

Partial Discharge Signal Denoising by Discrete Wavelet Transformation

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Abstract

There are several techniques to eliminate noise on signals such as signal analysis in time zone, frequency area and short time Fourier Transform. As we know, frequency and time domain analysis are the basic methodologies in signal processing. In the partial discharge signal, the signal analysis can be realized in the time domain or in the frequency domain. When the signal is processed in the frequency domain, the time domain information becomes lost. To overcome these weaknesses, wavelet transformation is developed which can provide information in time and frequency domain. Wavelet transforms have been applied in various fields for signal processing in recent years. In this paper, a study of wavelet transformation was done to reduce noise from partial discharge signals obtained from previous experiment.

Keywords: Noise; partial discharge; threshold; wavelet

1. Introduction

According to IEC 60270 standard, partial discharge (PD) is a local electrification phenomenon that partially connecting the insulation between the conductors and occurs either on the surface of the conductor or in the insulation (void). This can occur in a conductor (conductor) in a short time, either at close range or at a great distance [1].

Many methods have been developed to detect PD signal. In the PD measurement, noise may arise from various sources that reduce the quality of measured data, consequently, the result signal is different to the PD signal. Fortunately, the noise may be removed. The technique for removing noise from PD signals can be realized in the time domain or in the frequency domain. PD and noise may be seen in different frequency characteristics [2]. However, when the signal is processed in the frequency domain, the time domain information becomes lost. To overcome these weaknesses, wavelet transformation is developed which can provide information in time and frequency domain. Wavelet transform (WT) has become a new and excellent tool for signal processing in recent years and has been successfully applied to various fields and applications [3].

In this paper, a wavelet transformation is used to minimize noise contained inside PD signals which is obtained through previous experiment. The signal is already in the form of csv file from measurement through oscilloscope. The process of PD wavelet transformation is made using a matrix laboratory (MATLAB) program [4]. The method used in reducing PD signal noise in this study using wavelet transformation. The output of this application is a display of original PD signal that has not been filtered using wavelet, noise signal and signal that has been filtered through wavelet. In addition to measuring the level of noise, it also shows the value of Signal to Noise Ratio (SNR) to facilitate the analysis of wavelet transform (noise reduction) that has been done by the application.

2. Signal Denoising Process

2.1. Partial Discharge (DP)

Partial discharge occurs when the electric field inside the void exceeds the penetrating power of the gas in the void. When the AC voltage is given gradually then at a certain voltage value the partial discharge will begin to occur, this voltage is called the inception voltage (V_i). Where an inception voltage is the minimum voltage required for partial discharge to occur. When the voltage is raised and reaches

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the spark voltage, there will be no discharge until the initial avalanche electron begins to emerge partial discharge [5]. These electrons can arise due to the difference in the electric field in an area (electrons 1 in Fig. 1).

The electron avalanche

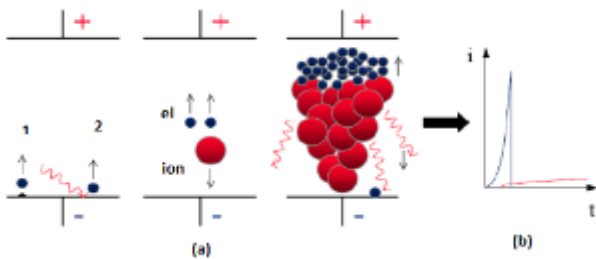


Figure 1. Discharge Process (a) avalanche electron and (b) discharge current [5]

2.2. Wavelet Transformation

Wavelet Transformation is a transformation that can provide resolution of frequency and time in the same time as well. There are two types of wavelet transformation, namely: *Continu Wavelet Transform (CWT)* and *Discrete Wavelet Transform (DWT)*, as follows :

2.2.1. Continue Wavelet Transform (CWT)

CWT works by calculating the convolution of a signal with a modulation window at any time with each desired scale. Modulation windows that have this flexible scale are called wavelets or wavelet base functions [9].

