CLASSIFICATION OF POWER QUALITY DISTURBANCES USING WAVELET TRANSFORM

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Abstract—**This paper proposed the Discrete Wavelet Transform (DWT) Technique to identify and classify power quality disturbance by using Symlets and Daubechies wavelet family to extract the detail signal of the disturbance for the classification. A few data containing power quality disturbances that were collected before have been analyzed to show the effectiveness of the proposed technique. There are many power system disturbances such as sag, swell, transients and notch that are generated in the power system. The statistical parameters such as mean, standard deviation, max, min, mode, median, magnitude and also the duration of the disturbance are also been found out using MATLAB programming software. The wavelet technique was automated using Guide User Interface (GUI)**

Keywords—**classification, daubechies, discrete wavelet transform (DWT), guide user interfaces (GUI), MATLAB, power quality, symlet, wavelets.**

1.0 INTRODUCTION

Poor power quality may cause many problems for affected loads, such as malfunctions, instabilities, short equipment lifetime, and so on. Poor quality electric power is normally caused by power-line disturbances, such as lightning impulses, voltage swell, interruptions, voltage sag, harmonic distortion, notch and flicker, and this results in failure or disoperation of end-user's equipment. In order to improve power quality, the sources and causes of such disturbances should be identified and localized before appropriate mitigating actions can be taken [1].

The accurate detection and classification of abnormal conditions can help in taking effective countermeasure(s) to maintain acceptable stability and reliability levels of operation [2]. In order to determine the causes and sources of the disturbances, it is not only required to detect and localize those disturbances but also identify and classify their type [3]. Existing methods of analyzing and identifying power disturbances are laborious since they are based on visual inspection of disturbance waveforms. Due to the complexity of power quality problems and the lack of reliable techniques to analyze these problems, power utilities are unable to ensure the required level of power quality without a considerable increase in cost.

An automated system for disturbance recognition and classification will have many advantages over a manual system. These advantages include the speed of processing, amount of data that can be processed, ease of data collection and storage, reliability and cost [4]. Monitoring power quality disturbance is carried out by changing from one time domain to other mathematical domains, which provide more detailed analysis [5]. The application of wavelet transform on a signal produces approximations that can provide detection capabilities. While the details at each level of resolution can provide capabilities of classification and localization of all the frequencies present in the processed signal.

In the paper, the wavelet analysis is briefly introduced first. Then the algorithms of disturbance detection were shown. For the ease of use of the user, the General User Interface (GUI) was created to classify the disturbances. Finally, the results of the investigated disturbances and statistical parameter are presented.

1.1. POWER QUALITY

There can be completely different definitions for power quality, depending on one's frame of references. A utility may define power quality as reliability and show statistic demonstrating that its system is 99.98 percent reliable. A manufacturer of load equipment may define power quality as those characteristics of the power supply that enable the equipment to work properly. Power quality is ultimately a consumer-driven issue, and the end user's point of references takes precedence [6]. Therefore the most using definitions is

"Any power problem manifested in voltage, current, or frequency deviations that result in failure or misoperation of customer equipment [7]"

Power quality type and disturbances need to be understood first before any method of detection and classification can be proposed.

Voltage sag is decrease to between 0.1 and 0.9 pu in rms voltage or current at the power frequency for durations from 0.5 cycle to 1 minutes. The power quality community has used the term sag for many years to describe a short-durations voltage decrease. Voltage sags are usually associated with system faults but can also be caused by energization of heavy loads or starting of large motors.

Voltage swells is defined as an increase to between 1.1 to 1.8 pu in rms voltage or current at the power frequency for durations from 0.5 cycle to 1 minutes. As same as sag, swells are usually associated with system fault conditions but they are not as common as voltage sags.

Notching is a periodic voltage disturbances caused by the normal operation of power electronic devices when current is commutated from one phases to another

The transient is that part of the change in a variable that disappears during transition from one steady state operating condition to another [6].

