LIST OF SYMBOLS AND ABBREVIATIONS

ANN - Artificial Neural Network
ATP - Alternative Transient Program
CBEMA - Computer Business Equipment Manufacturers Association
CR - Compression Ratio
CWT - Continuous Wavelet Transform
DWT - Discrete Wavelet Transform
ER - Energy Ratio
ETP - Electromagnetic Transients Program
FFT - Fast Fourier Transform
FIR - Finite Impulse Response
HD-PLC - High Definition Power Line Communication
ITIC - Information Technology Industry Council
MRA - Multi Resolution Analysis
MSE - Mean Square Error
OFDM - Orthogonal Frequency-Division Multiplexing
PNN - Probabilistic Neural Network
PSNR - Peak Signal to Noise Ratio
RPM - Reliable Power Meter
SLGF - Single Line-To-Ground Fault
STFT - Short Time Fourier transform
f - Bandwidth of the signal at every level OF decomposition
$g[n]$ - Highpass filter impulse response
$h[n]$ - Lowpass filter impulse response
$\phi(t)$ - Scaling Function
ψ (t) - Wavelet Function

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Introduction

It is very clear that electric power quality is an important issue in power systems nowadays that demand for clean power has been increasing. This phenomenon is due to the increased use of microelectronic processors in various types of system. Most of these systems quite susceptible to disturbances in voltage supply. Electric utilities control the voltage levels and quality but unable to control current. Thus the utilities should control and maintain the bus voltage quality all the times to get clean power. This limitation leads to the consideration that power quality equal to voltage quality. In order to investigate the voltage quality, we can analyze the voltage sags and swells that occur in the system. The very essential step before analyzing any power quality disturbances is detection. Accurate detection of undesired transient disturbances is very important to provide better service.

1.2 Project objective

The main objective of this study is to figure out the most suitable mother wavelet to be exercised in detection of the power quality disturbances occurred at 22kv transmission line in Skudai, Johor Bahru. It is important in order to develop the best power disturbance detection system for the transmission line.

1.3 Problem statement

The field of study in this research is related mainly to power quality disturbances issues. Since it is unable to avoid, something must be done to provide better power quality service. In order to do that, the power supplied to the system must be analyzed based on the types of disturbances occurred in the system. Before the analyzing process, the very important process is power disturbances detection.

As mentioned earlier, power quality is equal to voltage quality. So it is reasonable to conduct an analysis on the voltage deviations such as voltage sags and swells in the electrical system. It is well known that the main power quality disturbances are due to the widely used of electric and electronics equipments and it is a growing amount nowadays. So, before poor power quality supplied to the loads, the power quality from the distribution line must be monitored. That is why 22kv transmission line is chosen as the raw data to be detected.

Wavelet transform is a powerful tool in signal processing over Fourier transform. Since discrete analysis ensures space-saving coding and is sufficient for exact reconstruction, DWT is employed to detect power quality disturbances. There are many mother wavelets can be used. Since the study involves actual data from 22kv transmission line in Skudai, Johor Bahru , the best mother wavelet must be found out to develop the best power disturbance detection system for the transmission line.

1.4 Project scopes

This study is focusing on detection of voltage sags and swells which occurred at 22kv transmission line based in Skudai, Johor Bahru . The raw data will be processed by using Reliable Power Meter (RPM) equipments to extract the interrupted signal which later to be decomposed using four mother wavelets of DWT in MATLAB. Haar, Dmey, Daubechies and Symlet are the selected mother wavelets. Comparison of the performance or the capability of the mother wavelets to detect the time location of the event accurately will be made to find out the best mother wavelet.

1.4.1 Voltage sag

As defined by IEEE Standard 1159-1995, IEEE Recommended Practice for Monitoring Electric Power Quality, voltage sag is a reduction in rms voltage on ac power system at the power frequency to between 0.1 and 0.9 pu for a short period of time between half cycle and one minute. It is the most common disturbance and very important aspect of power quality. It is really hard to predict because it occurs randomly depend on the source of the system faults.

1.4.2 Voltage swell

A swell is an increase in rms voltage or current at the power frequency to between 1.1 and 1.8 pu for durations from half cycle and one minute as defined by IEEE Standard 1159-1995, IEEE Recommended Practice for Monitoring Electric Power Quality. Swell is commonly caused by system fault conditions, switching off a large load or energizing a large capacitor bank. A swell can occur during a single line-to-ground fault (SLGF) with a temporary voltage rise on the normal phases. It is not as common as voltage sag and is characterized also by both the magnitude and duration.

