A Comparison of Two Methods Using R.M.S. Value and Wavelet-Based Mann and Morrison Algorithm for Voltage Dip Characterization

by

Syahirah Binti Abd Halim

Project dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)

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CERTIFICATION OF APPROVAL

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Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

June 2009

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Syahirah Binti Abd Halim

ABSTRACT

Voltage dips have been identified as the major problem among power quality disturbance events which affect the industrial customers. The dips involve short reduction in Root Mean Square (RMS) voltage caused by faults in electrical supply system or starting of a large load. It is crucial to measure and analyze the voltage dip events before considering any mitigation action to reduce and eliminate it. This work presents comparison of two methods used for voltage dip detection and characterization. A less complicated method performed is to determine the lowest magnitude of the RMS voltage during the disturbance. Another method is a combination of wavelet-based analysis using Mann and Morrison algorithm which estimates the amplitude and the phase angle to characterize the dips. The performances of both methods are examined using simulation of system voltage dip, duration of the dip occurrences and point-on wave at beginning in a sinusoidal voltage supply. The voltage dips are then being classified into some classes according to their characteristics. The numerical approach using RMS value results in simplicity method which is easy to be implemented and understood. Eventhough the wavelet-based method seems to be more complicated, it provides higher accuracy in determining the voltage dip characterization.

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1.1 Background of Study

1.1.1 Overview of Power Quality Phenomena

The power quality and reliability is a topic that has gained quite a lot of attention lately. Power quality is a widely defined term used to describe various issues caused by voltage disturbance in the supply system which affects the electrical industry. The IEEE Standard Dictionary of Electrical and Electronics terms defined power quality as "the principal of powering and grounding electrical equipments in a proper and safe way to maintain the equipments performances". However, The International Electrotechnical Commission (IEC) defined power quality as "characteristics of the electricity at a given point on an electrical system, evaluated against a set of reference technical parameters", as in IEC 61000-4-30 [1]. The IEC 61000-1-1 also defines power quality as: "electromagnetic compatibility is the ability of an equipment or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment [2]. This definition relates both performances of equipment and possibility of measuring and classifying the problems.

1.1.2 Power Quality and Voltage Quality

Several terms have been widely used to define power quality and reliability. Those terms are quite hard to be well-defined since we cannot talk about the quality of a physical quantity like power. Since each term that exists in power quality issue has its limitations, it is better to remain the more general term to avoid any confusion or objection. Below are some terminologies regarding to power quality.

a) Voltage quality and current quality

Both voltage and current quality concern on the deviation of waveform from the constant magnitude and frequency. So, any deviation of current or voltage from the ideal one can be considered as power quality disturbance. Voltage quality usually is concerned with a situation where the produced voltage deviates from the nominal voltage (ideal voltage). It can be defined as the quality of the supply delivered by the utility to end-user. Both voltage and current quality relates to each other and if either voltage or current vary from the nominal value, it is impossible for the other on to remain ideal.

b) Power quality

Power quality is a combination of voltage and current quality which involves interaction between the system and the load. Hence, power quality concerns with deviation of voltage and current from the nominal value.

c) Quality of supply

The term includes interaction between the utility and the customer or in other way referred to quality of service. For example, the speed with which the utility reacts to complaints. This basically concerns most on the power quality developments which are driven by the utilities. The generation company with which the customer has a contractual agreement would be responsible for reliability and quality of the power supplied.

d) Electromagnetic compatibility (EMC)

Electromagnetic compatibility is a relation between equipment and supply. Two basic terminologies are used in defining electromagnetic compatibility: the 'emission' is the electromagnetic radiation produced by equipments; the 'immunity' is the equipment's ability to avoid from electromagnetic pollution which may affect its operation.

1.1.3 Power Quality Events

Any deviation of voltage or current from the ideal one can be considered as power quality disturbance. Power quality issues are caused by two main factors which are internal causes such as equipment shutdown or start-up and external causes such as weather conditions and equipment failure. Below are some of the most common power quality problems which happen to give impacts on sensitive electrical equipments:

a) Frequency variation

A frequency variation occurs when there is a change in frequency from the normal condition to unstable one. This event is usually caused by usage of emergency generator or unstable condition of the frequency supply itself. This problem can be solved using voltage regulations or power conditioners.

b) High-voltage spikes

The phenomenon occurs when there is a sudden change in voltage peak up to 6000 volts. These spikes are usually caused by lightning strikes where the negative effects of the disturbances can include loss of data and damage to circuit board.

c) Transients

Transients are the most damaging power quality problem that can be grouped into two categories which are impulsive and oscillatory.

d) Voltage swell

Voltage swell is a momentary increase in voltage level that lasts for a few seconds or less. The swell occurs during tripping of large loads when there is fault on 3-phase supply system resulting the remaining phases' voltage to rise relative to ground.

e) Harmonics

Distorted currents caused by harmonics producing loads will disturb voltage as they pass through the system impedance. This even may result in distorted voltage, overheated equipment, low voltage level at end load and heating of natural conductors.

f) Voltage dip

A brief reduction in supply voltage that lasts for a few seconds or less is classified as voltage dip. Voltage dip is reduction of RMS voltage value to between 10% and 90% of the nominal voltage. Two important parameters that defined voltage dip are magnitude of the voltage and duration of the event.

Those problems really give big impacts especially when the industrial production is interrupted and this will result in high amount of losses. Furthermore, the disturbances may damage the equipment itself and this will surely need some restoration of production, diagnosing and correcting the problem. Many industrial customers are now demanding for higher level of power quality due to the increase in complicated production process and reliance on computer devices. Hence, some necessary mitigation actions should be taken to reduce the disturbance since wrong solution will only make the problem worse.

1.1.4 Voltage Magnitude Events

Majority of power quality disturbances are mainly caused by a reduction or an increase in the magnitude of the supply voltage. A voltage magnitude event is a deviation from the nominal voltage magnitude for a certain time period. The magnitude and duration of power quality disturbances can be represented as one point in the magnitude-duration plane which can be used to classify the variation in voltage magnitude events. The voltage magnitude during disturbance can be divided into three parts [2]:

a) Interruption : voltage magnitude is zero.
b) Undervoltage : the voltage magnitude is below nominal value.
c) Overvoltage : the voltage magnitude is above nominal value.

The duration of power quality event is classified into four parts [2]:

a) Very short, corresponding to transient and self-restoring events.
b) Short, corresponding to automatic restoration of the pre-event situation.
c) Long, corresponding to manual restoration of the pre-event situation.
d) Very long, corresponding to repair or replacement of faulted components.

The classification of events through magnitude and duration representation has proven to be very useful and has provided related information about power quality. However, the method also has some limitations which may need further improvement to give more accurate classification. The limitations are inclusive of [2]:

a) The during-event rms voltage varies with time.
b) Events which last for about one cycle or less in duration are quite impossible to be characterized.
c) Repetitive events can cause error in determining the severity of the events. (under-estimation or over-estimation of the events)
d) Device is sensitive to other external factors beside of magnitude and duration.

Figure and figure explain on different types of events which are defined in EN 50160 and IEEE Std.1159-1995 [2].

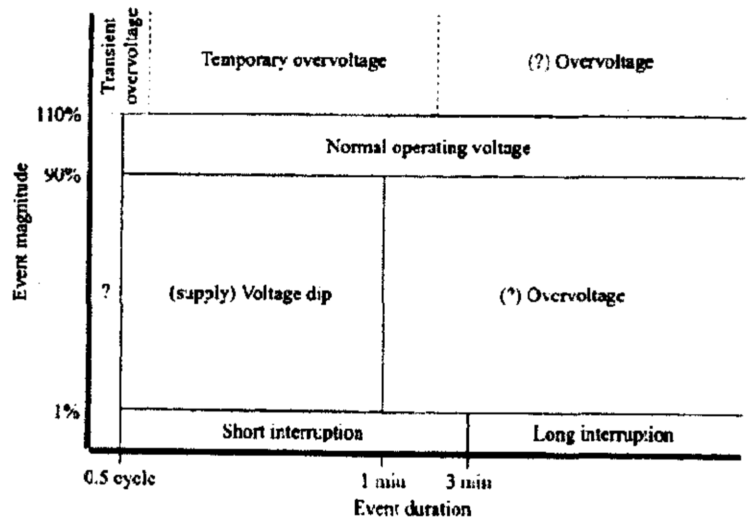


Figure 1 : Definitions of voltage magnitude events as defined in EN 50160.

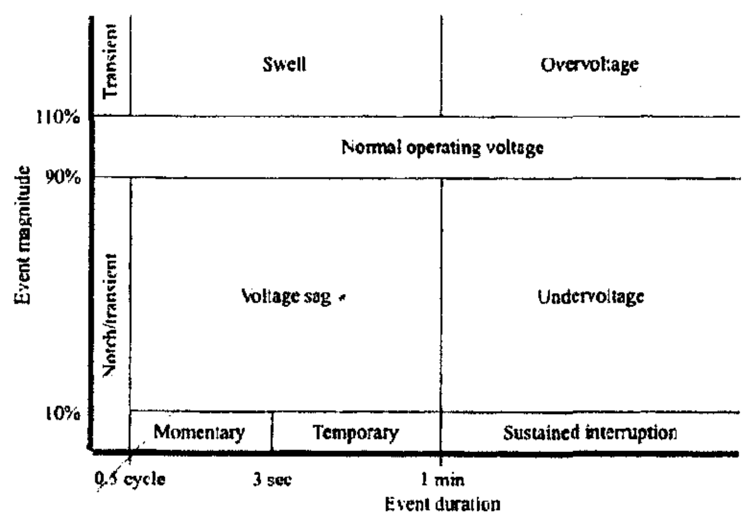


Figure 2 : Definitions of voltage magnitude events as defined in IEEE Std.1159-1995.