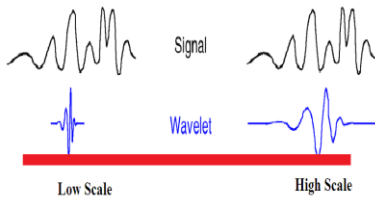
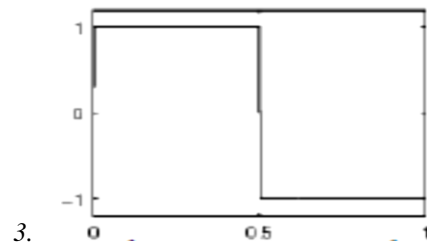


Figure 2. High-low scale relation with frequency [12]

In Fig. 2, we know that for low scale, wavelet signal undergoes compression and corresponds to higher frequencies. As for high-scale, the changes are roughly and slowly.

2.2.2. Daubhecies Wavelet

DWT is one of the wavelet transformation that represent signals in the time and frequency domain. The advantages of this DWT, easy to implement and efficient in terms of computing time. DWT is used to calculate the wavelet coefficients on all possible scales. DWT also generates enormous amount of data. Generally, the DWT process as follows : decomposition, filtering, downsampling and reconstruction [13].



4. Figure 3. Haar Wavelet

2.3. Coiflet Wavelet

2.3.1. Haar Wavelet

Haar Wavelet is the eldest and simplest wavelet. *Haar Wavelet Haar* is the same as *Db1 Wavelet* (1st orde Daubechies) with the Haar Wavelet filter length is being 2. [4, 12].

2.3.2. Daubhecies Wavelet

Daubhecies wavelet has a simple name, *Db.*, and for *N* orde is written with *DbN*. The Daubechies Wavelet Order is *N = 1* or Haar, *N = 2, ..., N = 45*. Wavelet daubechies filter length is $2N$ [4, 12]. We can see the Daubhecies wavelet in Fig. 6.

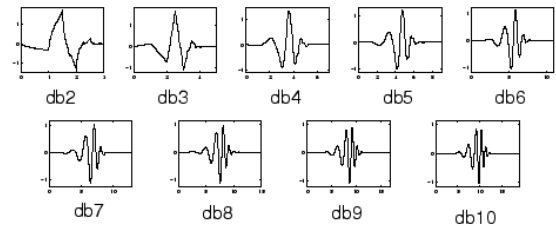


Figure 4. Wavelet Daubhecies

2.3.3. Coiflet Wavelet

Wavelet Coiflet has a short name *Coif*, and for the order *N* is written with *CoifN*. The length of the Coiflet Wavelet filter is $6N$ [4, 12]. For its figure as attached below.

2.3.4. Symlet Wavelet

Wavelet Symlet has a sym short name, for the order *N* written with *SymN*. Wavelet Symlet has the order $N = 2, ..., 45$. The filter length for Wavelet Symlet is $2N$ [4, 12].

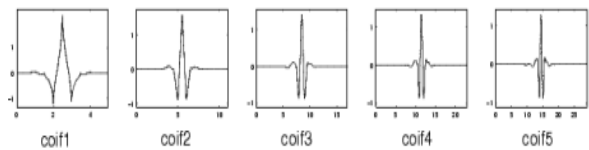


Figure 5. Wavelet Coiflet

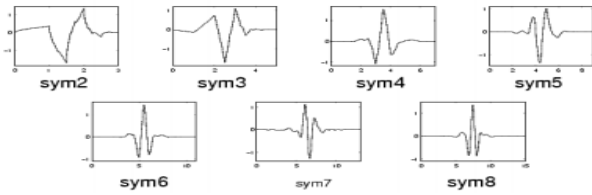


Figure 6. Symlet Wavelet

In this paper, we will use four types of wavelets namely, haar, daubhechies, symlet and coiflet. Although the haar is 1st Daubhechies type and Symlet-Daubhechies are having the same length, we want to know form and SNR its signal.

Another purpose is the use of wavelets with the type of symlet and coiflet because this wavelet type has a different filter length so it can see which wavelet transformation is better, particularly for noise reduction.

