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A Method for Extracting Partial Discharge Signals in Transformer Winding with Wavelet Analysis

MOHAMMAD S. NADERI [1]*, M. VAKILIAN [1], T.R. BLACKBURN [2],
B.T. PHUNG [2], MEHDI S. NADERI [3]

[1] School of Electrical Engineering, Sharif University of Technology, Tehran 11365-9363, IRAN
[2] School of Electrical Engineering, University of New South Wales, Sydney, NSW 2052, AUSTRALIA
[3] School of Electrical Engineering, Amirkabir University of Technology, Tehran 15914, IRAN
* Visiting Fellow at the UNSW, E-mail: salaynaderi@hotmail.com

Abstract: In this paper a method for extracting Partial Discharge (PD) signals is introduced, which is implemented for evaluating electrical measured partial discharges on a 66 kV / 25 MVA fully interleaved winding of a power transformer. Applying wavelet transform to a signal produces a wavelet detail coefficient distribution throughout the time-scale, which depends on the mother wavelet chosen. This method is based on the capability of the chosen mother wavelet for generating coefficients with maximum values. The paper demonstrates that the wavelet based de-noising method proposed in the paper can be employed in extracting the PD pulses from the measured signal successfully to provide enhanced information and further infer the original site of the PD pulse through capacitive ratio method. In fact, the basic idea of this method is described and applications to partial discharge studies are explored.

Key-Words: Partial Discharge, Transformer, Transformer Winding, PD Location, Wavelet Transform, Signal Denoising, Signal Processing

1 Introduction

Power transformers are in service in different environmental, electrical and mechanical conditions. Many experiences have proved that the inner insulation system degradation may pose the transformer to fail while in service. On the other hand, partial discharges (PD) are recognized as the main cause of insulation deterioration process. Therefore, reaching the optimum inner insulation system is one of the challenges a transformer designer is faced with. The solution lies in the correct and accurate modelling of different types of transformer windings. Therefore, Partial Discharge monitoring and diagnosis is essential to identify the nature of insulation defects causing discharge.

Monitoring means mainly data acquisition, sensor development, data collection, and development of methods for condition measurement of power transformer. Diagnostics contains interpretation of off-line and on-line measured data [1]. In this sense, during the monitoring in an AC system or off-line measurements, interferences and disturbances affect the measurement data in noisy conditions and PD signal is buried in the noise.

Noise can be defined as any unwanted signal that is not related to the input signal. The primary sources of random, unpredictable noise are from radio waves, electrostatic discharges (ESD), power utility transients, corona and lightning, and thermal noise. During the last decades, interference from noise sources has been a persistent problem, which has increased with the advent of solid state power switching electronics [2].

Despite the advances achieved during past decades in measuring instruments, partial discharge detection circuits, e.g., the ultra wide-band detectors coupled to real-time oscilloscopes of very wide band-width, a sophisticated analytical tool of similar power to pre-process PD data has yet to be realized [3].

The wavelet and its associated transforms [4-7] represent a powerful signal processing with a wide variety of applications. The main reason for this growing activity is the ability of the wavelet transform not only to decompose a signal into its frequency components, but also to provide a non-uniform division of the frequency domain, whereby it focuses on short-time intervals for the high-frequency components and long intervals for low frequencies. This attribute to tailor the frequency resolution can greatly facilitate signal analysis and the detection of signal features.

2 Noise Suppression and PD Signal Extraction

The main objective of de-noising is to suppress the noisy part of the signal. However, the ability to separate the "true" signal from noise improves with increased knowledge about the signal source as well as noise attributes.

With reference to the noise characteristics, which are normally involved, the two main kinds can be mainly distinguished. Firstly, continuous type noises, which include sinusoidal and white noise and secondly, pulse shape noises, which periodically appearing noise pulses and stochastically occurring pulse shaped noises are in this category.

Sinusoidal noises are usually generated by radio or communication services and can be suppressed by frequency rejection filter. White noise owes especially to optical transmission and the suppression of white noise can be usefully performed with the wavelet transform [2,8]. Cross correlation methods are using to eliminate periodically appearing noise pulses and localization methods in various investigations have shown good results to suppress stochastic pulse shaped noises like corona discharges.

The wavelet transform normally uses both the analysis and synthesis wavelet pair. Synthesis is used for waveform reconstruction. The signal obtained from the measurement is decomposed into its constituent wavelet levels. Each of these levels represents that part of the noisy signal occurring at that particular time in that particular frequency band. In this sense, the key idea underlying the WT strategy is that a given signal can be disassembled into a series of scaled and time-shifted forms of a mother wavelet producing a time-scale view of a signal from which the original can be recovered. As it can be seen, the decomposed signals possess a powerful time-frequency localization property, which is one of the major benefits provided by the wavelet transform. On the other hand, wavelet de-noising methods are based on either hard or soft thresholding approaches. Denoised signal can be retrieved by inversing wavelet transform, which genuinely is the inverse of the threshold wavelet coefficients.

The mentioned algorithm is a rough description of a de-noising algorithm based on wavelet transform and it implies another advantage of this kind of de-noising. In fact, a peculiarity of this filtering technique is that no reference signal is needed.