1.2 Wavelet transform

Wavelet analysis allows the use of long time intervals where precise low-frequency information can be obtained and from shorter regions high-frequency information will be obtained [8]. **Figure 1.2.1** shows the wavelet transform.

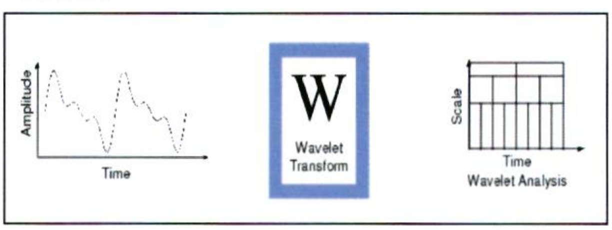


Figure 1.2.1: The Wavelet transform

Wavelet analysis of signals involves the decompositions of the signals into their approximations and details as shown in **Figure 1.2.2.** Notice that by using upsampling and the reconstruction filter, the approximation at a given level can be reconstructed and will form the approximation and detail coefficients of the level below. The signal is denoted as S, and it can be reconstructed from its first-level approximation and detail coefficients [8].

$$S = A_1 + D_1$$

Where,

$S = original\ signal$

$A_1 = approximation\ coefficient\ at\ level1$

$D_1 = detail\ coefficient\ at\ level1$

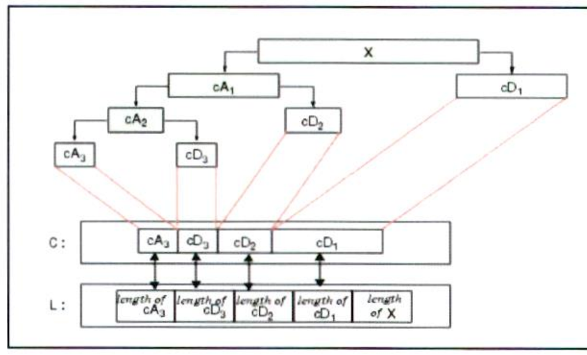


Figure 1.2.2: The decomposition structure

Wavelet analysis deals with expansion of functions in terms of a set of basic functions, like Fourier analysis. However, wavelet analysis expands functions not in terms of trigonometric polynomials but in terms of wavelets, which are generated in the form of translations and dilations of a fixed function called the mother wavelet. Compared with Fourier transform, wavelet can obtain both time and frequency information of signal, while only frequency information can be obtained by Fourier transforms [9]. The Daubechies and Symlet mother wavelet can be seen in the **Figure 1.2.3** and **Figure 1.2.4.**