1.4.3 Mother wavelet functions

Haar wavelet is the first known and simplest wavelet. It is discontinuous, and resembles a step function. It represents the same wavelet as Daubechies, Db1. It has asymmetric, orthogonal, biorthogonal properties of decomposition. Dmey wavelet is a Finite Impulse Response (FIR) based approximation of the Meyer wavelet. It allows fast wavelet coefficients calculation using Discrete Wavelet Transform (DWT). It has symmetric, orthogonal and biorthogonal properties. Daubechies wavelets have no explicit expression except for Db1, which is the Haar wavelet. It has asymmetric, orthogonal and biorthogonal properties of decomposition. Daubechies proposes modifications of the wavelets that increase their symmetry while retaining great simplicity. Daubechies is a big family wavelet. There are a lot of members in the family. Yet, this paper presents only three members of the family namely Db2, Db3 and Db4. The Symlets are nearly symmetrical wavelets proposed by Daubechies as modifications to the Db family. The properties of the two wavelet families are similar but it is more symmetrical compared to Daubechies. For Symlets, this paper presents three members of the family; Sym2, Sym3 and Sym 4.

1.5 Literature review

Gonzalez and Moreno from University of Cordoba chose Haar and Daubechies 4 as mother wavelets to do the detection and localization of disturbances in the voltage waveform. By using MATLAB, they developed the most common types of disturbances in power quality. Such as frequency variations, slow and fast voltage variations, flicker, sags, swells and harmonics. Then they applied only the first level of decomposition for both wavelets to detect the disturbances. Finally they found that Daubechies 4 is better than Haar in order to determine the time in which the disturbance appears and disappears because there are two maxims of the coefficients in such times.

While, Harish Kashyap and Jayachandra Shenoy from India proposed automation of power system fault identification using information conveyed by the wavelet analysis of power system transients. The work focused on identification of simple power system faults. Different types of faults were simulated using Electromagnetic Transient Analysis in Mipower package. Different types of faults were created and the transients were recorded for analysis using Meyer wavelet until the 4th level. They obtained that the application of wavelet transform to determine the type of fault and its automation incorporating Probabilistic Neural Network (PNN) could achieve an accuracy of 100% for all type of faults.

In June 2010, Anoop, Gunasekar, Bensiker and Uma proposed a novel technique for detecting and characterizing disturbances of voltage swell in power systems based on wavelet transforms. This proposed scheme is implemented using MATLAB, Simulink, DSP and Wavelet toolboxes. Simulated source signal with noise was first de-noised and then wavelet transform is applied using Daubechies 4. The signal was decomposed until level 4 that voltage disturbance is detected and its duration is determined. The combination of an adaptive prediction filter based sub-band decomposition structure with a rule based histogram analysis block produce successful detection and classification results.

In the year of 2009, Sudipta, Arindam and Abhijit presented a method that characterizes power quality disturbances. The discrete wavelet transform has been used to detect and analyze power quality disturbances. The disturbances of interest include sag, swell, outage and transient. A power system network has been simulated by Electromagnetic Transients Program. Voltage waveforms at strategic points have been obtained for analysis, which includes different power quality disturbances. Then level 4 of Daubechies 4 mother wavelet has been chosen to perform feature extraction.

From University of Firat, Turkey, Ekici and Yildrim presented a wavelet transform (WT) and artificial neural network (ANN) based algorithm for estimating fault location on transmission lines. Fault simulation of 380 kV transmission line was carried out in Alternative Transient Program (ATP). The DWT was used for data preprocessing and later used for training and testing ANN. Five types of mother wavelets, Daubechies (db5), Biorthogonal (bior5.5), Coiflets (coif5), Symlets (sym5) and Reverse Biorthogonal (rbio5.5) have been considered for signal processing to identify a suitable wavelet family that is more appropriate for use in estimating fault location. They found that better results can be produced using level 3 of Daubechies 'db5' wavelet. The use of ANN as a pattern classifier to simulate a fault locator has been also investigated and very satisfactory.

Sharmeela, Mohan, Uma and Baskaran from University of Anna, Chennai proposed a method to detect and classify power quality disturbances using wavelets. The proposed algorithm uses different wavelets and 8th level of decomposition each for a particular class of disturbance. They are DMeyer, Daubechies, Sym5, Coif, Bior and Haar wavelets. A qualitative comparison of results shows the advantages and drawbacks of each wavelet when applied to the detection of the disturbances. Can be concluded that, Db3 detects transients, Db10 and Sym8 detects voltage flicker, Dmey detects harmonics and Db4 detects voltage Sag/Swell accurately. This method is tested for a large class of test conditions simulated in MATLAB.