The complexity of the noise suppression when measurements are on a power transformer is obvious. When signal propagates from its site of origin to the measuring terminals in the line and neutral ends of the transformer is strongly modified. Depending on the original location of the PD and transfer characteristics of the windings between the PD source and terminals, pulses will be distorted and attenuated in magnitude significantly. Therefore selecting the most suitable wavelet for noise suppression specially when the measurements are on power transformer is vitally important and this has been investigated on PD pulses measured in the laboratory for PD location purposes.

3 Selecting Optimal Mother Wavelet

The selection of the suitable wavelet and its associated analysis algorithm depends on desired application and improving to the optimal method needs to have exact understanding as to the detection circuit and PD pulse shape.

In practical measurements, discharge voltage signals are captured by feeding the discharge current into a detection circuit. Therefore depending on the configuration of the detection circuit voltage signals will likely have different shapes.

Measuring voltage signals causes some problems in practice. In fact, for the normal transformer connection, the neutral end of the winding is grounded, which makes calibration at this end impossible. Including an inductance with low impedance at power frequency in the neutral end will alleviate the problem.

Detection circuit has been concerned in many investigations [9, 10] and usually is realized as an either RC impedance circuit or a RLC impedance circuit. Simulated pulse in this paper is supposed to be obtained from a RLC circuit.

Obviously, based on what measurement circuit has been chosen, the mother wavelet which provides the optimal results with the obtained data would be different from another circuit with another data.

By the word “Optimal”, it is meant that the characteristics of the synthesized signal are closer to the main signal as much as is possible by the software tools available.

For better understanding, a simulated PD pulse, which is supposed to be obtained utilizing a detection circuit with a RLC impedance circuit, is considered. Transfer function of RLC impedance circuits can be expressed as below:

$$G_{RLC}(s) = \frac{1}{C} \cdot \frac{s}{s^2 + s/\tau + \omega_0^2} \tag{1}$$

Where $\tau = RC$, and $\omega_0 = 1/\sqrt{LC}$. Fig.1 shows detection circuit of a RLC impedance circuit.

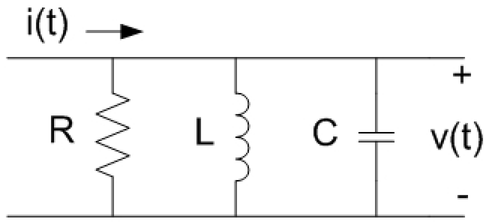


Fig.1. RLC detection circuit

For the input of a Dirac current pulse *i(t)*, the output voltage pulse *v(t)* is represented as a damped oscillatory pulse, as shown in Fig.2.

Wavelet detail coefficient distribution, wavelet pattern, throughout the entire time-scale is used to determine the most suitable wavelet for a given pulse.

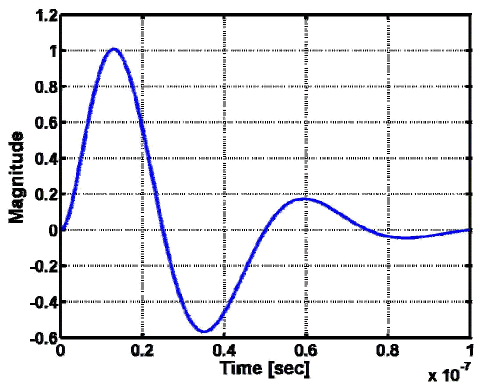
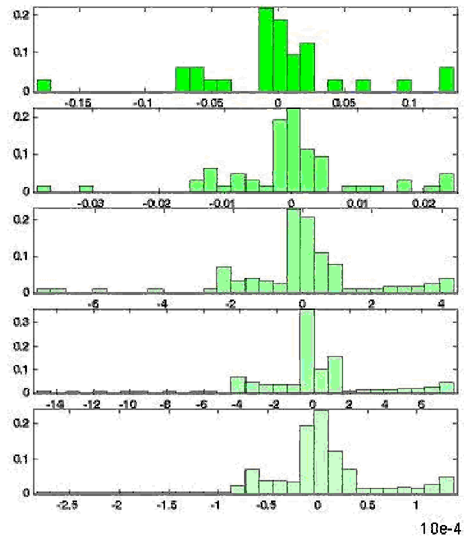


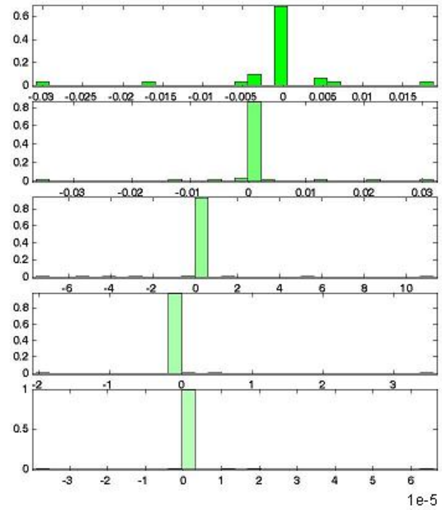
Fig.2. Simulated PD pulse

Fig.2 demonstrates the magnitude of the simulated PD pulse versus time in second. Pulse magnitude has been normalized to provide a better view on the wavelet pattern histogram, which is used to recognize the optimal wavelet suited to the simulated pulse.