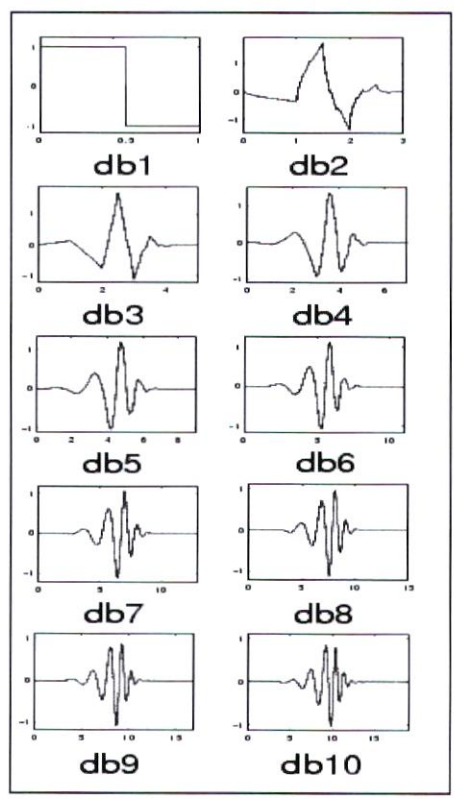


Figure 1.2.3: The Daubechies Family Wavelet

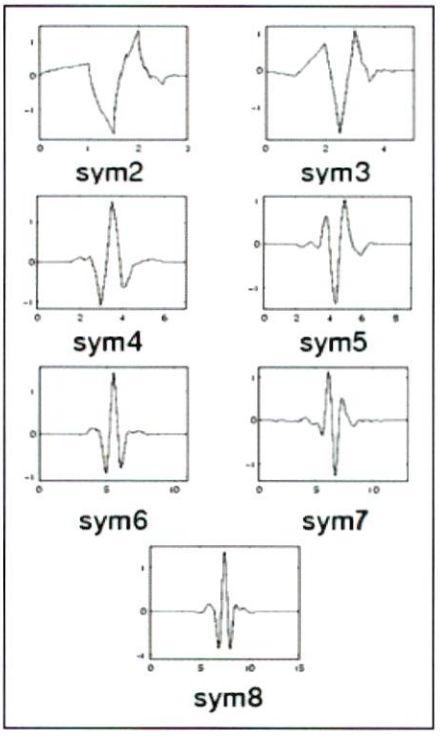


Figure 1.2.3: The Daubechies Family Wavelet

1.3 Discrete Wavelet Transform (DWT)

Discrete Wavelet Transform (DWT) generates a sparse set of values on the time-scale plane [10]. The **Equation 1.3.1** leads shows how the decomposition of discrete wavelet transform happens,

$$x[n] = \sum_{j=1}^{J} \sum_{k \in Z} X^{(j)}[2k+1] g_1^{(j)}[n - 2^j k] + \sum_{k \in Z} X^{(J)}[2k] g_0^{(J)}[n - 2^J k] \quad (1.3.1)$$

Where,

$$X^{(j)}[2k+1] = \langle h_1^{(j)}[2^j k - l], x[l] \rangle, \qquad j = 1, \dots, J,$$
$$X^{(J)}[2k] = \langle h_0^{(J)}[2^J k - l], x[l] \rangle,$$

In equation6 the sequences $g_1^{(j)}[n]$ is the time-domain version of equation4, while $g_0^{(J)}[n]$ is the time-domain version of equation3 and $h_i^{(j)}[n] = g_i^{(j)}[-n]$. Because any input sequence can be decomposed as in equation6, the family of function $\{g_1^{j}[2^j k - n], g_0^{J}[2^J k - n]\}$, $j = 1, \dots, J$, and $k, n \in Z$, is an Orthonormal basis for $l_2(Z)$. Note that special sampling is used in the discrete-time wavelet series. Each subsequent channel is down sampled by 2 with respect to the previous one and has a bandwidth that is reduced by 2 as well. This is called dyadic sampling grid [11].

In wavelet analysis, we often speak about the *approximations* and *details*. The approximations are the high-scale, low-frequency components of the signal. The details are the low-scale, high-frequency components. The filtering process, at its most basic level, looks like in the **Figure 1.3.1** below where S is the original signal, A is the approximation signal and D is the detail signal [8].

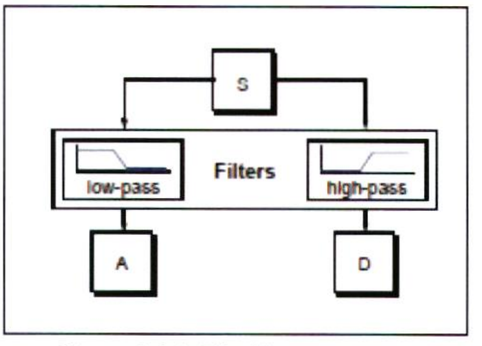


Figure 1.3.1: The filtering process

1.4 Guide User Interface (GUI)

A graphical user interface (GUI) is a graphical display that contains devices, or components, that enable a user to perform interactive tasks. There are many GUI components such as menus, toolbars, push buttons, radio buttons, list boxes, and sliders. In MATLAB® software, a GUI can also display data in tabular form or as plots, and can group related components [8]. The **Figure 1.4.1** below illustrates a simple GUI.