1.1.5 Power Quality Standards

1.1.5.1 The European Voltage Characteristics Standard

European standard 50160 [3] provides the main characteristics of the voltage at the customer's supply terminals in public low-voltage and medium-voltage network under normal operating conditions [2].

a) Voltage variations

i. Voltage magnitude: 95% of the 10 minute averages during one week shall be within ±10% of the nominal voltage of 230 V.

ii. Harmonic distortion: For harmonic voltage components up to order 25, values are given which shall not be exceeded during 95% of the 10 minute averages obtained in a week.

b) Events

i. Voltage magnitude steps: do not exceed ±5% of the nominal voltage, but changes up to ±10% can occur repetitively a day.

ii. Voltage sags: frequency of occurrence is between a few tens and one thousand events per year. Duration is less than 1 second, and voltage drop rarely below 40%.

iii. Short interruptions: Occur between a few tens and several hundred times per year. The duration is about 70% of the cases less than 1 second.

iv. Transient overvoltage: Not exceeding 6 kV peak in a 230 V system.

v. Voltage swells: Occur because of undervoltage due to short circuit faults elsewhere in the system generally not exceed 1.5 kV in a 230 V system.

1.1.5.2 MS IEC 61000-2-12:2003 Standards

a) MS IEC 61000-2-12:2003 Electromagnetic compatibility (EMS) – Part 2 Environment – Section 12. [4]

b) Compatibility level for low frequency conducted disturbances and signaling in public medium voltage power supply.

c) Extract from the standard:

"Moreover, immunity of electrical equipment is not, in the strict sense, an appropriate concept in the case of short interruptions or the more severe voltage dips. That is because no electrical device can continue to operate as intended in the absence of its energy supply."

1.2 Problem Statement

1.2.1 Problem Identification

Voltage dips are potentially the most damaging type of power quality disturbances that cause instant reduction of AC voltage in power systems [1]. Not enough energy is being delivered to the load later may cause some complex consequences. The IEC 61000-4-30 defines voltage dip as "a temporary reduction of a point of the electrical systems below a threshold". The existence of voltage dip as a topical issue in power systems has more negatively affected industrial customers that use sensitive electronic equipment compared to domestic customers.

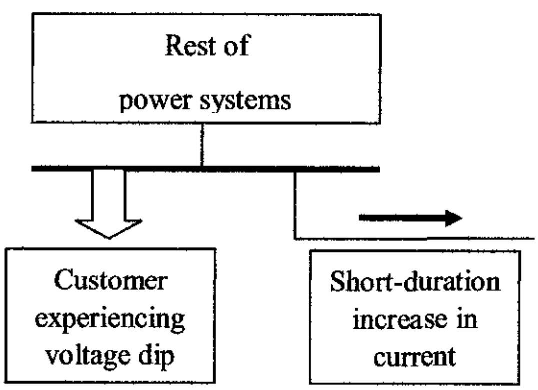


Figure 3 : Voltage dip source

Two major sources of voltage dips are large increase in current and increases in system impedance. The occurrence is usually caused by starting of large loads and faults on other branches of the network. For the dips caused by large loads, the starting current can be many times higher than the nominal current. The high starting current will definitely causes a voltage drop in the network since the supply system and the cabling configuration are installed for normal operating condition. Voltage dip issues do impact the users in terms of lost production, damaged product, maintenance, hidden cost and power interruptions. Figure 4 and figure 5 show data breakdown on number and causes of voltage dip interruptions affecting industrial customer in Malaysia [4].

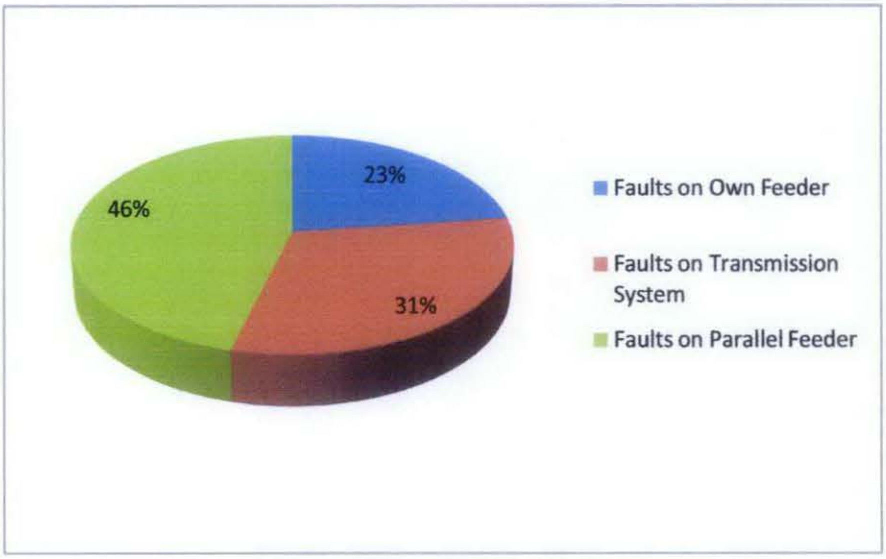


Figure 4 : Causes of voltage dip problems affecting an example industrial customer supplied at the distribution level

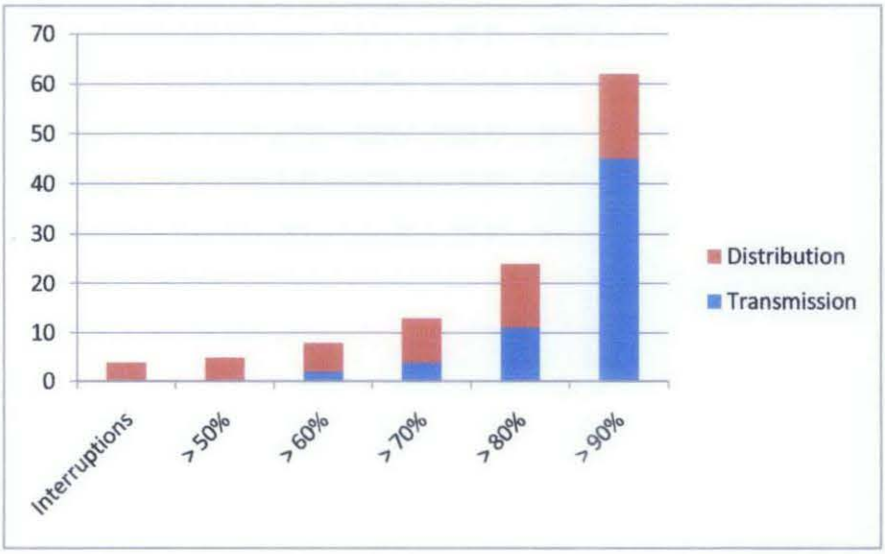


Figure 5 : Voltage dip performance with a breakdown of the events cause by transmission system faults vs. the events caused by distribution system faults

To quantify sag magnitude in transmission and distribution system, the voltage divider concept as shown in Figure 6 can be used.

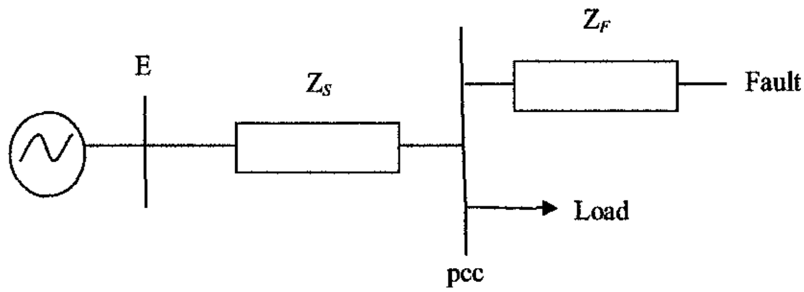


Figure 6 : Voltage divider model for voltage dip

A single-phase model which represents a simplified model in radial system has been used here to examine and predict some of the properties of voltage dips. Two impedances present in this model: Z_S is the source impedance at the point-of-common coupling (pcc) and Z_F is the impedance between the point-of-common coupling and the fault. The load current before and during the fault occurrence is neglected. Hence, we assume that there is no voltage drop between the load and the pcc. The voltage at the equipment terminals (voltage at pcc) can be defined as:

$$V_{sag} = \frac{Z_f}{Z_s + Z_F} E \tag{1}$$

We will assume the pre-event voltage to be exactly 1.0 pu, hence $E = 1$. The following expression is obtained:

$$V_{sag} = \frac{Z_f}{Z_s + Z_F} \tag{2}$$

Any fault impedance should be considered in the feeder impedance Z_F. The theoretical calculation proves that the dip becomes deeper for faults closer to customer (Z_F becomes smaller) and for systems with a smaller fault level (when Z_S becomes larger) [2]. The dip magnitude will also increase if distance to the fault is increased as well as fault level is increased. The dip magnitude as a function of the distance to the fault can be defined as:

$$V_{sag} = \frac{zL}{Z_s + zL} \tag{3}$$

where z is the impedance of the feeder per unit length and L is the distance between the fault and the pcc.