From the literatures review explained above, decided that Haar, Dmey, Daubechies and Symlet will be exercised as mother wavelets in this study. For the level of decomposition, seems like level 4 was the most common level used. Yet, to see slightly more details, this paper presents until level 5 of decomposition. Plus most of the works were implemented using simulated source signal of disturbance events. Therefore, an actual sample data recorded from 22kv transmission line in Skudai, Johor Bahru will be used in this study.

1.6 Structure of the thesis

This thesis consists of six chapters overall. As explained above, Chapter 1 describes the surface of this project. There are a few lines of introduction about power quality studies for the beginning. Then, continued with statements of project objective and the problem statement. The project scope in this first chapter explained some terms that going to be used in this entire project. Literature review also discussed in Chapter 1 as it is one of the important element in this paper.

Chapter 2 will tell us about the detail of power disturbances involve in this paper which are voltage sag and voltage swell. It also consists of IEEE standard for power disturbance as a reference. Since this project involve of power disturbance detection, there is a need to review the approaches that are being used before and today. The detail of the implementation of DWT and the multi resolution analysis (MRA) decomposition process will be explained in Chapter 3. This includes the mathematics equations of DWT and MRA. For more details, the flow chart of MRA decomposition process for every label also describe in this third chapter. For Chapter 4, all the mother wavelets exercised in this paper will be comprehensively explained. As mentioned before the mother wavelets are Haar, Dmey, Daubechies and Symlet. The explanation is involved of mathematic equations, properties and the corresponding diagram of the mother wavelets.Chapter 5 describes about the methodology implemented in this project. Starting from the method used to extract data from RPM. Then, continued with the MATLAB process. The MATLAB process is including plotting the interrupted signals, wavelet toolboxes for analysis and the time location detection.

After all the methodologies explained in Chapter 5, then all the results will be recorded and discussed in Chapter 6. This chapter shows the results of the time location detection for every mother wavelet. The difference of the time location between the decomposed signal peaks and the original event signal peaks is calculated and recorded in this chapter too. Then the accuracy for each mother wavelet in detection of voltage sag and voltage swell will be calculated and recorded here.

Lastly Chapter 7 will conclude the result according the project objective that mentioned before. Besides that this chapter discusses the results by comparing them with the previous research work mentioned in the literatures in Chapter 1.

CHAPTER 2

POWER QUALITY DISTURBANCES

2.1 Introduction

Power quality can be defined as the limits of electrical properties that allows electrical system to be well functioned without any significant loss of performance. Without the proper power in electrical system, it may cause many problems to an electrical device or load such as malfunctions, instabilities, short life time or may not operate at all. The quality of electric power has become an important issue nowadays. Customers, in particular have become less tolerant when it comes to poor power quality service. Poor power quality is normally caused by some disturbances which are well known as power quality disturbances. These disturbances degrade the performance and efficiency of customer loads especially power electronic loads.

Power quality has cause a great concern to electric utilities with the growing use of sensitive and susceptive electronic and computing equipment. There is an increasing number of electric and electronics equipment that has carried out a growing number of disturbances that decreased the power quality.

Power quality deviations are commonly caused by many types of disturbances such as frequency variations, slow and fast voltage variations, flickers, voltage sags, voltage swells, harmonics and transients. The growing use of microprocessors in appliances, office equipment and process controls has outburst awareness of the power quality demands for equipments and the unpredictability of its supply. Poor power quality supply can cause damage to electrical equipments and machinery or even fail to operate. A few seconds of outage or a surge can bring any business down for hours or days. This problem has led to a growing interest in the study of power quality.

The study of power quality is covered from the process of disturbances detection until the analysis of the disturbances. Many methods or techniques are found in order to implement all the process. Namely, wavelet transforms, Fourier transform, S-Transform, Multiresolution Analysis, Fuzzy Logic, Neural Network, Hidden Markov model and many more methods which are build from different mathematic equations or tools.

2.2 Power quality disturbances

Power quality disturbances, problems, or events are terms used to describe voltage or current deviations from its ideal waveform. For most application, a good power quality system supplies pure sinusoidal waveform of electric power with the rated frequency and nominal voltage. Power quality disturbances are the variation of these parameters. These disturbances are bound to occur and can cause failure of loads or equipments. Some may only briefly interfere with the most highly sensitive equipment. Others, due to extensive damage on our electric delivery system, could result in the total loss of power for days. Electronic devices are designed to be operated from a uniform clean sine wave. If the AC wave becomes disturbed or distorted, electronics may send false signals, and this conversion process becomes disoriented, disrupted or even damaged.