4.1. Thresholding [10]

Threshold is a process that make zero for existing values within a predefined threshold value. Thresholding can be done globally where a threshold value is applied to all level of scale of the wavelet transform, or each scale level has its own threshold value. There are two threshold functions used in this task, as follow:

2.4.1 Hard Treshold

Hard threshold has an equation as follows :

$$\delta_{\lambda}^H = \begin{cases} x & \text{if } |x| > \lambda \\ 0 & \text{if } |x| \leq \lambda \end{cases} \quad (1)$$

In the hard threshold there is a discontinuity in the threshold function so that the value of x which has been mentioned before, above the threshold is not touched. At hard threshold only coefficients with absolute values below the threshold value are affected and the coefficients are replaced by zero whereas other than fixed.

2.4.2 Soft Treshold

$$\delta_{\lambda}^H = \begin{cases} x & \text{if } x > \lambda \\ 0 & \text{if } |x| \leq \lambda \\ x + \lambda & \text{if } x < \lambda \end{cases} \quad (2)$$

with λ is threshold parameter.

The function of soft threshold is continue since x value is above threshold. The use of soft threshold comes from the principle that noise affects the whole wavelet coefficient. At the soft threshold, all coefficients undergo a modification process. Coefficients with absolute values above the threshold value will be reduced in value whereas the other coefficients will be zero.

4.2. Signal to Noise Ratio (SNR)

Signal to Ratio (SNR) is a measure in determining the quality of a signal disturbed by noise. In other words SNR shows the comparison between the power of the original signal (information) with the noise. Here is the formula used in SNR calculation on this task [11]:

$$SNR_{dB} = 20 \log \frac{V_s}{V_n} \quad (3)$$

With SNR_{dB} (Signal Derau Ratio in Decibel unit), V_s (Signal Voltage), and V_n (Noise Voltage).

5. Measurement Method

5.1. Partial Discharge (PD) Measurement System

Partial discharge measurement system that is used base on IEC 60270 standard. This detection method uses the recommended series of tests.

The main equipment which is used in Fig. 7: Voltage source 220 V, transformer step-up 220V/100kV, limiter resistor 6100 Ω , Coupling Capacitor 100 pF, Divider capacitor 68 nF and Detecting impedance 50 Ω . The discharges occurring in the sample are detected using the detection circuit High Frequency Current Transformer (HFCT), RC detector and Loop Antenna shown in fig. 7.

PD measurement result is given by oscilloscope that connect to Personal computer (PC). The PC is used to record and store test data in the form of images and CSV files. The test data is taken using Freeware software.

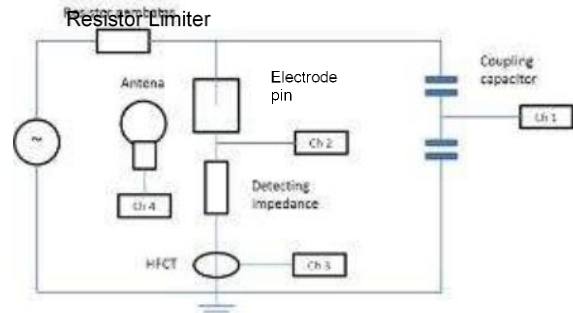


Figure 7. PD Measurement scheme [5]

After the PD data in CSV format has come out, it usually contain noise which cause difficult to make an analyze, the next step was denoising process by wavelet transformation.

5.2. Wavelet Design

This application was created using Graphical User Interface (GUI) Matrix Laboratory software (MATLAB) R2016a [1, 12]. The application which has been made, can reduce noise on the partial discharge signal by using the wavelet transform technique by passing signals on two different filter bands, then performing sub-sampling

operation, then the signal is modified, and the last signal will be reconstructed.