It is important to determine the source of the voltage dip and to be able to characterize them before trying to eliminate the dip. This work introduces comparison of two methods used for voltage dip characterization which are RMS-voltages and wavelet-based Mann and Morrison Algorithm. The RMS-voltage is a straightforward method to characterize voltage dip where the lowest magnitude of the RMS voltage during the dip will be calculated. However, the method has limitation where it is not capable of detecting phase angle jump to give information on where the voltage dip event started. Hence, the wavelet-based Mann and Morrison algorithm is a method for improvement of voltage dip characterization where the method can estimate the amplitude and the phase angle of the system voltage. Quick and accurate characterization of voltage dip is essential to determine the source of the dip so that possible mitigation action can be taken to reduce or to eliminate the effects.

1.2.2 Significant of the Project

Voltage dip has become one of the major power quality problems recently as the country progresses. There were no papers presented or conferences organized regarding the power quality problem before the year 1990. However, it has been a big issue for electrical power consumers as a result of increase in the amount of activity in the power quality area. The increased interest in power quality and reliability is caused by several reasons which are:

a) Electronics equipment has become more sensitive to voltage quality disturbances.

Production processes are greatly affected by the incorrect operation of the equipment which will lead to much higher production cost due to short interruptions of voltage dip. The industrial customers also give a great concern on voltage dip problems which may cause losses to their production due to malfunction of machines and power failure.

b) Equipment causes disturbances in the produced current.

Power electronic equipments are mostly powered by simple electronic converters which have higher possibilities in causing distortion. This proved that the equipments are not only sensitive to voltage dip disturbances but also can be the source of disturbances for other electronic devices.

c) The liberalization of electricity supply industry.

Conventional network expansion and development project carried out by electricity supply companies have further improved the electrical power systems performances. High quality of electrical supply has become the main topic in electricity distribution nowadays since electricity demand is expected to grow moderately in the futures.

d) Development of renewable energy causes power quality problems.

Most interfaces that use renewable energy are more sensitive to power quality problems such as voltage dip. However, such introduced interfaced can be used to provide mitigation action to power quality problem occurrence.

e) Advancement in measuring and analyzing power quality problems.

The voltage disturbances and distortions have become topical issue in power systems. Hence, variety of theory and computational methods had been proposed for measuring and processing and analyzing those problems. Some of the methods include of wavelet transform, root-mean square voltage, filter design and multi resolution analysis.

1.3 Objectives

Upon completing this project, a few objectives need to be achieved. The objectives of the study are as follows:

a) To study the advantages and limitations in the use of the root mean square (RMS) value and the wavelet-based Mann and Morrison algorithm in detecting and analyzing voltage dip event.

b) To perform simulation of real voltage dip occurrence using MATLAB software in order to determine some parameters for characterization such as voltage magnitude, phase angle jump, duration and instant of beginning of the dip.

c) To analyze the results obtained to determine the best method which provides less complicated approach to be implemented and less error in determination of voltage dip type at the beginning.

d) To suggest some improvement for both proposed methods to further improve the study of voltage dip event characterization especially in locating accurately the source of the dip.

1.4 Scope of Study

The wavelet-based Mann and Morrison algorithm provides some improvement to the Root Mean Square (RMS) numerical approach where it is higher in accuracy and precision of the estimated type and voltage dip characteristics [5]. Although the RMS method is said to give sufficient information on voltage dip occurrence, the wavelet-based method has been successfully proven to give results that would be useful for the causes of dips. The first part of the work will cover on the procedure used to estimate the measurement of magnitude, duration and amplitude of the system voltage waveform before characterizing the voltage dips. The next part will include steps taken in employing both methods for dips characterization with consideration of the needs and expectations in analyzing the events. A test is performed on some electrical equipment and the discussion parts on various designed method considerations are also included in this work. Results obtained from the simulation done will be analyzed and interpreted to provide supportive information for the discussion part.

1.4.1 The Relevancy of the Project

Voltage dip has been identified as the major problem in power quality issues. Improving the network performance to totally eliminate dips is quite impossible to be implemented since it requires high cost. A better way to estimate the severity of voltage dip problem is by performing some methods of detection and characterization. In order to reduce the dips effect, it is necessary to understand how and why they occur before characterizing them into certain groups. Hence, this works is expected to provide a comparison of two methods used for voltage dip characterization by considering some important parameters such as RMS voltage, phase angle jump and duration of the dip event.

1.4.2 Feasibility of the Project within the Scope and Time Frame

The project must be completed in two semesters given. Due to time constraint, the author has narrowed down the scope of studies by making comparison only for two methods of voltage dip characterization. The methods are RMS magnitude voltage and wavelet-based Mann and Morrison algorithm. Eventhough voltage dip problem usually gives impact to industries, the author decided not to conduct a case study based on industrial environment due to time limitation. The field-measured signal from simulation using Matlab/Simulink environment will be used in order to study the proposed methods on the real condition.

CHAPTER 2

LITERATURE REVIEW

2.1 Voltage Dip Characterization

Voltage dip evaluation is often divided into problem identification, classification and characterization, and finally followed by solution assessment and design. The development in measurement technology causes an increase in number of data being gathered which needs to be analyzed. The Root Mean Square method is the most commonly used in measuring and analyzing voltage dip characterization for power system with alternating current (AC) by determining voltage magnitude. Hence, time frequency decomposition method such as Discrete Fourier transform and short time Fourier transform are proposed which overcome the limitations of RMS method by providing information on the dip propagation. However, these methods are also not without limitations regarding efficiency in capturing short term voltage dip event.

Wavelet-based techniques which use wavelet transform are being proposed as an improvement to the previous characterization methods. The techniques are more suitable in tracing changes in voltage dip event compared to the others. One of the proposed methods is a combination of the discrete wavelet transform and the Mann and Morrison algorithm to estimate the amplitude and the phase angle which are then being used for the characterization. The next part will discuss on some theories related to the two methods; RMS voltage and wavelet-based Mann and Morrison algorithm, which are going to be compared for voltage dip characterization.

2.2 Root Mean Square (RMS) Voltage Magnitudes

For a few years time, the Root Mean Square (RMS) computational method has been used to determine important characteristics in voltage dip measurements which are the magnitude and the duration of the disturbance. The numerical approach is used to get the magnitude of the system voltage as well as the duration taken when the RMS voltage magnitude is exceeding or below a certain threshold [6]. In IEEE Std. 1159-1995, voltage dip is defined as 'a decrease between 0.1 and 0.9 pu in RMS voltage or current at the power frequency for duration of 0.5 cycles to 1 minute. The minimum value of the remaining RMS voltage during the disturbance is calculated to analyze the single-phase voltage. The time taken for the dips event is also important information to determine before proceeding with the analysis part [7]. The duration of the dips is defined as the time in which the measured RMS voltage is below 90% of the pre-fault RMS voltage. The rectangular voltage dip of different magnitude and duration are simulated and computed to obtain the depth and time taken for the occurrence. It is assumed that no phase jump and no hysteresis voltage take place in the simulation.

The RMS-voltage is determined using the following equation:

$$V_{rms} = \sqrt{\frac{1}{N}\sum_{i=1}^{N} v_i^{\,2}} \qquad \textbf{(4)}$$

where v_i is voltage samples and N is the number of samples taken in a window.

2.3 Wavelet-based Mann and Morrison Algorithm

Precision of the estimation done on voltage dips characteristics also depends on the ability to determine the system voltage phasor. The wavelet-based method presents in this work will overcome the drawback of the numerical-based approach which uses RMS voltage magnitude value as the main parameter. This method is suitable in determining the amplitude and phase angle for the tested system as well as capable of providing information on the duration time of voltage dips event [8]. It is based on wavelet transform theory which can be used in analyzing a stationary signal by decomposing the signal into different levels and scales of resolution. The wavelet transform provide time and frequency information of a measured signal which is suitable in determining disturbance of voltage transition that occurs in a short time duration [9]. Distortion and disturbances occur in the voltage waveform are eliminated bye the discrete wavelet transform (using high pass and low pass filter concept) before the desired signal within the power frequency is being given as an input of the Mann and Morrison algorithm. The amplitude and phase angle of the resultant waveform are determined by considering three consequent sampled points using the following equation:

$$V_p \sin\theta = V(t)\,|_{t=0} \tag{5}$$

$$V_p \cos\theta = \frac{V(t)\,|_{t=+\Delta t} - V(t)_{t=-\Delta t}}{2\omega_0 \Delta t} \tag{6}$$

where θ is the phase angle and V_p is the amplitude of the system voltage. The frequency to determine phase voltage is obtained using the given equation:

$$\omega_0 = 2\Pi\left(\frac{1}{2(t_2 - t_1)}\right) \tag{7}$$

A symmetrical components algorithm is used to evaluate the voltage dip characteristic by using the calculator block to analyze the phasor values. For this step, the voltage dip events are being classified accordingly to their characteristics. The main objective of the algorithm usage is to determine the dip type based on the characteristic voltage, V and PN factor, (F). The lowest magnitude of the RMS voltage value obtained during the dips is being compared for the symmetrical component algorithm and voltage dip characterization.