There are various kinds of power quality disturbances in an electrical power system. They are classified into categories and summarized in Table 2.1 and Table 2.2

which are originally enshrined in Tables 5.3 and 5.5 from IEEE P1159.1 Guide for Recorder and Data Acquisition Requirements for Characterization of Power Quality Events.

Table 2.1: Short-duration variation category and typical event characteristic defined by the IEEE 1159

Categories		Typical voltage magnitude
Instantaneous	Sag	0.1-0.9 pu
	Swell	1.1-1.8 pu
Momentary	Sag	0.1-0.9 pu
	Swell	1.1-1.4 pu
Temporary	Sag	0.1-0.9 pu
	Swell	1.1-1.2 pu

Table 2.2: Long-duration variation category and typical event characteristic defined by the IEEE 1159

Categories	Typical voltage magnitude
Overvoltage	1.1-1.2 pu
Under voltages	0.8-0.9 pu

Power quality disturbances are categorized because that there are different ways to solve them depending on the particular variation and classifying will also help in implementing the proper approach and analysis.

2. 3 Short-duration voltage variations

Referring to Table 2.1, there are three types of short-duration voltage variations, namely, instantaneous, momentary and temporary, depending on its duration. Short-duration voltage variations are caused by fault conditions, energization of large loads, which require high starting currents or loose connections in power wiring. The fault condition can be close to or remote from the point of interest. These short duration voltage variations can adversely affect equipment, particularly variable speed drives, computers, programmable logic controls, and motor contactors. Normally short duration voltage variations were not a major concern before the wide-spread use of electronic equipment. The increased use of sophisticated electronic equipment has made it necessary for utility customers to take steps to mitigate the affect of any voltage variations.

2.3.1 Voltage Sag

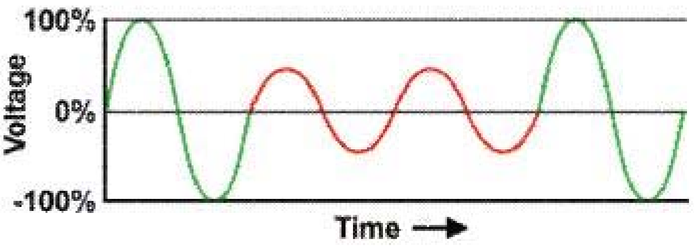

Figure 2.1: Voltage sag signal

Voltage sag as shown in Figure 2.1 is a reduction to between 0.1 and 0.9 pu in root-mean-square (rms) voltage or current at the power frequency for a short period of time from 0.5 cycles to 1 min. Voltage sag durations are subdivided into three categories: instantaneous (0.5 cycle to 30 cycles), momentary (30 cycles to 3 seconds), and temporary (3 seconds to 1 minute). These durations are intended to correlate with typical protective device operation times as well as duration divisions recommended by international technical organizations. Sags are widely recognized as among the most common and important aspects of power quality problems affecting commercial and industrial customers

A lot of research has been done on the monitoring of voltage disturbance. "An industrial monitoring program determined an 87% of voltage disturbances could be associated to voltage sags." (Siew Leng, 2001). This shows that voltage sags are particularly troublesome because they are virtually unnoticeable by observing lighting blinks and they occur randomly and are difficult to predict.

2.3.1.1 Common causes and effect of voltage sags

Voltage sags are generally caused by utility equipment problems, accidental damage, animal contact, weather or tree interference which normally leads to system faults on the transmission or distribution system. For example, a fault on a parallel feeder circuit will result in a voltage drop at the substation bus that affects all of the other feeders until the fault is cleared. The same concept would apply for a fault somewhere on the transmission system. Most of the faults on the utility transmission and distribution system are single-line-to-ground (SLG) faults. Voltage sags are normally associated with system faults on the distribution system, sudden increase in system loads, lightning strikes or starting of large load like induction motors. One of the most common causes of faults occurring on high-voltage transmission systems is a lightning strike.

For less serious cases, most appliances will continue to operate normally, but lights may dim briefly and television pictures may, for a moment, shrink slightly during voltage sag event. While for more severe cases, possible effects of voltage sags would be system shutdown or reduce efficiency and life span of electrical equipment, particularly motors. According to Pinnacle West Capital Corporation (2000),

> When a short circuit occurs on one of the feeders, all customers on the faulted feeder will experience a complete loss of voltage. Customers connected to adjacent feeders may see the voltage sag to 60% of normal voltage.