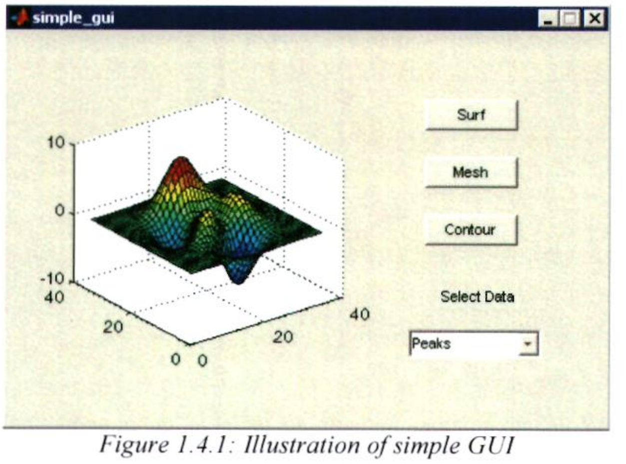


Figure 1.4.1: Illustration of simple GUI

2.0 METHODOLOGY

In this paper there are two methods used to classify the disturbances. First, using the wavelet and second implemented it in the GUI to automate the system.

2.1 WAVELT TRANSFORM

In this paper Discrete Wavelet Transform (DWT) was used to extract the detail and the approximation signal of the disturbances. The multilevel of decomposition technique at level 3 was used. In these paper two kinds of wavelet family was used to extract the detail because as mention before the detail signal will give the coefficient that can be used for classification. First, the Symlet wavelet (sym3) was used to extract the detail and approximation signal of the disturbances as shown in **Figure 2.1.1** below.

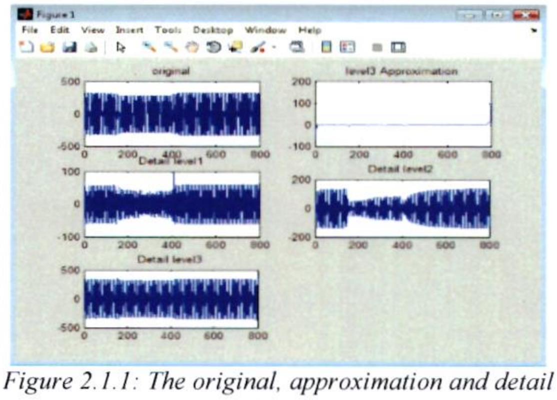


Figure 2.1.1: The original, approximation and detail signal

Then, the detail from level 1 (D1) was chosen because the signal is more suitable. After that the signal will be absolute to make the classification easier. The signal can be seen in **Figure 2.1.2** below.

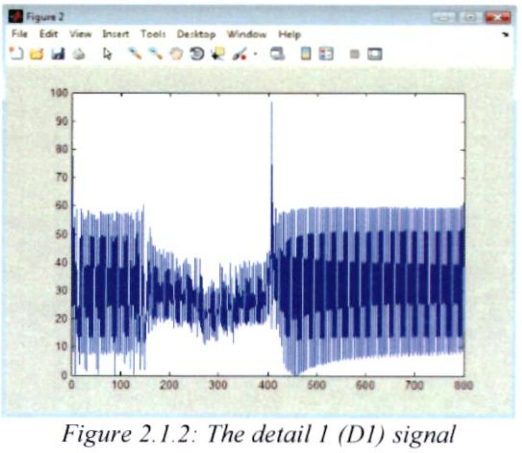


Figure 2.1.2: The detail 1 (D1) signal

From the **Figure 2.1.2** seen that the signal are still not simplified enough to do the classification. Thus another multilevel of decomposition was made. This time, the Daubechies wavelet (db3) was used to extract the detail from the P (the D1 signal as shown in the appendix) and the detail signal that has been extracted as shown in **Figure 2.1.3** below.