In this program, to different output with one another and make it easy determining better one, it give SNR value before and after signal process. Figure 8 is the overall programming flowchart of this application :

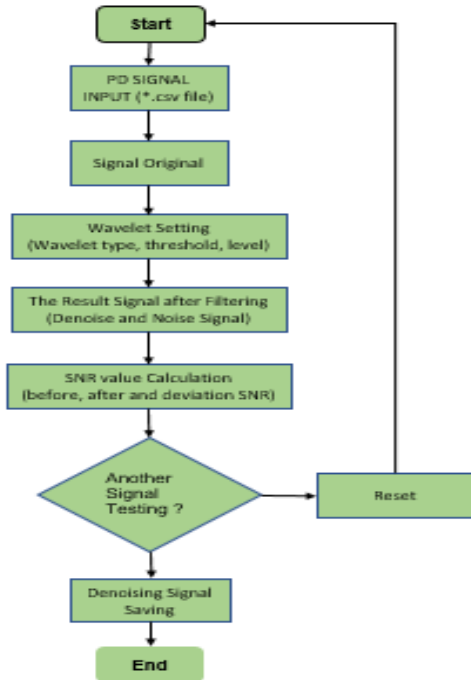


Figure 8. Programming Flowchart

3.3. Process Analysis for Wavelet Design

The first step is scaling. Volt/div is the value for each box on the oscilloscope in the vertical position. For each box on the oscilloscope will be written as many as 25 points in the CSV file. Therefore the y-axis value for each point on the CSV needs to be multiplied by the value of volt/div divided by 25.

The next process is wavelet transformation process of PD signal with threshold parameters. There are 2 types of threshold used, namely soft and hard threshold. Uncorrect election of thresholding will result in less than maximum gain or noise generated.

After the process of selecting the type of threshold, the next process is selecting the type of wavelet process. There are four types of wavelets used in this task, haar, daubhecies, symlet and coiflet. For haar type, daubhecies type (db1,db2,db3,db4,db5,db6,db7,db8,db9,db10), the symlet type (sym2, sym3, sym4, sym5, sym6, sym7, sym8) and coiflet (coif1, coif2, coif3, coif4, coif5).

The fourth process is the selection of wavelet transformation levels consisting of levels 1 through 6. After that we do denoising process. The noise signal itself is the difference between the original signal and signal after the wavelet process. Another important step is calculating the SNR value. It compares SNR before and after the wavelet transformation process.

The final step is storing the result by the *.CSV form. Furthermore, this file can be used for judgment system or SNR evaluation. After analyzing one data, to make it easier to display other data, it can be done reset all values and display from previous data.

4. Result and Discussion

Consisting of application usage procedures, application testing, analysis through SNR values and graphical visualization of PD signals from practice results using a combination of three parameters (threshold, level and wavelet type). Because if it can be done, all combination of three parameters have 144 data, then in this report 144 data will be sampling for graphical visualization. For SNR value, it will be shown all number 144 data.

4.1. Result [13]

The test is done by simulating the combination of three wavelet parameters and comparing them visually and through the SNR value. The three wavelet parameters are: threshold, wavelet type and wavelet level.

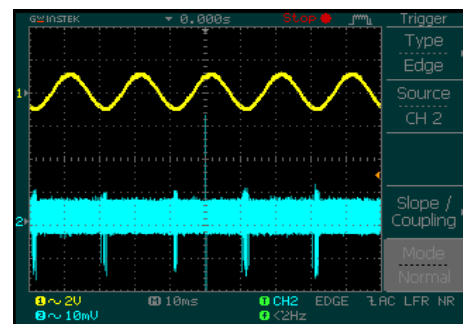


Figure 9. Positive PDIV on HFCT

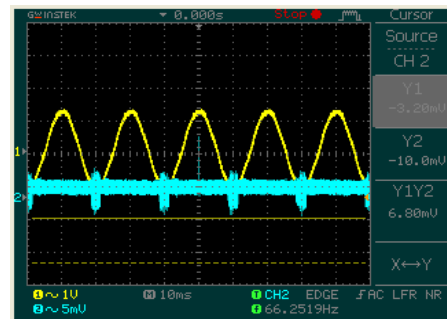


Figure 10. Positive PDIV on RC Detector

As a signal testing material, it will be used a partial discharge test signal by using the High Frequency Current Transformer (HFCT) and RC Detector [13]. The selection of this test signal at the time of partial discharge inception positive voltage (PDIV positive) as shown in Figs. 9 and 10.