In addition, Ian K.P. Ross (2006) found that when there is a fault caused by a lightning strike, the voltage can sag to 50 % of the standard range and can last from four to seven cycles. Most loads will be tripped off when encounter this type of voltage level. Therefore, such disturbances are particularly problematic for industry where the malfunction of a device may result in huge financial losses.

2.3.2 Voltage swell

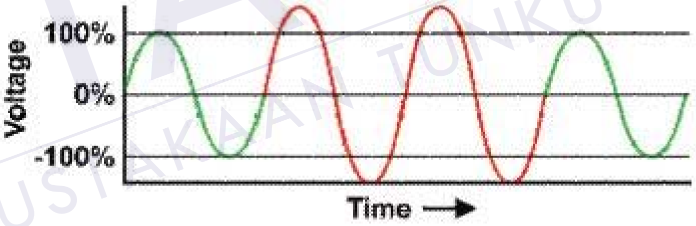

Figure 2.2 Voltage swell signal

Voltage swell as shown in Figure 2.2 is an increase in rms voltage or current at the power frequency to between 1.1 and 1.8 pu for durations from 0.5 cycle to 1 min. Voltage swell durations are also subdivided into three categories: instantaneous (0.5 cycle to 30 cycles), momentary (30 cycles to 3 seconds), and temporary (3 seconds to 1 minute). Voltage swells are usually associated with system fault conditions just like voltage sags but are much less common. Joseph Seymour (2001) agrees that although the effects of a sag are more noticeable, the effects of a voltage swell are often more destructive and potentially be a critical event at a power grid.

2.3.2.1 Common causes and effects of voltage swells

A voltage swell can be due to ungrounded or floating delta systems, where the sudden change in ground reference that result in a voltage rise on the ungrounded phases. In the case of a voltage swell due to a SLGF on the system, the result is a temporary voltage rise on the unfaulted phases, which last for the duration of the fault. Voltage swells are always caused by an abrupt reduction in load on a circuit with a poor or damaged voltage regulator, although they can also be caused by a damaged or loose neutral connection. They can also be caused by the deenergization or switching off a very large load. The abrupt interruption of current can generate a large voltage, per the formula: $V = L\,di/dt$, where L is the inductance of the line and di/dt is the change in current flow. Moreover, energizing a large capacitor bank can also cause a voltage swell.

During a fault condition, the severity of a voltage swell is very much dependent on the system impedance, location of the fault and grounding. The effect of this type of disturbance would be hardware failure in the equipment due to overheating. It may cause breakdown of components on the power supplies of the equipment, though the effect may be a gradual or accumulative effect. Besides that, it can cause control problems and hardware failure in the equipment, due to overheating that could eventually result to shutdown. Also, electronics and other sensitive equipment are prone to damage due to voltage swell.

2.4 Long-duration voltage variations

Long-duration variations can be either overvoltages or undervoltages. They contain rms deviations at power frequencies for a period of time longer than one minute. They are usually not caused by system faults but system switching operations and load variations on the system.

2.4.1 Overvoltage

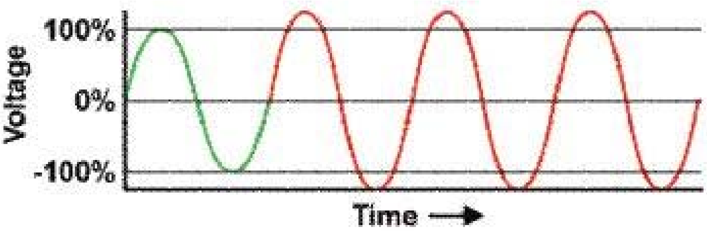

Figure 2.3: Overvoltage signal

Overvoltage is classified as Long-duration voltage variation event, which is defined by the IEEE 1159 as an increase in the rms ac voltage typically to 110% - 120% of nominal power frequency for duration longer than one minute as shown in Figure 2.3 above. Overvoltage transients can be due to excessive correction for voltage drop on the transmission and distribution systems such as energizing several capacitor banks or when switching off a large load. They also often the result when circuit breakers operate, incorrect tap settings on transformers or when lightning hits a feeder. These occur mainly because either the voltage controls are inadequate or the system is too weak for voltage regulation. Possible effect could be hardware failure in the equipment due to overheating.

For electric and electronic devices, overvoltage can lead to problems such as overheating, malfunction, premature failure, shut down and shorter operating life. The devices are designed to operate at a prescribed voltage range (rated voltage) in order to achieve specified levels of efficiency, performance, reliability and safety. The increased voltage will decreases current flow in the device resulting to lower copper losses. Thus, efficiency improves and the operating temperature decreases. The challenge becomes one of determining and maintaining a voltage level that maximizes efficiency for certain devices without adversely affecting the life or operation of other devices.