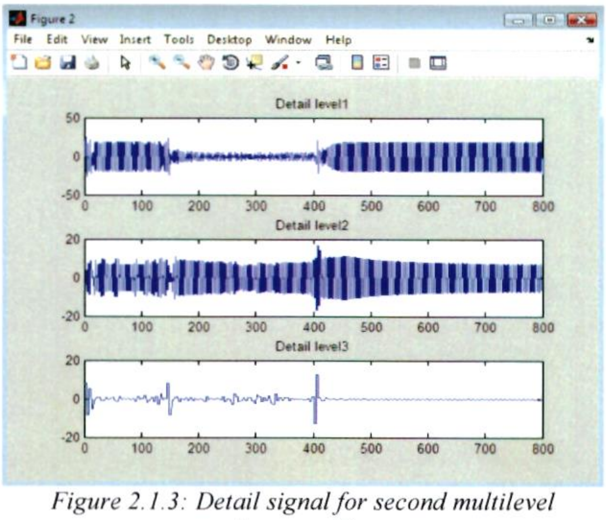


Figure 2.1.3: Detail signal for second multilevel decomposition

The detail signals at level 1 (D1) will be used because it is more suitable. Then the signal will be absolute again and the result obtained was shown in the **Figure 2.1.4** below.

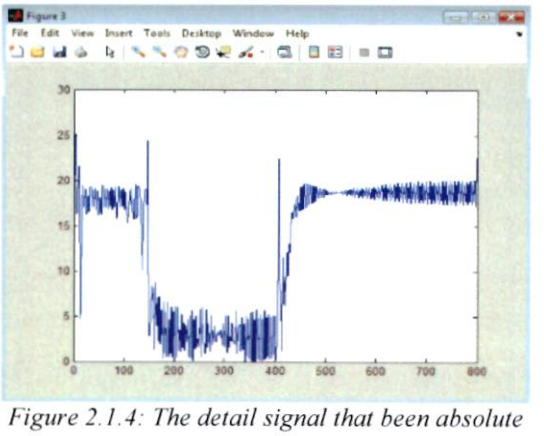
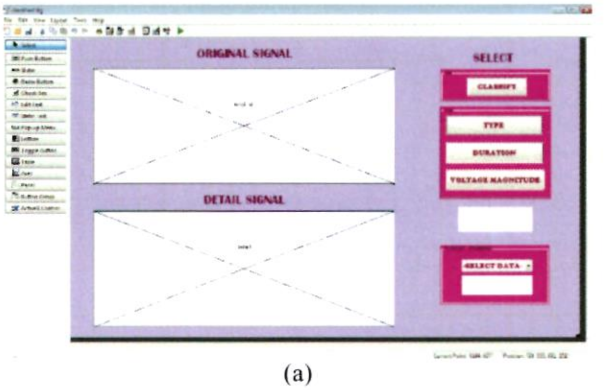


Figure 2.1.4: The detail signal that been absolute

After that, from the graph obtained the calculation will be made using the data from the graph that had been plotted. For the voltage sag disturbances, the calculation was done using the criteria that is the voltage drop within 0.1 to 0.9 per unit. While for the voltage swell disturbances, the calculation done was using the increase of voltage within 1.1 to 1.8 per unit. The notch disturbance was calculated using the criteria that it is occurs only in the short duration that is less than 0.5 cycles. The transient disturbances have the same criteria accept that it occurs in more short duration compare to notch.