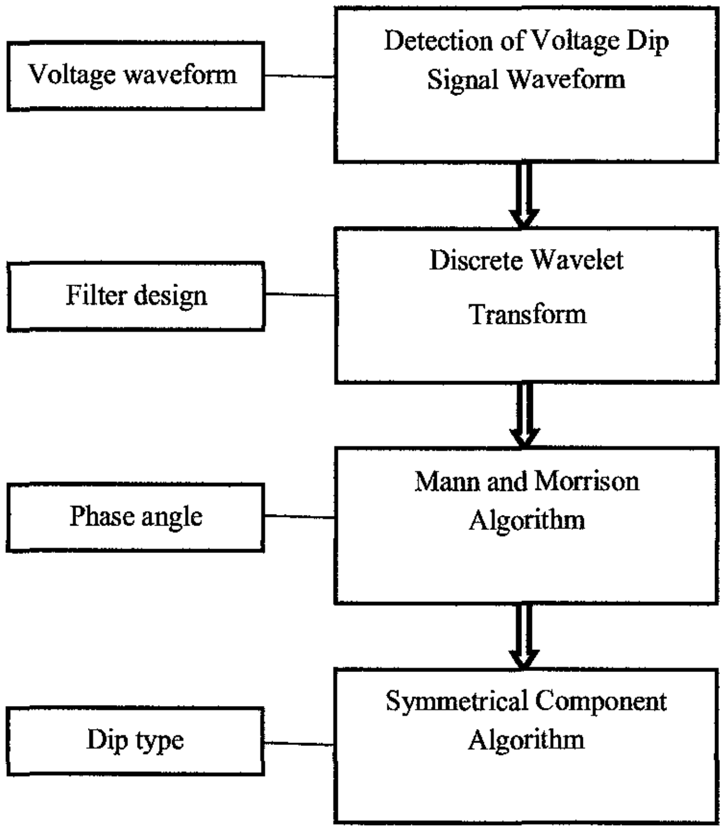


Figure 7 : Flow chart of the proposed algorithm

2.4 Comparison of R.M.S. Magnitude Voltages and Wavelet-Based Mann and Morrison Algorithm for Voltage Dip Characterization

Table 1 : Comparison of the proposed methods for characterization

FEATURES	R.M.S. VOLTAGE	MANN & MORRISON ALGORITHM
Drawbacks	• Dependency on the window length and on the time interval for updating the values.	• Cannot provide accurate information about the direction of the voltage dip.

	• Cannot detect a sudden change in the magnitude of voltage supply by using calculation. • Cannot detect the phase angle jump to give information about the instant where the voltage event started.	• More complex approach since it requires further algorithm development.
Advantages	• Simple and easy to be implemented. • Easier to be understood. • Less complexity in the equation used for calculation. • Provide information on the duration of the voltage dip. • Can be used for both sinusoidal voltage supply and for voltage supply with harmonic distortion to characterize voltage dip.	• Leads to quick and accurate response in simulation. • Accuracy in determining amplitude and phase angle of voltages. • Reduce harmful effect of voltage waveform distortion using wavelet transform. • Using short window length for sinusoid waveform. • Frequency of the obtained signal has small fluctuations around nominal value. • Symmetrical components algorithm is used to obtain the characteristics.

2.5 Classification of Voltage Dip by Symmetrical Component Algorithm

After obtaining the amplitude and phase angle of the power system voltages, classification of voltage dip is done by applying the symmetrical component algorithm. Since the tested system will be experiencing a three-phase voltage dip, there are three main parameters that need to be determined inclusive of [2]:

a) The dip type is determined. Voltage dip classification is usually divided into three classes which are A, C and D types. A dip of type A is an equal drop in all of the three phases. A dip of type C is a drop in either two of the three phases which means that the dip is deeper in two phases compared to the other. Type B contains a zero-sequence component which is rarely transferred down to the equipment terminals. Finally, a dip of type D is deeper in one phase with a small drop in the other two phases.

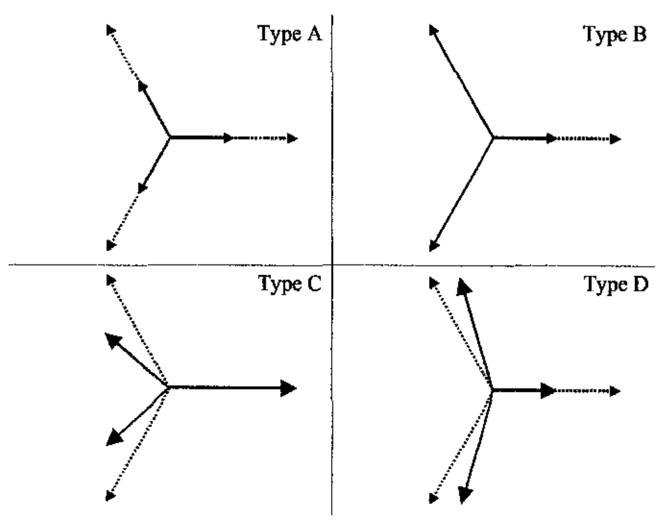


Figure 8 : Types of three-phase unbalanced dip

b) The characteristic voltage is defined as a phasor value which will be used to detect the severity of the voltage dip event.

$$V_{characteristic} = V_{positive} - V_{negative} \tag{8}$$

The negative sequence voltage is first being multiplied by below exponential equation before performing the subtraction:

$$e^{(-i*k*\pi/3)} \quad \textbf{(9)}$$

where k = depends on the dip-type.

c) The Positive and Negative factor (PN-factor) is another phasor to determine a three-phase unbalanced dip but with the condition where the system's positive and negative impedances are not equal. Here, the PN-factor is calculated as:

$$Pn - factor = V_{positive} + V_{negative} \quad \textbf{(10)}$$

The negative sequence voltage is also first being multiplied by the early mentioned exponential equation before performing the subtraction.

2.6 Daubechies Wavelet

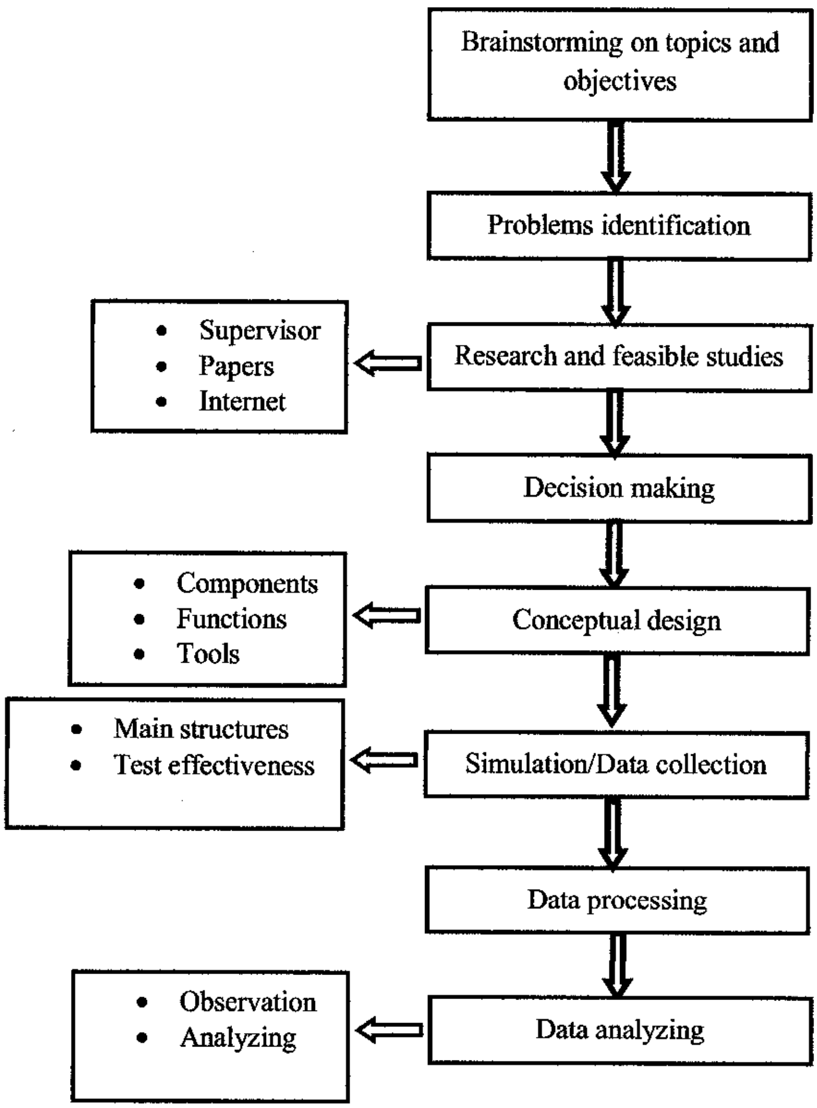
For the wavelet-based characterization method, discrete wavelet transform method is used to obtain the frequency range of the fundamental frequency. To perform this step, a mother wavelet need to be chose after obtaining the signal in the range of power frequency. A wavelet is defined as building block that can immediately correlate data. For the wavelet-based voltage dip characterization, Daubechies-4 wavelet which consists of eight sample window is chosen as mother wavelet. Daubechies-4 is the most suitable wavelet to be used for processing per sinusoidal signal due to some factors.