The result of simulation test of partial discharge signal can be seen for HFCT processing signal with Hard Threshold, Level 6 and Coif5 wavelet type as shown Fig. 11 below:

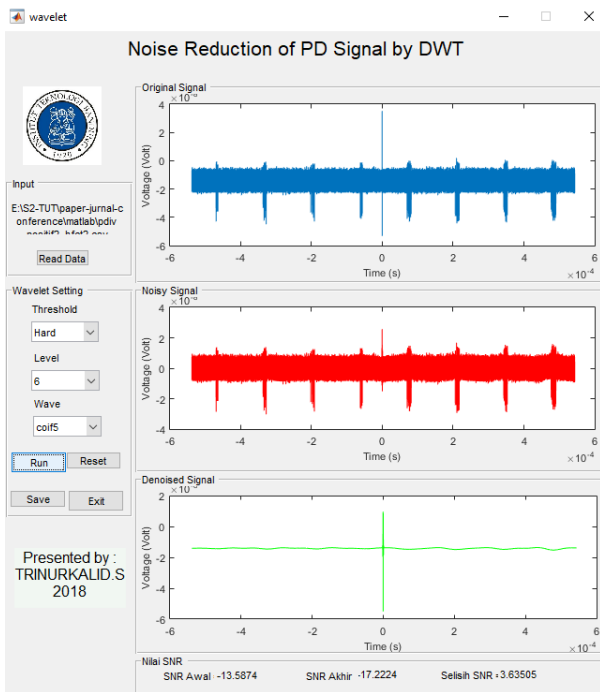


Figure 11. HFCT Denoising Signal Hard Threshold, level 6, coif5 wavelet type

For HFCT processing signal with Soft Threshold, Level 1 and Coif5 wavelet type as shown Fig. 12 below:

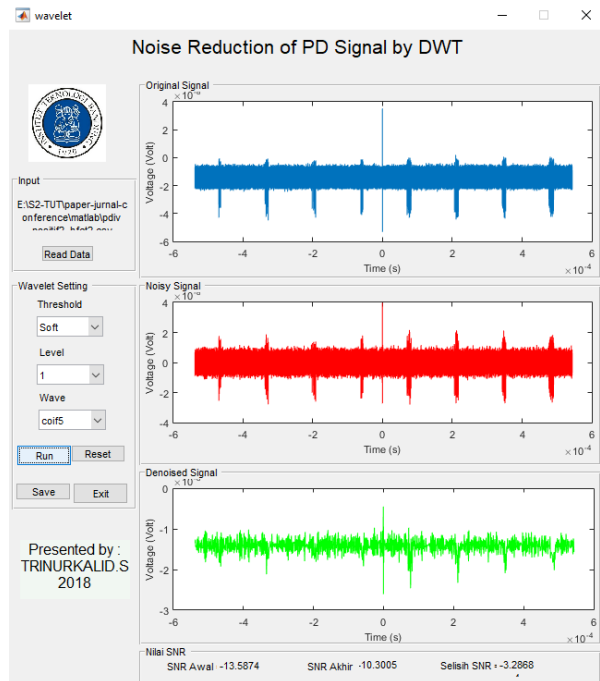


Figure 12. RC Detector Denoising Signal Hard Threshold, level 1, coif5 wavelet type

For HFCT processing signal with Soft Threshold, Level 6 and Coif5 wavelet type as shown Fig. 13 below:

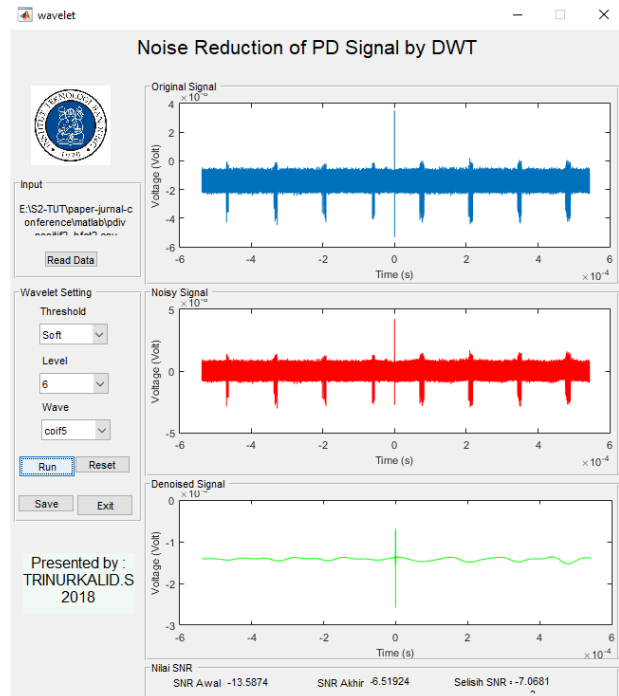


Figure 13. HFCT Denoising Signal Soft Threshold, level 6, coif5 wavelet type

By Fig. 11, we can see original signal, noisy signal and denoised signal with the result of first, last and SNR deviation are -13.5874 dB, -17.2224 dB and 3.63505 dB. For Fig. 12, the result of denoising signal is -13.5874 dB, -10.3005 dB and -3.2868 dB. For Fig. 13, we could see the SNR value before, after and deviation : -13.5874 dB, -6.51924 dB and -7.0681 Db.

For RC detector processing signal with Hard Threshold, Level 6 and Coif5 wavelet type as shown Fig. 14 below:

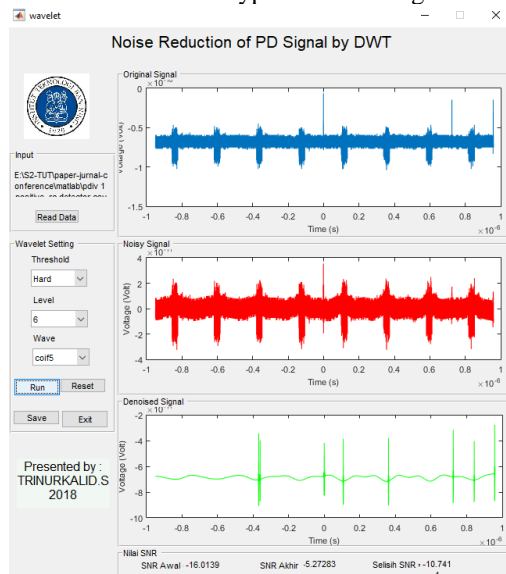


Figure 14. RC Detector Denoising Signal Hard Threshold, level 6, coif5 wavelet type

For RC detector processing signal with Soft Threshold, Level 1 and Coif5 wavelet type as shown Fig. 15 below:

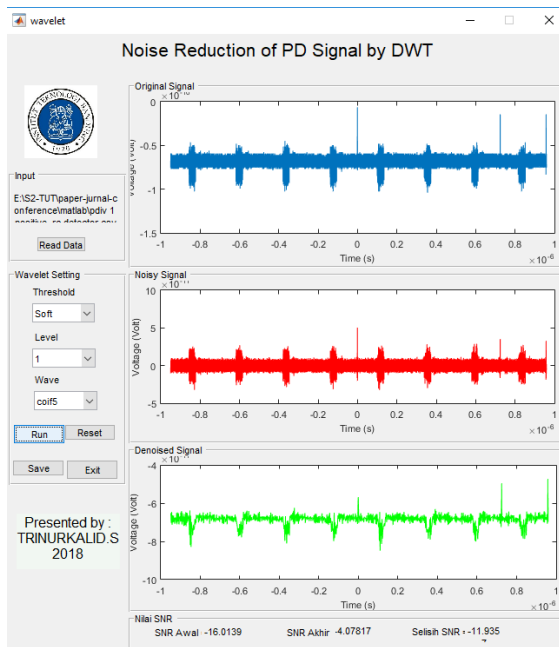


Figure 15. RC Detector Denoising Signal Hard Threshold, level 1, coif5 wavelet type

For RC detector processing signal with Soft Threshold, Level 6 and Coif5 wavelet type as shown Fig. 16 below:

By Fig. 14, like the result of HFCT, SNR in RC detector measurement give SNR as follow: -16.0139 dB, -5.27283 dB and -10.741 dB. If we change the threshold become soft and level become 1, as like Fig. 15, the SNR will be: -16.0139 dB, -4.07817 dB and -11.935 dB.