2.2 GUIDE USER INTERFACE (GUI)

Firstly, the layout of the system was designed in the GUIDE. The layout was designed so that it is suitable with the system that will be operated as automated classification system. The basic layout of the system is shown in the **Figure 2.2.1(a)** below. Then the property of the layout that has been designed can be changed by using the property inspector as shown in **Figure 2.2.1(b)** below. The properties that can be changed are the background colour, type of Font, the colour of the word and the tag name of the layout. Then the layout will be saved and an M-file will be created. Then the wavelet programming that had been developed before was implemented in the GUI. After that, the required command was created so that every element in the GUI system will be linking.



(a)

(b)

Figure 2.2.1: (a) The layout of the system in GUIDE (b) The Property Inspector

Below is the flowchart of the wavelet transform that shows in **Figure 2.2.2(a)** and the **Figure 2.2.2(b)** shows the flowchart of automated system implemented using GUI.

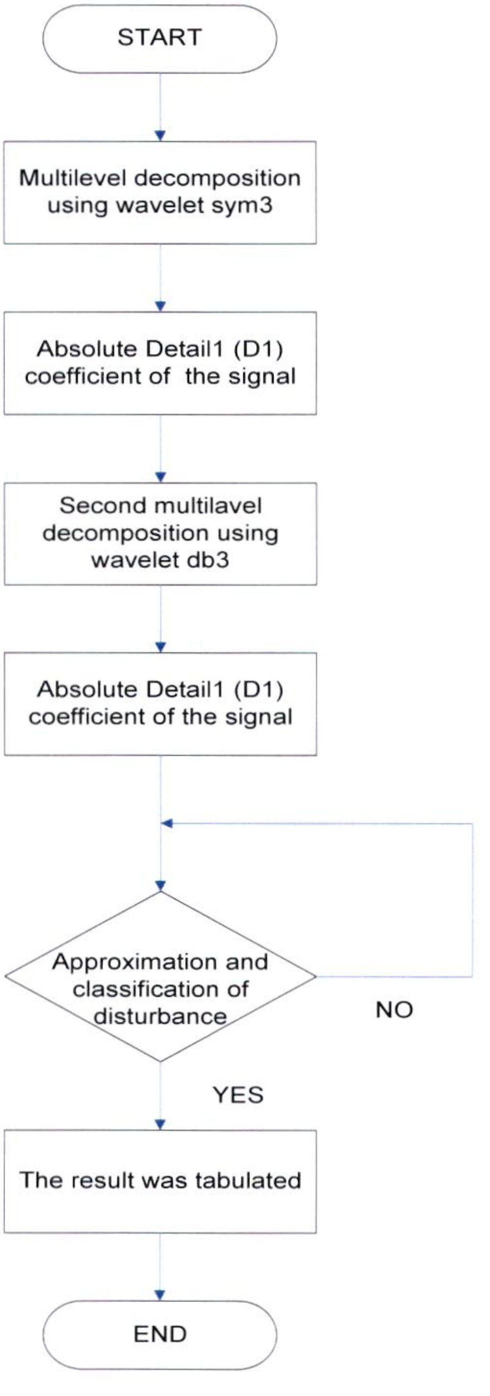


Figure 2.2.2(a): Flowchart of the wavelet program

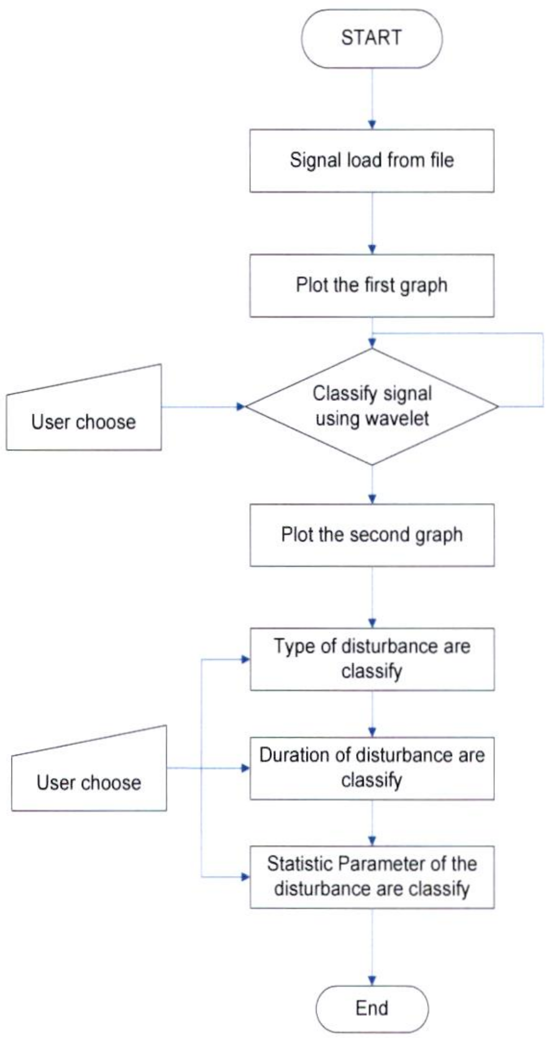


Figure 2.2.2(b): Flowchart of the Automated program GUI

3.0 RESULTS AND DISCUSSION

In this section the results and discussion were shown and discussed. The results obtained were tabulated in the **Table 3.1** below. The results were obtained from the automated system, where the wavelet transforms programming have been implemented in it as shown in **Figure 3.1** below. The automated system