2.4.2 Undervoltage

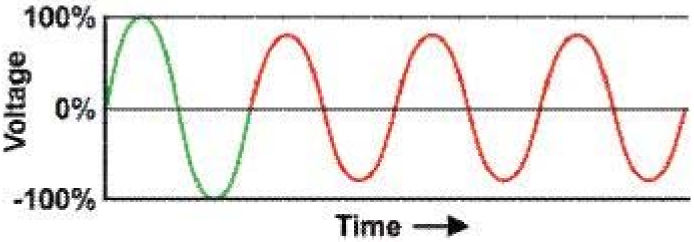

Figure 2.4: Undervoltage signal

Figure 2.4 above shows under voltage signal which is also known as brownout. Undervoltage is described by IEEE 1159 as the decrease in the rms ac voltage, typically to 80% - 90% of nominal power frequency for a period of time greater than 1 minute. Electrical transient voltages can originate inside a facility or out on the utility's grid, and can propagate through various levels of electrical and data systems. Sources of destructive transient voltages can range from the obvious source such as a lightning stroke strike during a thunderstorm, to the subtle one such as static discharge from a human finger.

Generally, undervoltage was results from switching on a large load or group of loads, or switching off a capacitor bank. It also occurred due to low distribution voltage because of heavily loaded circuits that lead to considerable voltage drop. Undervoltage can expose electrical devices to some problems such as overheating, malfunction and premature failure especially for motors-based devices. Common symptoms of undervoltage are including motors run hotter than normal and fail prematurely, dim incandescent lighting and batteries fail to recharge properly. The worst effect of undervoltage event is system shutdown. Most electronic controls are very sensitive as compared to electromechanical devices, which tend to be more tolerant

2.5 Power disturbances detection review

This review is closed up into two main categories, the classical and the modern technique in power disturbances detection. With this review we can see how the techniques developed to make the process easier and more effective based on what are the parameters for concern.

2.5.1 Classical technique

Every power disturbance is originated from particular causes and also the mitigation technique is based on the type of disturbances. In addition, every disturbance has its own deviation pattern and value particularly voltage or current characteristic. The specific ranges of unaccepted deviation for each type of disturbances are enshrined in IEEE 1159 standard.

In 1970s, an organization called Computer Business Equipment Manufacturers Association (CBEMA) developed a method as a guideline to the members in designing their power supplies. The method was named as CBEMA Curve and was originally derived to describe the magnitude and duration of voltage variations on the power system. It also becomes the guideline to the organization to determine a reliable system for their electronic equipment. Eventually, it became a standard design for sensitive equipment to be applied on the power system and a common format for reporting power quality variation data. The CBEMA curve was adapted from IEEE Standard 446 (Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications), whichis typically used in the analysis of power quality monitoring results.

Referring to a CBEMA curve display, on the horizontal axis is representing the time duration of the event, while the vertical axis indicates the percent of voltage applied to the power circuit. The center of the plot is considered as an acceptable area. Meaning, all the deviation voltage values are plotted outside the curve. Values plotted above the curve indicate malfunctions such as insulation failure, over excitation and over voltage trip. On the other hand, voltages below the envelope are assumed to cause the load to drop out due to lack of energy. For example in Figure 2.5, we can see the some signals plotted inside and some are below the curve.