The choice of the wavelet algorithm depends on the application. The choice of mother wavelet is an important factor in detecting and analyzing voltage dip characteristics. For Daubechies wavelet family, Daubechies-4 and Daubechies-6 are usually suitable for short and fast transient disturbance while Daubechies-8 and Daubechies-10 are better for analyzing slow transient disturbance. Since the voltage dip event usually occurs from 0.5 cycles to 1 minute time period, it can be classified as temporary and short power quality disturbance. Hence, Daubechies-4 algorithm is the most suitable wavelet for this type of power system transient analysis. This is because at the lowest scale which is 1, the mother wavelet is most localized in time and oscillates rapidly within a very short period of time. Higher scale wavelet will cause the analyzing wavelet to become less localized in time and oscillate less due to the dilation nature of wavelet transform.

The wavelet transform is usually performed by expanding a mother wavelet rather than contracting it. Therefore, Daubechies-4 is the chosen as mother wavelet since it is the most localized or compactly supported in time. However, the Daubechies-4 algorithm has a higher and more complex computational compared to other algorithm such as Haar wavelet.

CHAPTER 3
METHODOLOGY

3.1 Procedure Identification



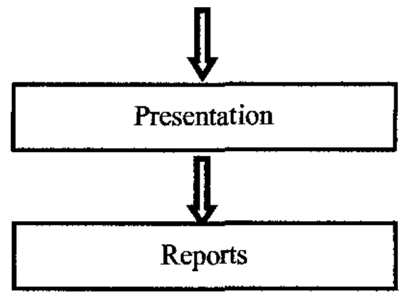


Figure 9 : Schematic flow process of the project

3.2 Research Methodology

a) Research/literature review on proposed method.

The first step implemented in this project is by doing research on the related title of voltage dip detection and measurement. Existing design of voltage dip characterization are referred to and compared. The best title is picked up which had been considered in term of title toughness and through feasibility of implementation throughout the given period. For the next stage, all the information regarding the topic is collected in order to determine the real definition and concept. The next approach is to focus on three important steps to be conducted within the time given which are detection, measurement and characterization.

b) Laboratory/simulation test

Tools and equipment to be used will be identified and familiarized prior to the tests performed to avoid malfunctioning or error of the proposed methods. The author has identified some approaches in completing this work. For this work, the voltage dip occurrences are analyzed in two approaches such as:

i. Transformation of data into frequency domain for wavelet-based Mann and Morrison algorithm.
ii. Using mathematical solution via numerical techniques for RMS voltage magnitude method.

c) Analysis and discussion

The simulated results will be presented to compare between the RMS magnitude voltage calculation method and wavelet-based Mann and Morrison algorithm. They will clearly show and indicate the best method that brings more advantages to be used in determining the voltage dip characterizations.

3.3 Tools

a) MATLAB software

The design process includes the usage of MATLAB software. By using the capability of MATLAB simulation, it is possible to analyze the signal data using waveform obtained. The software also provides usage of computational method to be used for calculating some complex numerical approach to obtain the characterization. The MATLAB software consists of blockset that provides an easier approach to construct and simulate the proposed methods using the Simulink Environment. For example, the wavelet-based Mann and Morrison algorithm requires implementation of schematic block which consists of the discrete wavelet transform part, the Mann and Morrison algorithm part and lastly the symmetrical component algorithm. MATLAB software is powerful software consisting of programming toolbox that is able to perform variety of computing methods. MATLAB software is also enhanced with the ability to display result while simulation is running besides of capable of processing complex computational. Since this project requires some filter design and analysis, MATLAB is chosen as a platform since it has quite a high and stable processing capability. For applying the proposed algorithm, the signal in the power range of frequency is extracted by discrete wavelet transform. After the signal in the frequency range is obtained, it is then being given to the Mann and Morrison algorithm as an input.

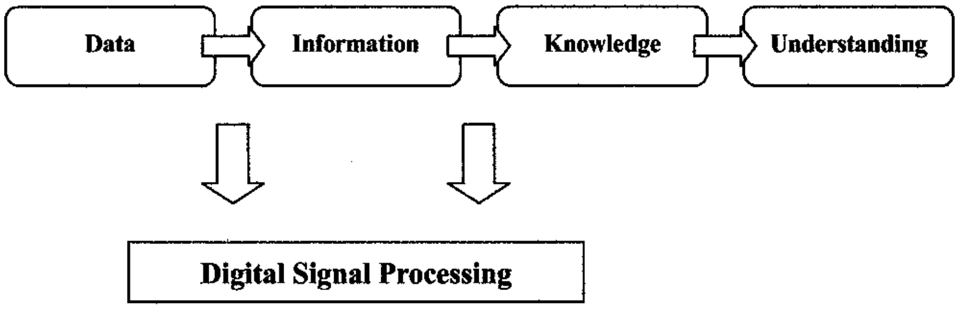


Figure 10 : Role of signal processing in extraction of information from power quality data

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Simulation Results

4.1.1 Simulation of Three-Phase Faults System

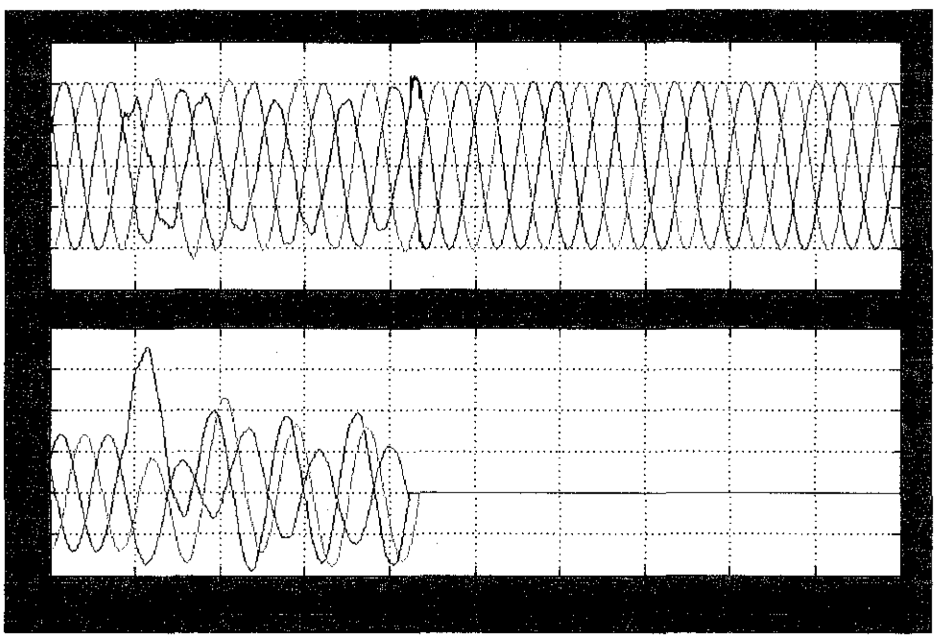


Figure 11 : Phase A Fault and Ground Fault selected

Legend: Phase A Phase B Phase C

Table 2 : Minimum remaining voltage and duration of the dips for Phase A – Ground fault

Fault Type	Minimum Remaining Voltage (pu.)			Duration (s)
	Phase A	Phase B	Phase C	
Phase A - Ground	**0.81**	1.0	0.92	0.063

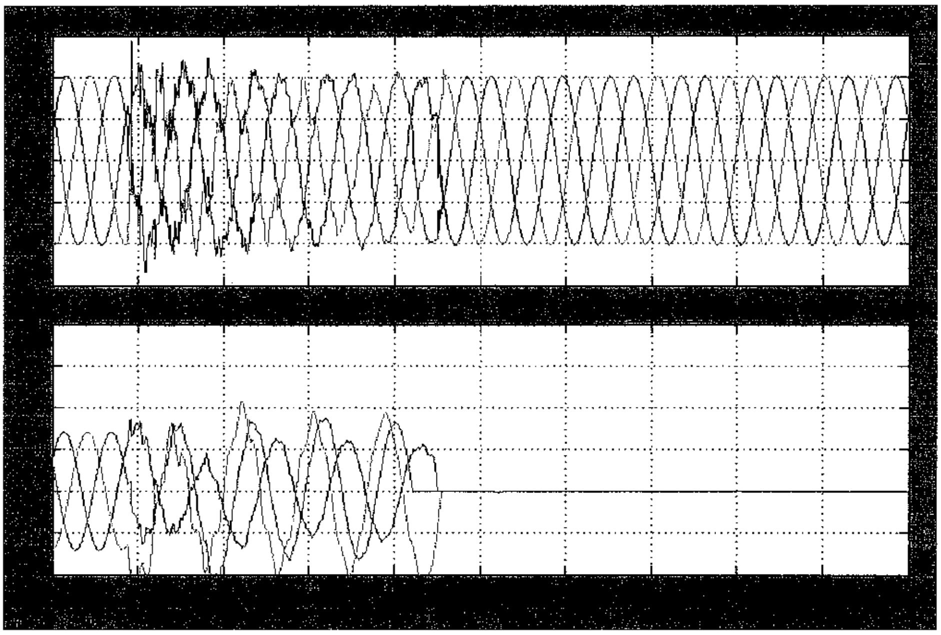


Figure 12 : Phase B Fault and Ground Fault selected

Legend: Phase A Phase B Phase C

Table 3 : Minimum remaining voltage and duration of the dips for Phase B – Ground fault