Same as Fig. 15 but we change level to 6, the SNR become: -16.0139 dB, -19.9331 dB and -35.947 Db as shown in Fig. 16.

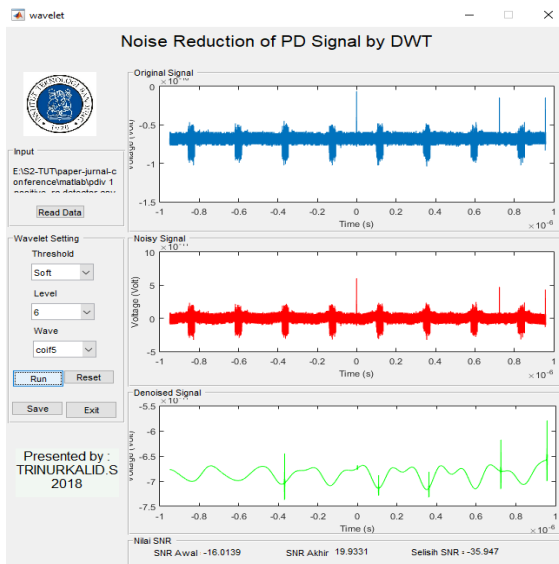


Figure 16. RC Detector Denoising Signal Soft Threshold, level 6, coif5 wavelet type

4.2. Discussion

From Figs. 11-13, the wavelet transformation simulation test result, threshold: hard; level: change; and wavelet type: coiflet5, we can get the following result:

Table 1. Test Result; type:coif5, threshold:hard

Threshold	Level	Wavelet	SNR		
			before	after	Diff
Hard	1	Coif5	-13.587	-14.1579	0.5705
	2			-17.9043	17.9043
	3			-17.698	17.688
	4			-17.601	17.601
	5			-15.5385	15.5385
	6			-15.4951	15.4951

Table 2. Test result; type:coif5, threshold:soft

Threshold	Level	Wavelet	SNR		
			before	after	Diff
Hard	1	Coif5	-13.587	-10.3005	-3.2869
	2			-10.4317	10.4317
	3			-9.13318	9.13318
	4			-8.36113	8.36113
	5			-7.14755	7.14755
	6			-6.51924	6.51924

From the results shown in Tables 1, it can be concluded that in the same wavelet type and threshold, generally, the higher the level of decomposition the better the value will be got. This can be seen from the increasing value of SNR after denoised and the smaller the difference.

Now, if we change the threshold to soft threshold like Figs. 12 and 13, we will see almost the same result like table-1 but in more higher in final result after denoising process. The higher the decomposition level, the higher SNR will be got and the lower difference SNR will produced.

If we compare between Table 1 and 2 with the same level, it implies that the soft threshold give better result than hard threshold because it is cleared from Table 1 and 2, the SNR of soft threshold more higher than hard threshold SNR and also, by comparing the noised signal between Figs. 14 and 16 or Figs. 11 and 13, the amplitude signal of soft threshold more smaller than hard threshold so that soft threshold could eliminate the noise quite well.

Below the tabel summary for all wavelet parameter combination, Table 3 for HFCT and Table 4 for RD detector.