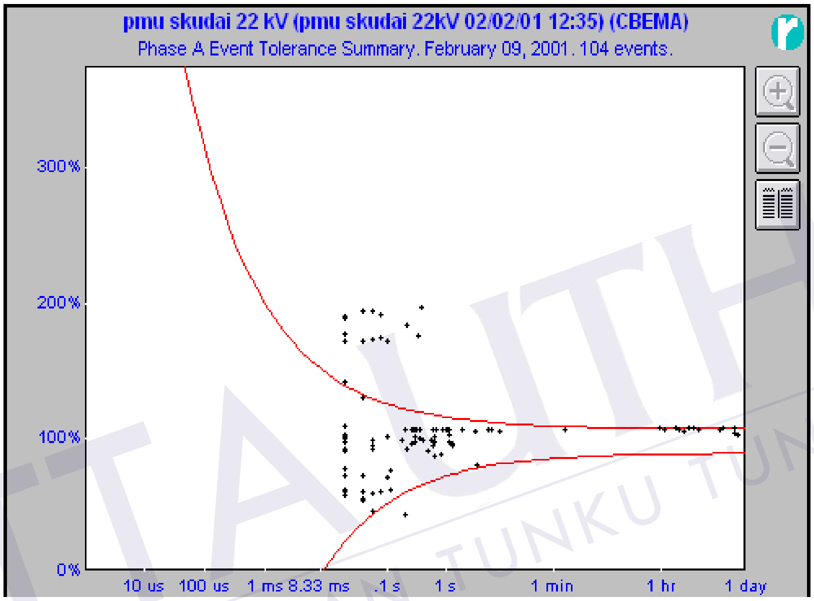

Figure 2.5: CBEMA curve

In using the CBEMA curve, one must first determine the nature of the power quality disturbances that are most prevalent in a facility. Power quality phenomena associated with powering, grounding, and protecting solid-state devices can be measured, analyzed, and evaluated using test equipment specifically intended for digital logic systems. These instruments, when located near the suspected disturbance, or when measuring the unusual operation of the power distribution system, will provide data on voltage variations and fluctuations and the specifics on how the power quality problem places the equipment at risk. The measurements and results can then be analyzed in combination with the CBEMA curve to help understand the nature of power quality disturbances.

However, in 1994, the Information Technology Industry Council, (ITIC) was formed by a working group of the CBEMA. They developed the so called ITIC Curve, which has replaced the CBEMA curve in general usage for single-phase 120 Volt 60 Hz systems. ITIC Curve as shown in Figure 2.6 is a modified version of the CBEMA power acceptability curve, but the concept remains the same. The intent was to derive a curve that can better reflect the performance of typical single-phase, 120 V, 60 Hz computers and their peripherals.

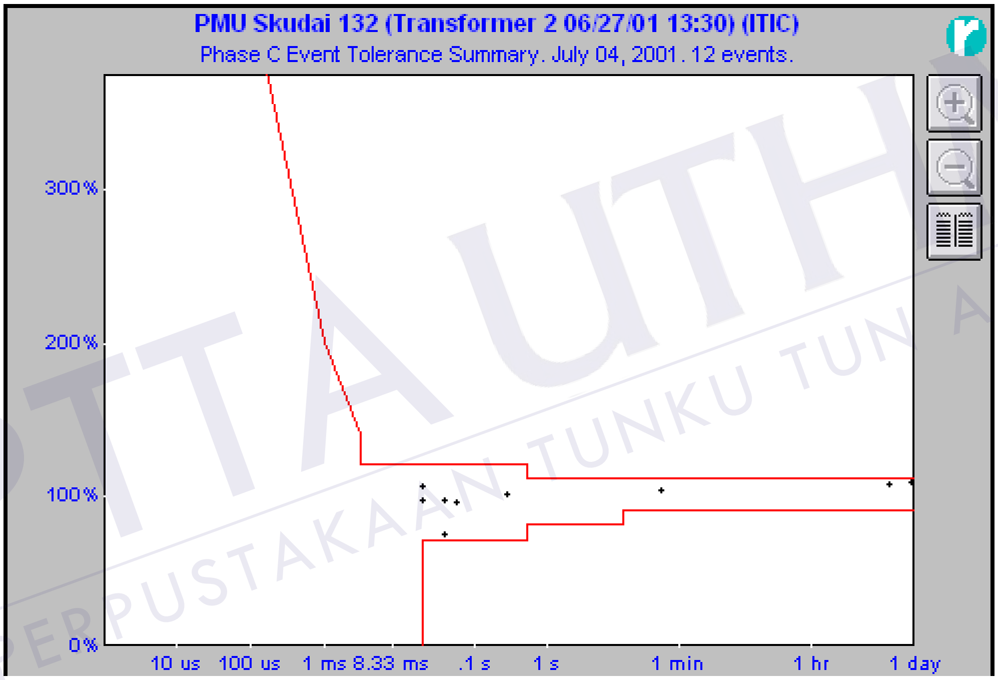

Figure 2.6: ITIC curve

Besides being used in general power quality evaluation, ITIC curve has been applied as a reference to define the withstand capability of various loads and devices for protection from power quality problems. This is because the curve is generally applicable to other equipment containing solid-state devices aside from being specifically applicable to computer-type equipment. However the ITIC curve is not intended to reflect the performance of all electronic-based equipment because there are too many variables to be considered such as power loading, nominal operating voltage level and process complexity. Compared to the old CBEMA curve, the ITIC curve has an expanded acceptable power area. Moreover, the instrumentation to check compliance with the curve appears to be easier to design because of the simplified way the acceptable region is represented.

2.5.2 Modern technique

In this very modern era, computer science technology has been developing rapidly because of its capability in solving problems in many fields of life. This advance technology has made possible to high power signal processing. One of the very important modern techniques is DWT which is widely used in signal processing tools especially to extract the power disturbances signal.