Fault Type	Minimum Remaining Voltage (pu.)			Duration (s)
	Phase A	Phase B	Phase C	
Phase B - Ground	0.97	**0.86**	1.02	0.083

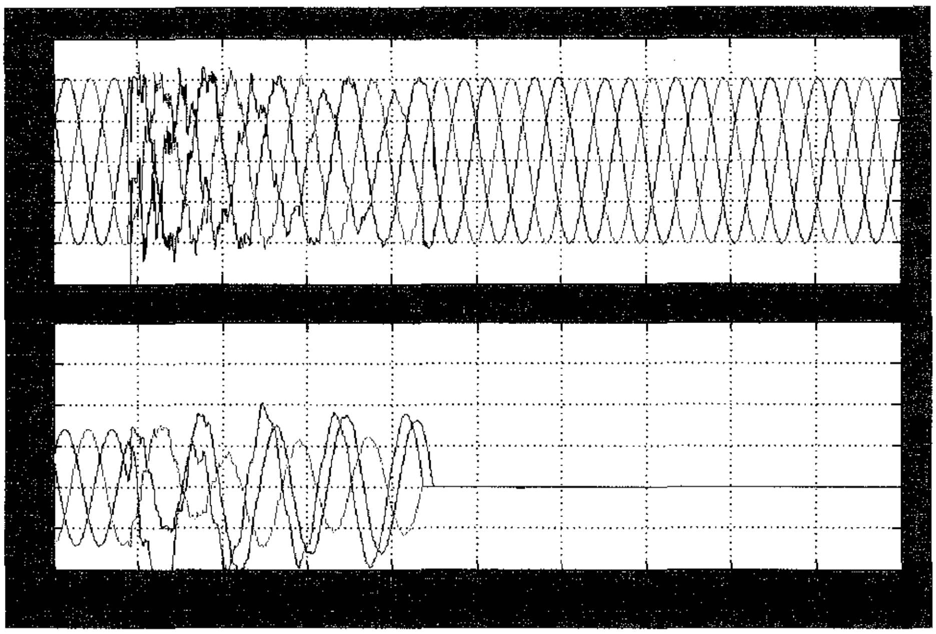


Figure 13 : Phase C Fault and Ground Fault selected

Legend: Phase A Phase B Phase C

Table 4 : Minimum remaining voltage and duration of the dips for Phase C – Ground fault

Fault Type	Minimum Remaining Voltage (pu.)			Duration (s)
	Phase A	Phase B	Phase C	
Phase C - Ground	0.98	1.0	**0.79**	0.079

4.1.2 Simulation of Wind Farm Using Doubly-Fed Induction Generator Wind Turbines

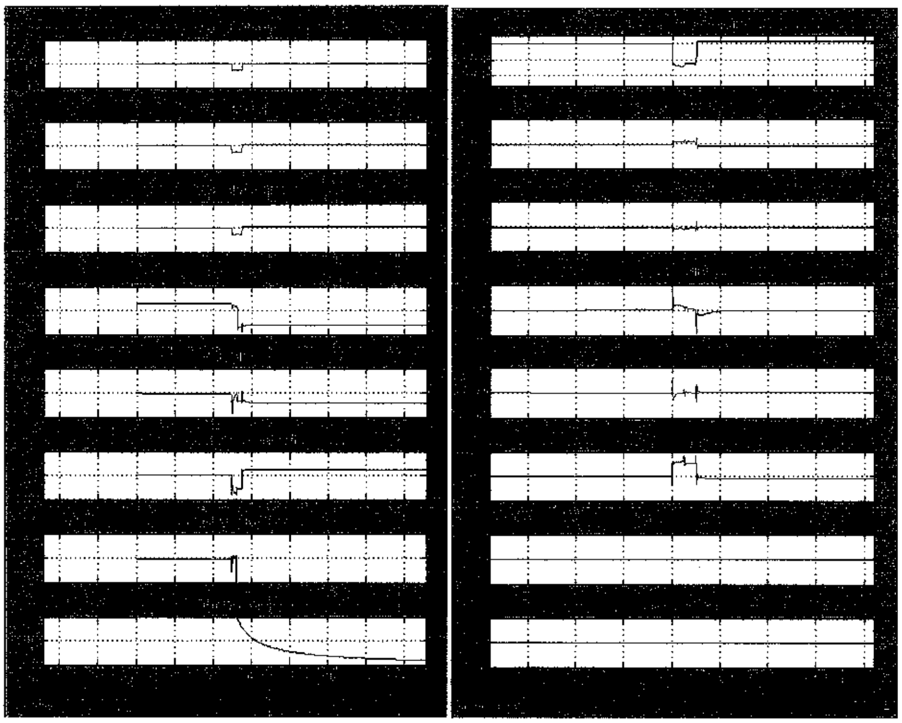


Figure 14 : Voltage Sag on the 120 kV System (Wind Farm in Var Regulation)

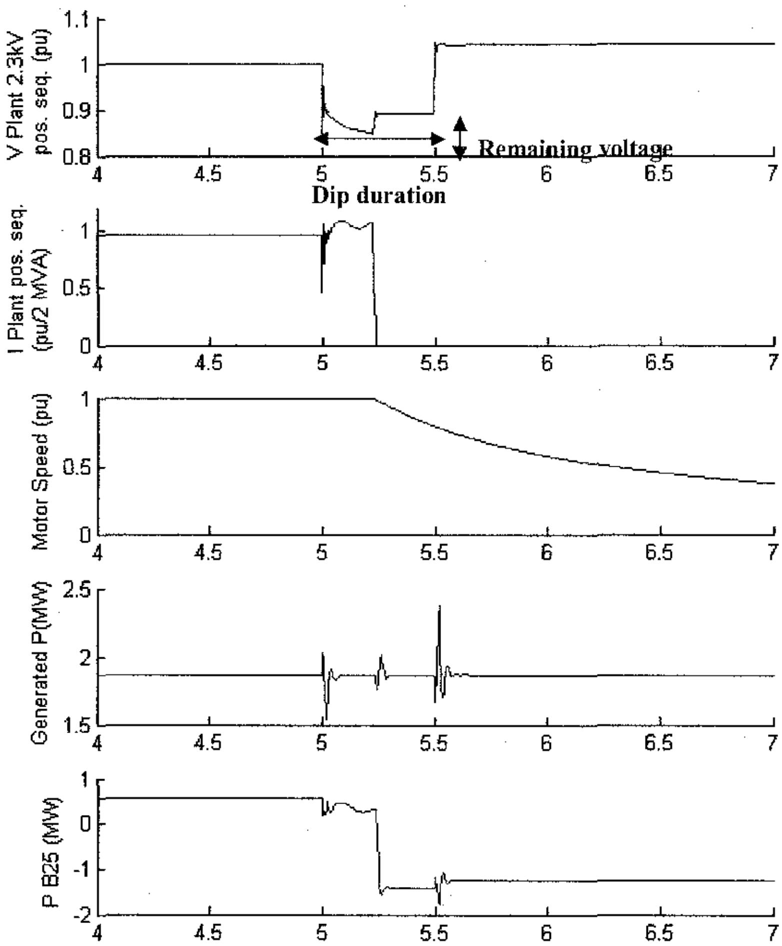


Figure 15 : Voltage Sag on the 120 kV System

Table 5 : Minimum remaining voltage and duration of the dip for 0.15 pu. voltage drop

Voltage Dip Magnitude (%)	Minimum Remaining Voltage (pu.)	Duration (s)
0.15	0.83	0.5

