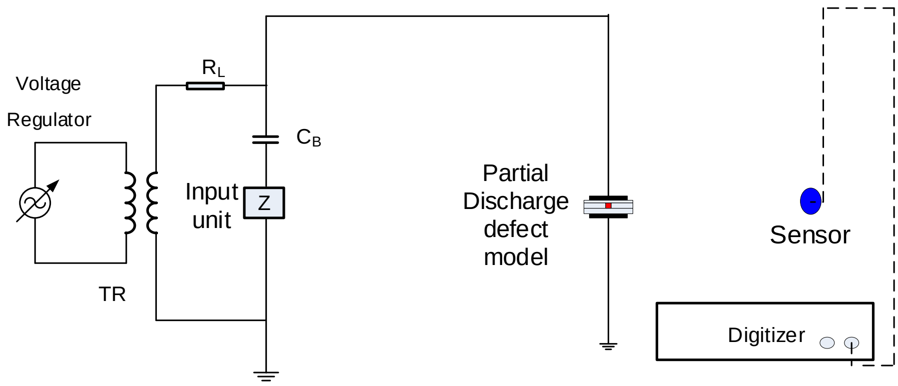


Figure 6. Diagram of the experiment set-up

5. Results and Discussion

The denoising process is done using waveforms produce by a surface discharge source. The PD signals captured by a fractal sensor recorded by using a digitizer or oscilloscope. Two waveforms are use as input of the denoising process. The first waveform has amplitude at around ~1 mV and the second one has amplitudes ~0.8 mV. A white-noise is used as to alter the original waveforms, with amplitude of 0.5 mV and 0.75 mV respectively, named as case I dan case II.

Figure 7, 8 and 9 show the denoising process for the two partial discharge waveforms. Figure 7 shows the white-noise with amplitude 0.5 mV used to flooded the partial discharge waveform. Figure 8.a and 9.a are two original partial discharge waveforms. The two original waveforms than swamped with the white-noise to produce two noisy waveforms, as shown in figure 8.b and 9.b. The multivariate wavelet than applied to denoise the noisy waveforms. Figure 8.c and 9.c show the denoised waveforms after applied multivariate wavelet denoising method.

By comparing the original waveforms with the denoised waveforms, it can be seen the two denoised waveforms have similar characteristics with the original waveforms. The magnitude of the original and the denoised waveforms have almost similar magnitude. The denoising process able to reconstruct the waveforms although buried by high noise as the original and the denoised waveforms shows similar forms. However, some of the added white-noise still recognizable in the denoised waveforms. This can be seen in front of the denoised waveforms.

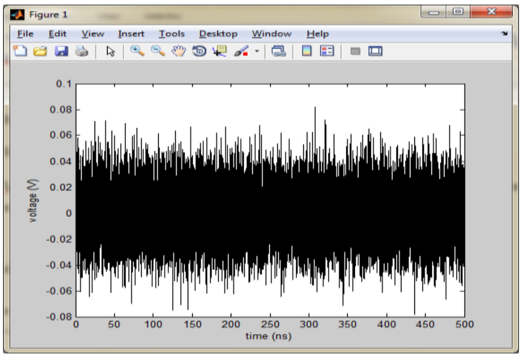
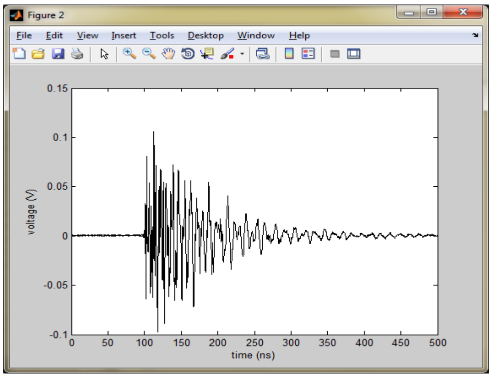
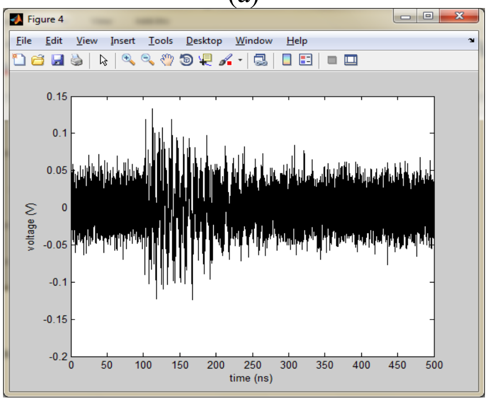