Table 3. HFCT of wavelet parameter combination

Threshold	Level	Wavelet type		Result SNR (dB)	
		Highest	Lowest	Highest	Lowest
Hard	1	coif1	haar	-13.8665	-19.2227
	2	db6	db2	-15.8936	-19.0412
	3	db6	haar	-15.7129	-19.0143
	4	db5	haar	-16.5404	-19.0315
	5	db6	haar	-15.5385	-19.3231
	6	db6	coif1	-15.4951	-19.9518
Soft	1	db8	sym7	-9.89927	-12.8173
	2	coif3	db5	-10.3567	-12.063
	3	db4	db5	-8.82599	-10.5901
	4	db4	db5	-7.58862	-10.0539
	5	db4	db5	-6.54698	-9.3563
	6	db4	db5	-6.51924	-9.49774

Table 4. RC detector of wavelet parameter combination

Threshold	Level	Wavelet type		Result SNR (dB)	
		Highest	Lowest	Highest	Lowest
Hard	1	sym6	db6	-6.20452	-11.6479
	2	sym6	db6	-2.83113	-10.9276
	3	sym6	db6	-2.03524	-10.721
	4	sym6	sym7	-1.31779	-10.6421
	5	sym6	db6	-1.20826	-10.6117
	6	sym6	db6	-1.21057	-10.852
Soft	1	haar	sym3	-0.82448	-6.6141
	2	haar	db2	2.30468	-1.46216
	3	coif4	db2	6.85471	2.11982
	4	sym8	sym2	14.8486	3.23104
	5	sym4	sym2	20.7808	3.7416
	6	sym6	db2	31.8172	1.87374

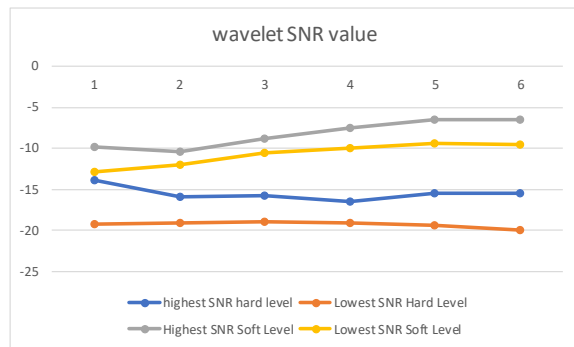


Figure 17. Comparison of HFCT SNR values

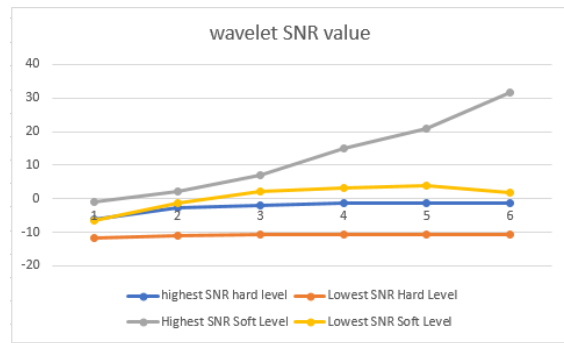


Figure 18. Comparison of RC detector SNR values

By Table 3 and 4, it can be seen that SNR signal increases inline with its level, for soft mode more better than hard mode. The highest SNR value, for table-3, at level 6 with wavelet Daubhecies-4 type, for soft threshold = -6.51924 dB and wavelet Daubhecies-6, for hard threshold = -15.4951 dB and for Table 4, with symlet-6 type for soft threshold = 31.8172 dB and hard threshold = -15.4951 dB This indicates that in soft mode there is more noise reduction than hard.

By Figs. 17 and 18, it can be seen visually that at each increase of wavelet level, more noise will be eliminated. This could be happened, because soft threshold is more sensitive than hard threshold. The soft threshold uses three equations to denoise the partial discharge signal, but the hard threshold only use two equations [4].

5. Conclusion

It is usually not easy to analyze partial discharge signal directly because noise comes from various sources that can reduce the quality of data received, consequently, the result signal which is obtained did not equal to the expectation. By the wavelet system, the noise could be reduced significantly.

In this system soft threshold mode is better than hard threshold mode for reduction noise and the higher level parameter was used in same level, the better signal can be analyzed for next pace. It happened because the soft threshold uses three equations to denoise the partial discharge signal, but the hard threshold only use two equations.

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