4.1.3 *Simulation of Wavelet Transforms Over Different Frequency Levels*

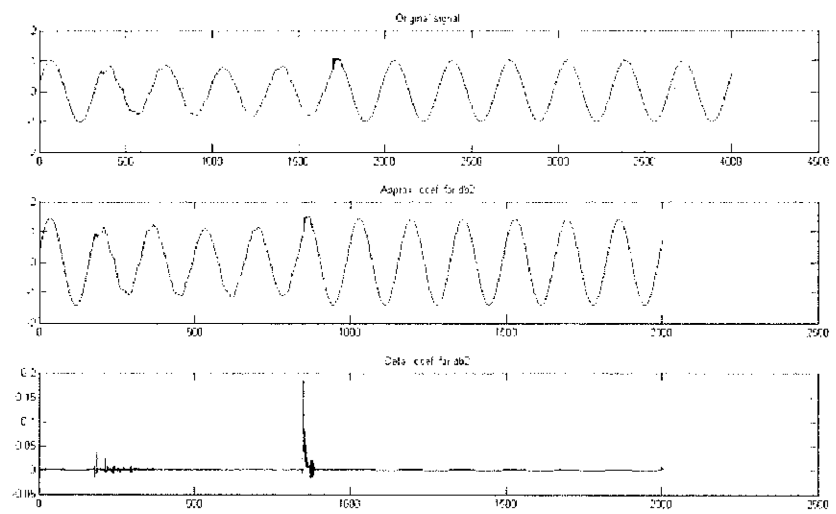


Figure 16 : Wavelet transform of phase A during phase A fault

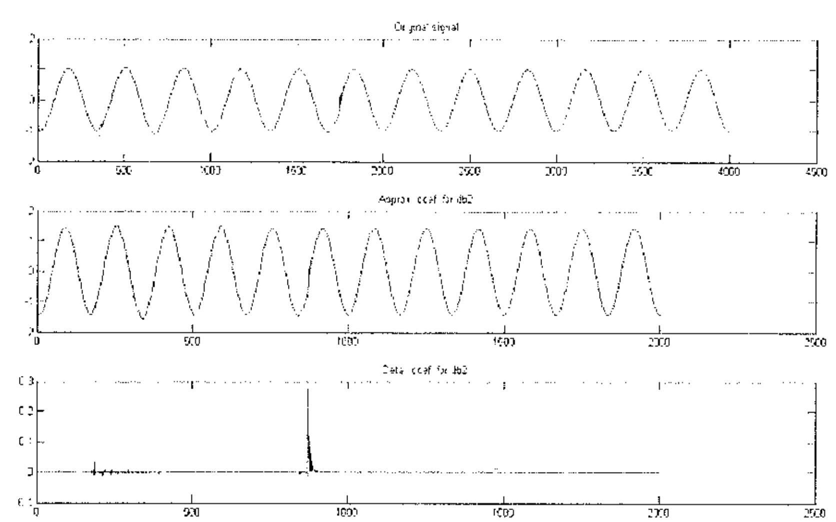


Figure 17 : Wavelet transform of phase B during phase A fault

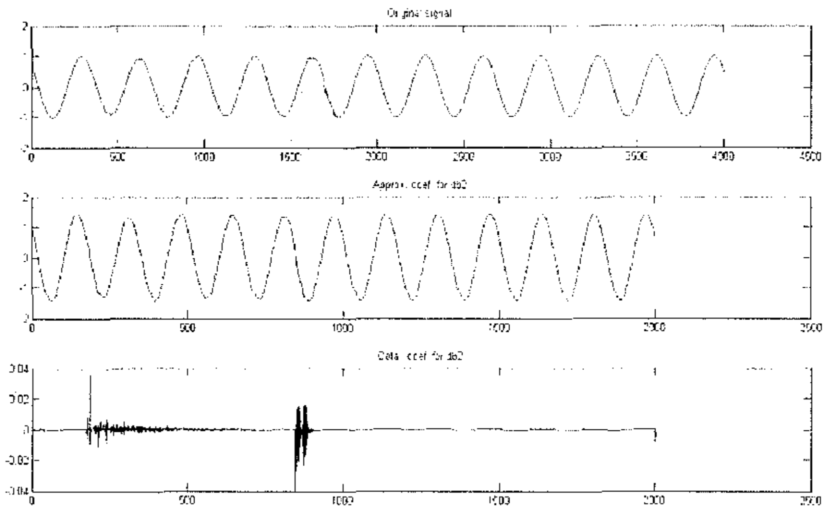


Figure 18 : Wavelet transform of phase C during phase A fault

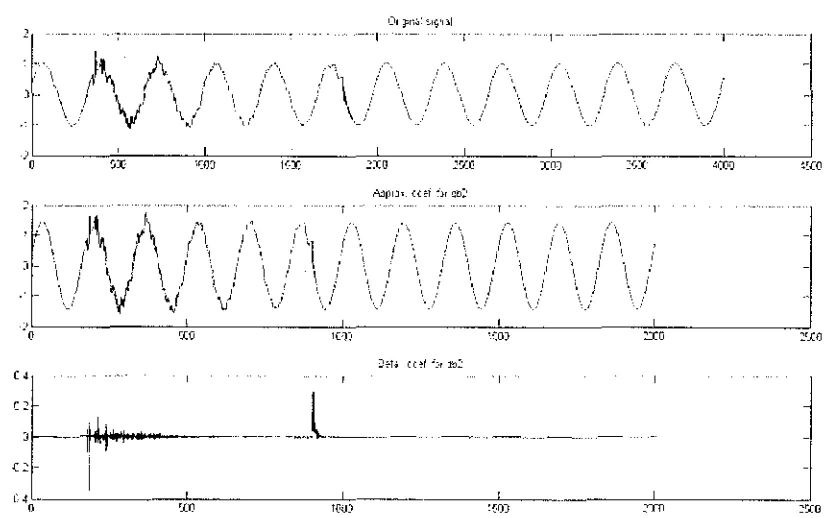


Figure 19 : Wavelet transform of phase A during phase B fault

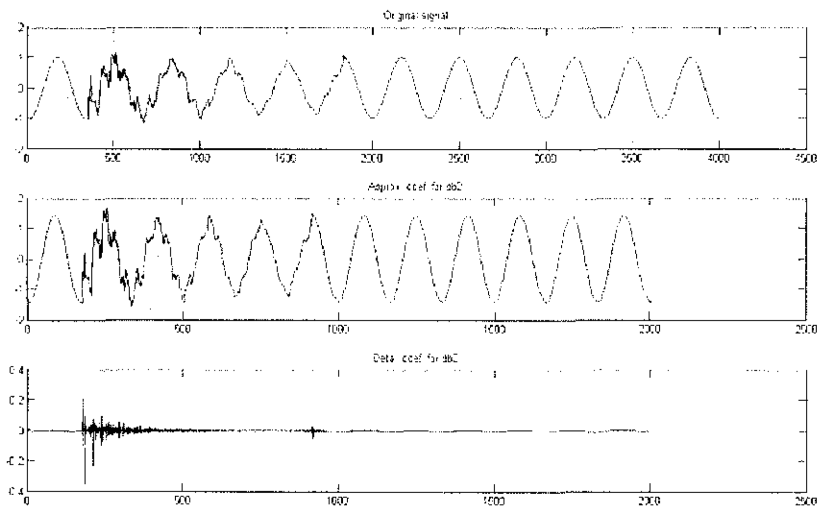


Figure 20 : Wavelet transform of phase B during phase B fault

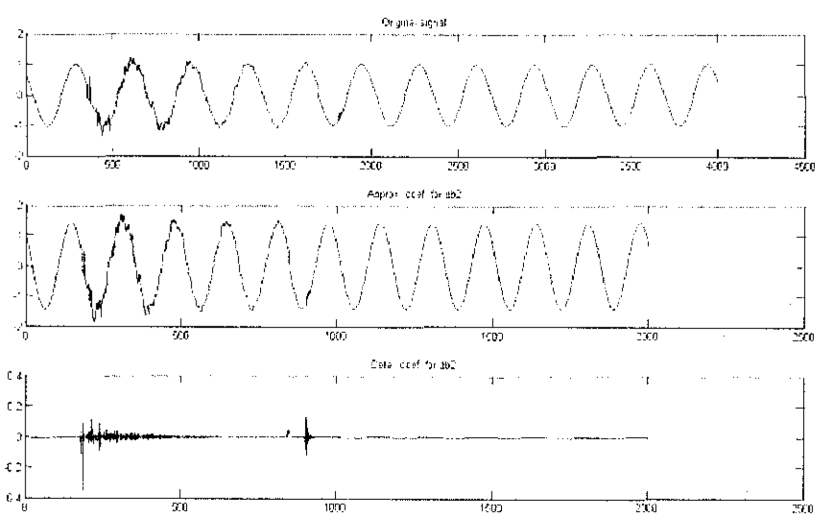


Figure 21 : Wavelet transform of phase C during phase B fault

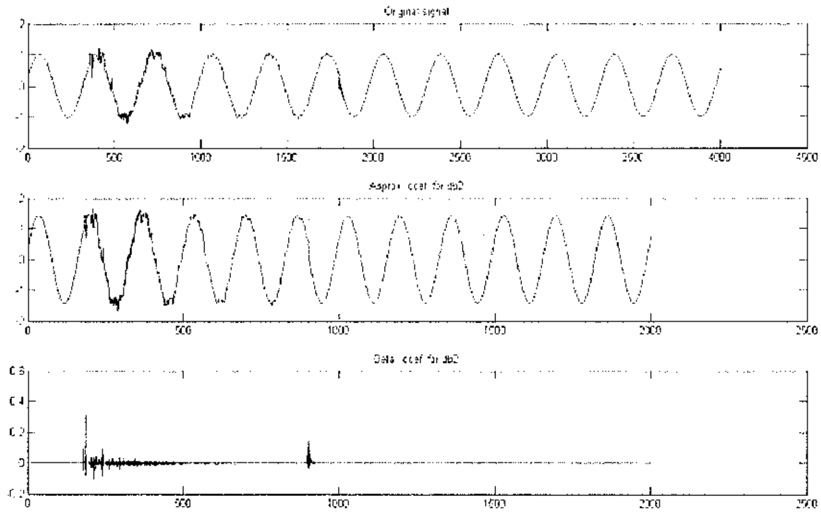


Figure 22 : Wavelet transform of phase A during phase C fault

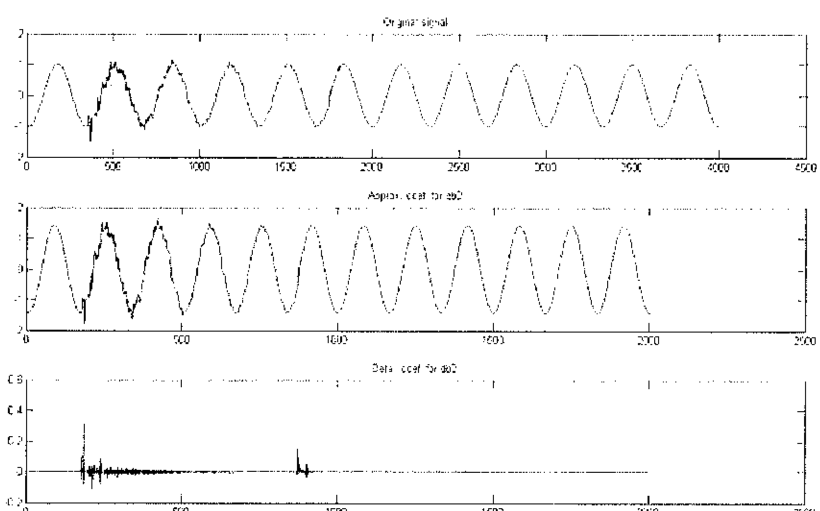


Figure 23 : Wavelet transform of phase B during phase C fault

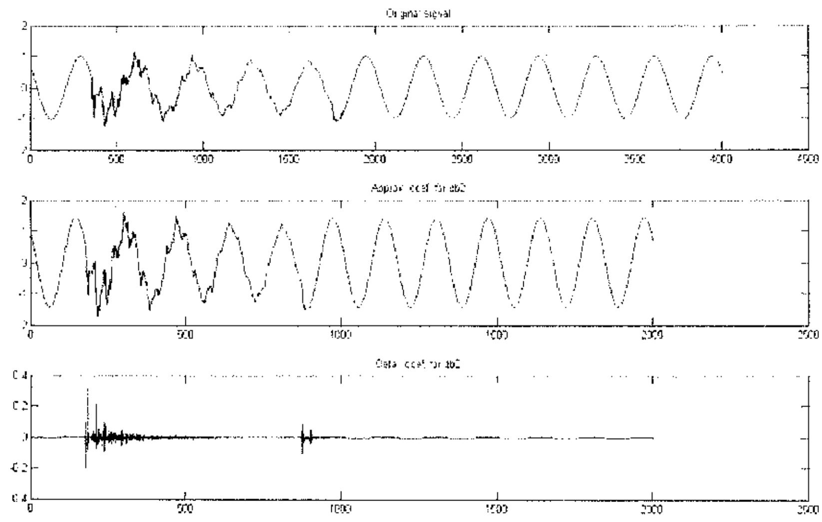


Figure 24 : Wavelet transform of phase C during phase C fault

nominal voltage. RMS voltages were calculated for all the three phases and phase A with the minimum remaining voltage was selected for further characterization. The result of characterization based on RMS voltage in the phase that gives largest dip for phase A fault and ground fault (i.e. the emphasized values) is summarized in Table 2. The duration of the dip is when the RMS voltage is below 90% of the pre-fault RMS voltage. The lowest remaining voltage during the dip was 0.81 pu.while the duration of the dip was 0.063s.

b) Phase B Fault and Ground Fault selected

A typical measurement of voltage dips when Phase B Fault and Ground Fault selected is shown in Figure 6. The voltage magnitude is in per unit value of the nominal voltage. RMS voltages were calculated for all the three phases and phase B with the minimum remaining voltage was selected for further characterization. The result of characterization based on RMS voltage in the phase that gives largest dip for phase B fault and ground fault (i.e. the emphasized values) is summarized in Table 3. The duration of the dip is when the RMS voltage is below 90% of the pre-fault RMS voltage. The lowest remaining voltage during the dip was 0.86 pu. while the duration of the dip was 0.083s.

c) Phase C Fault and Ground Fault selected