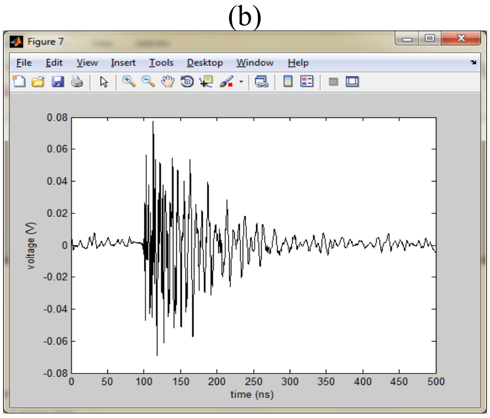
Figure 7. Gaussian white noise



(a)

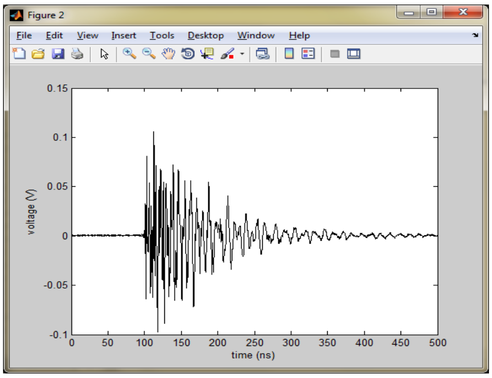


(b)

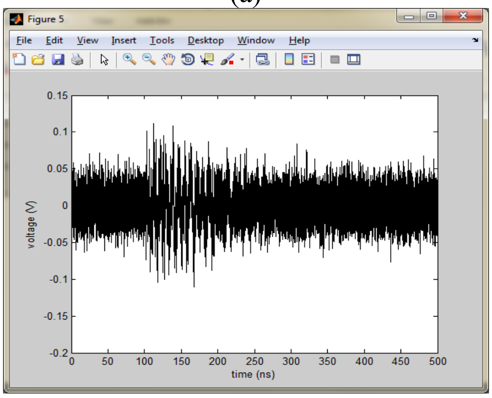


(c)

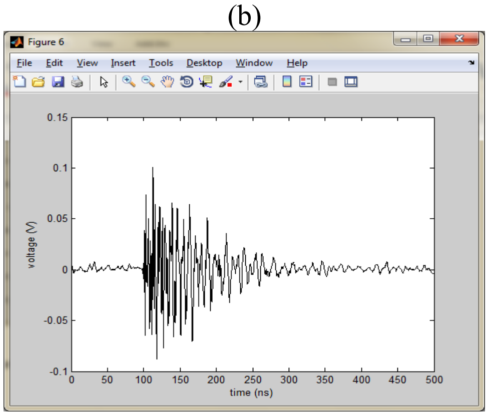
Figure 8. The denoising process of waveform I, a. Original waveform, b. white noise added to original waveform, and c. the denoised



(a)



(b)



(c)

Figure 9. The denoising process of waveform II, a. Original waveform, b. white noise added

waveform using multivariate wavelet method.

to original waveform, and c. the denoised waveform using multivariate wavelet method.

Effectiveness of the denoising method is determine as below:

1. Signal to noise (SNR) between partial discharge waveform with the white-noise is calculated using:

$$SNR1_{db} = 10\log\left(\frac{P_{signal}}{P_{noise}}\right) \tag{2}$$

Where P_{noise} is the white-noise and P_{signal} are the original partial discharge waveforms.

2. The white-noise and the partial discharge waveform then summed-up. The summed-up waveforms then denoised using multivariate wavelets. The new SNR then calculated as:

$$SNR2_{db} = 10\log\left(\frac{P_{signal}}{P_{denoise}}\right) \tag{3}$$

Where P_{signal} is the denoised waveforms and $P_{denoise}$ is the subtraction of the denoised signal with the original waveforms.

The calculated SNR of the denoising process is shown in Table 1. One can see, that the denoising process resulted a very clear waveforms with SNR2 value above 10 dB. Thus, it can be said the denoised waveforms is already clear from the noise.

Table 1. Signal to noise (SNR) ratio denoised waveforms

Case	Waveform	SNR1 (dB)	SNR2 (dB)
I	**1**	-1.8673 dB	15.2147
	2	-3.7000 dB	13.5063
II	**1**	-5.4087	13.6066
	2	-7.2414	11.8632

6. Conclusion

Multivariate wavelet denoising method shows ability to incite the original waveform even when the denoised waveform buried in heavy noise. The denoised waveform has characteristic similar to the original waveforms. The denoised waveforms have a good result as shown y the high SNR value. In this research the SNR of the denoised waveforms to the noise signal is greater than 10 dB.

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