can enable the user to choose the type, duration, voltage magnitude and statistical data of the disturbances that has been analyze using the system. The user can choose many different type of statistical data such as the minimum, maximum, median, mode, mean and also the standard deviation of the disturbances signal that have been plotted in the automated system.

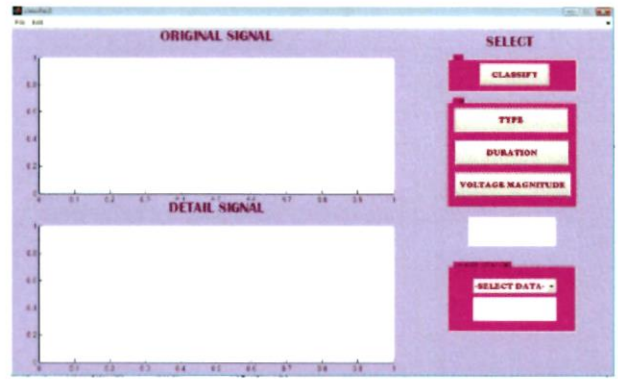


Figure 3.1: The automated system

By considering the **Figure 7.1** above, first the user can choose the file that contains the data that want to be analyzing by clicking at the *File* menu. Then, the data were plotted at the original axis as the *Original Signal*. After that the user clicked the *classify* button. This button triggered the wavelet command in which it analyze the original signal and the result of the analyzing were plotted in the detail axes as *Detail Signal*.

Then, when the user clicked the *type* button, the system classified the type of disturbance and it would be shown in the massage box below the *2nd* box. The system would only display the type of disturbance whether it is voltage sag, voltage swell, notch or transient and if the system could not identify the type of the disturbance it would be displayed as undefined.

When the user clicked the *duration* and *voltage magnitude* button, the result will be displayed at the same message box as the type of disturbance. When the user clicked to choose the statistical data from *choose statistic* box, the statistical data would be shown in the message box below the popup menu in the *choose statistic* box.