Fig.3a and 3b show the wavelet pattern histogram of the simulated PD pulse in the Fig.2. Wavelet patterns have been gained after applying DWT with 5 level using Daubechies wavelets, db2 and db7, respectively.



(a)



(b)

Fig.3. Detail coefficient histograms of the simulated PD pulse, sampling frequency, 10 GHz; 1001 points;
(a) With the db2; (b) With the db7

The values of the coefficients as Fig.3 illustrates are significantly different and those gained using db7 are greater than the db2. Detail coefficient distributions for other simulated pulses showed that similarity between mother wavelet and simulated pulse or correlation between them can be used as a criterion for choosing the optimal wavelet. More similarity gives better correlation.

In statistical analysis, the correlation coefficient, γ, is used to detect one particular relationship between mother wavelet and signal under examination. The greater the value of γ, the more approximate in wave shape between two variables [3].

4 Application in PD Location

A 66 kV / 25 MVA transformer winding with 19 fully interleaved discs is used in this study. In [10] it was shown that there exists a range of frequency in which the signal components do not change phase when traveling through the winding. This frequency range for the employed winding is between 100 kHz and 500 kHz. Experimental setup is depicted in the Fig.4.

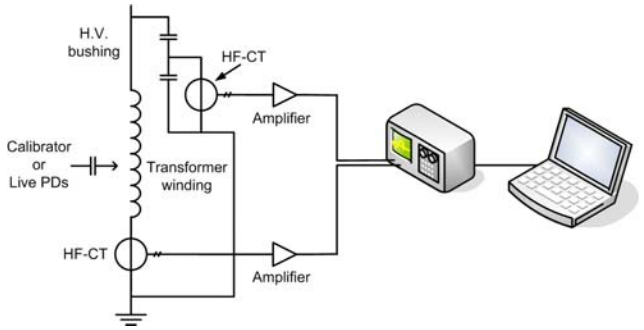


Fig.4. Experimental setup for PD location

The line end of the winding is connected to a HV bushing. The injected PD signal is generated by either an electronic calibrator or a live discharge source. The resulting line and neutral- end current signals are detected by two home-made high frequency current transformers (HF-CT) and recorded with a digital oscilloscope.

Fig.5 shows a recorded signal from neutral end when the PD is injected from line end. The need for denoising was discussed in [10, 11].

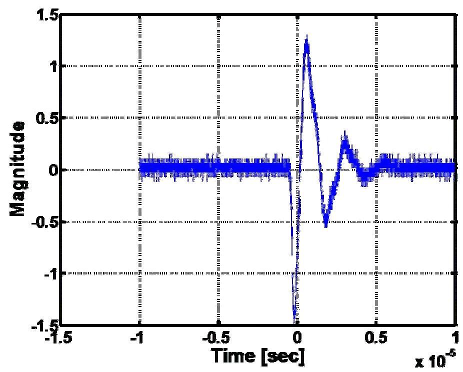


Fig.5. Sample recorded signal from neutral end

After applying wavelet, the ratio of the peaks of the two terminal signals as a function of PD location is depicted in Fig.6.

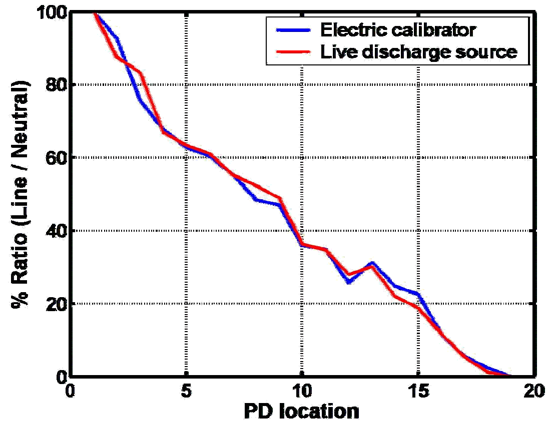


Fig.6. Ratio curves after denoising with db2

Maximum difference between electric calibrator and live discharge source is about 4%, which for the test object provides an accuracy to determine the PD location of two disc deviation.

5 Conclusion

A method for extracting partial discharge from a noisy measured signal introduced, which was based on selecting an optimal mother wavelet. The wavelet pattern throughout the entire time-scale was employed to determine the most suitable wavelet for a given pulse. Selecting a suitable wavelet and its associated analysis algorithm depends on desired application and improving to the optimal method needs to have exact understanding as to the detection circuit and PD pulse shape.

In addition to achieving acceptable levels of noise suppression, another notable feature of the proposed method is that, partial discharge signal distortion is in a level which gives the chance of applying the resulted de-noised signals to localize partial discharge in transformer winding. The capacitive ratio method was used to locate PD in which the ratio of the peaks of the two terminal signals is plotted as a function of the PD location.

Investigations on an interleaved power transformer winding showed that selecting optimal wavelet gives promising results concerning the location of PD sources using capacitive network method.

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