2.5.2.1 Discrete wavelet transform

Wavelet Transform is a mathematical tool, which provides an automatic detection of power quality disturbance. In recent years, wavelet transform is considered to be an efficient tool in digital signal processing. One of the main reasons for this is the easy computation, using the DWT which only requires a number of operations proportional to the size of the initial discrete data. DWT is any wavelet transform which the wavelet is discretely sampled. The DWT moves a time domain discritized signal into its corresponding wavelet domain. Basically, the DWT evaluation has two stages. The first consists on the wavelet coefficients determination. These coefficients represent the given signal in the wavelet domain. From these coefficients, the second stage is achieved with the calculation of both the approximated and the detailed version of the original signal, in different levels of resolutions, in the time domain.

There are several advantages of the wavelet transform. Compared to Fourier series, wavelet series converge uniformly for all continuous functions, while Fourier series do not. They are also adjustable and adaptable. Discrete analysis ensures space-saving coding and is sufficient for exact reconstruction. Many years back, wavelet transform have been developed to solve frequency-dependent problems in many areas. This is because the wavelet transform has many advantages over the traditional Fourier transform. One of the advantages of wavelet transform has over the Fourier transform is its ability to identify the locations containing observed frequency content. It is able to localize the information in the time-frequency plane. Even the Fourier transform can extract pure frequencies from the signal; it cannot indicate the locations of the extracted frequencies.

Power disturbances can be classified as stationary and non-stationary signals. Fourier transform is not suitable for analyzing non-stationary signals. To correct this deficiency, here comes the Short-Time Fourier Transform which was developed to extract time-frequency information. Yet, the disadvantage is that the size for the time-window is fixed for all frequencies. On the contrary, wavelet analysis represents a windowing technique with variable-sized of regions. Plus, there exists the MRA algorithm, which decomposes original signal into several other signals with different level of resolution. Wavelet decomposes and reconstructs functions actively using the MRA. The DWT with the MRA easily converts the function to its coefficients because of the reversibility property. It uses analyzing wavelet functions, which are localized in both time and frequency to detect a small change in the input signals.

CHAPTER 3

DISCRETE WAVELET TRANSFORM AND MULTIRESOLUTION ANALYSIS

3.1 Introduction

Before Continuous Wavelet Transform (CWT) and Discrete Wavelet Transform (DWT) were developed, Fourier Transform approach was widely used to overcome signal processing problems. Many mathematical tools were developed under Fourier Transform approach and the most significant is Short Time Fourier transform (STFT). The CWT was developed as an alternative approach to the STFT to overcome the resolution problem. The wavelet analysis is done in a similar way to the STFT analysis. However, there are two main differences between the STFT and the CWT:

1. The Fourier transforms of the windowed signals are not taken, and therefore single peak will be seen corresponding to a sinusoid where negative frequencies are not computed.

2. The width of the window is changed as the transform is computed for every single spectral component, which is probably the most significant characteristic of the wavelet transform.

CWT is used to divide a continuous-time function into wavelets. Unlike Fourier transform, the CWT possesses the ability to construct a time-frequency representation of a signal that offers very good time and frequency localization. Although the discretized continuous wavelet transform enables the computation of the continuous wavelet transform by computers, it is not a true discrete transform. In addition, CWT provides highly redundant information as far as the reconstruction of the signal is concerned. This redundancy, on the other hand, requires a significant amount of computation time and resources.

On the other hand, DWT provides sufficient information both for analysis and synthesis of the original signal, with a significant reduction in the computation time. The DWT is considerably easier to implement when compared to the CWT. Generally, an approximation to DWT is used for data compression if signal is already sampled, and the CWT for signal analysis. Thus, DWT approximation is commonly used in engineering and computer science, and the CWT in scientific research.

3.2 The discrete wavelet transform

In the year of 1976, DWT was found when Croiser, Esteban, and Galand devised a technique to decompose discrete time signals. Crochiere, Weber, and Flanagan did a similar work on coding of speech signals in the same year. They named their analysis scheme as subband coding. In 1983, Burt defined a technique very similar to subband coding and named it pyramidal coding which is also known as multiresolution analysis (MRA).

Although the DWT is merely one more tool added to the toolbox of digital signal processing, it is a very important concept for data compression. A wavelet, in the sense of the DWT is an orthogonal function which can be applied to a finite group of data. Functionally, it is very much like the Discrete Fourier Transform, in that the transforming function is orthogonal, a signal passed twice through the transformation is unchanged, and the input signal is assumed to be a set of discrete-time samples. Both

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