The automated system has been tested with the data that has been collected before. The result of the automated program has been tabulated and it can be seen in the **Table 3.1** below

Table 3.1: The result of the proposed technique

	Sag	Swell	Notch	Transient	Undefined
Sag 1	√				
Sag 2					√
Sag 3					√

	Sag	Swell	Notch	Transient	Undefined
Sag 4	√				
Sag 5	√				
Sag 6					√
Sag 7	√				
Sag 8					√
Sag 9					√
Sag10	√				
Sag11	√				
Sag12					√
Sag13	√				
Sag14	√				
Sag15	√				
Sag16	√				
Sag17	√				
Sag18					√
Sag19	√				
Sag20	√				
Swell 1		√			
Swell 2		√			
Notch 1					√
Notch 2					√
Notch 3					√
Notch 4			√		
Notch 5			√		
Notch 6			√		
Notch 7			√		
Notch 8			√		
Notch 9			√		
Notch 10			√		
Notch 11			√		
Notch 12			√		
Notch 13			√		
Notch 14			√		
Notch 15			√		
Notch 16			√		
Notch 17			√		
Notch 18			√		
Notch 19			√		
Trans -ient1				√	
Trans -ient2				√	

4.0 CONCLUSION

The proposed technique in these paper are the good tool for classification that are by using the wavelet technique that are automated using GUI made the recognition and classification of the disturbances gain more advantages such as the speed of processing, amount of data that can be processed, ease of data collection and storage and reliability.

5.0 FUTURE DEVELOPEMENT

Further development of this project will lead to identify more power quality disturbances. In the future, a research should be conducted for the improvement of these classifying the disturbances technique by implementing other technique such as Support Vector machine (SVM) or Fuzzy Logic and automated it to earn ease of use.

6.0 AKNOWLEDGEMENT

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7.0. References

[1] Nguyen Huu Phuc, Truong Quoc Khanh, and Nguyen Nhan Bon, "*Discrete wavelets transform technique application in identification of power quality disturbances*," unpublished. Available: http://gralib.hcmuns.edu.vn/gsdl/collect/hnkhbk/index/assoc/HASHef08.dir/doc.pdf.

[2] S. A. Saleh and M. A. Rahman, "*Innovative power system transient disturbances detection and classification using wavelet analysis*," presented at *3rd International Conference on Electrical & Computer Engineering (ICECE) 2004*, Dhaka, 28-30 December 2004.

[3] Malabika Basu and Biswajit Basu. (March, 2009). "*Application of wavelet transform for power quality (pq) disturbance analysis*". Available: http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=01348930

[4] M. Negnevitsky, K. Debnath, J. Huang, and M. Ringrose "*Studies of power quality: disturbance recognition*," unpublished. Available at: http://www.itee.uq.edu.au/~aupec/aupec99/negnevitsky299.pdf.

[5] A.K. Chandel, G. Guleria, and R. Chandel, "*Classification of power quality problems using wavelet based artificial neural network*," presented at *Transmission and Distribution Conference and Exposition, 2008. T&D. IEEE/PES*, Chicago, IL, 21-24 April 2008.

[6] Roger C Dugan, Surya Santoso, Mark F. McGranaghan and H. Wayne Beaty, "*Electrical Power Systems Quality*," Mc Graw-Hill, 2004, United States of America

[7] Noraliza Hamzah, Wan Nor Ainin Wan Abdullah and Pauziah Mohd Arsad, "*Classification and Identification of Power System Distribution using MATLAB in Power Quality Analysis*," February, 2003.

[8] "MATLAB Wavelet toolbox," Mathworks Inc™

[9] Chirtopher J. Melhorn Sr., Arindam Maitra, Wes Sunderman, Marek Waclawiak, Ashok Sundaram, "*Distribution System Power Quality Asessment Phase II: Voltage Sag and Interruption Analysis*," presented at *Petroleum and Chemical Industry Conferences*, 2005. Industry Application Society 52nd Annual, 12-14 Sept. 2005.

[10] Jaideva C. Goswami and Andrew K. Chan, "*Fundamental of Wavelet: Theory, Algorithms and Application*," Wiley-Interscience, 1999, United States of America

[11] MATLAB Central. Available at: http://www.mathworks.com/matlabcentral/fileexchange/?term=wavelet+gui

[14] Martin Vetterli and Jelena Kovacevic, "*Wavelets and Subband Coding*," Prentice Hall PTR