A typical measurement of voltage dips when Phase C Fault and Ground Fault selected is shown in Figure 7. The voltage magnitude is in per unit value of the nominal voltage. RMS voltages were calculated for all the three phases and phase C with the minimum remaining voltage was selected for further characterization. The result of characterization based on RMS voltage in the phase that gives largest dip for phase C fault and ground fault (i.e. the emphasized values) is summarized in Table 4. The duration of the dip is when the RMS voltage is below 90% of the pre-fault RMS voltage. The lowest remaining voltage during the dip was 0.79 pu. while the duration of the dip was 0.079s.

4.2.2 Voltage Dip in Wind Farm Using Doubly-Fed Induction Generator Wind Turbines

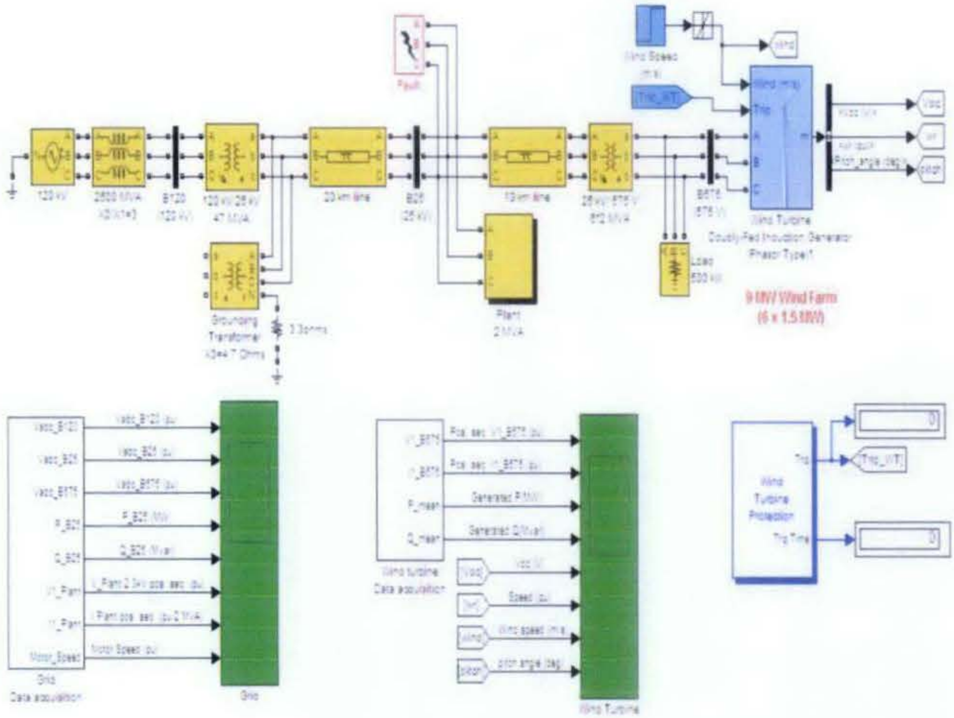


Figure 26 : SimPowerSystems diagram of the wind farm connected to the distribution system

A 9-MW wind farm consisting of six 1.5 MW wind turbines connected to a 25-kV distribution system exports power to a 120-kV grid through a 30-km, 25-kV feeder [10] [11]. The wind turbine and the motor load were designed as a system which comprises of a protection system monitoring voltage, current and machine speed. The wind-turbine model is a phasor model that can perform simulation on transient stability type with long simulation times and for the simulation done, the system is observed during 50 s. Simulation of a voltage sag on the 120-kV system was performed by creating a 0.15 pu voltage drop which is programmed to occur between t = 5s and t = 5.5s. For the characterization using RMS method, the minimum value of the remaining RMS voltage during the dip is determined. The RMS value is calculated over a time window corresponding to one period of fundamental frequency. The duration of the dip need to be determined by observing the duration in which the RMS voltage is below 90% of the pre-fault RMS voltage. Figure 9 shows the dip duration and remaining voltage during the voltage dip occurrence. The lowest remaining voltage during the dip was 0.83 pu. while the duration of the dip was 0.5s.

4.2.3 Wavelet Transforms over Different Frequency Level

For the application of the proposed algorithm, the signal in the range of the power frequency is extracted by using discrete wavelet transform (dwt). Daubechies-4 wavelet with four frequency levels is being used in the simulation as mother wavelet. Daubechies wavelet is chosen since it has shorter window length compared to the other wavelet such as Haar and Symlets. The processing per sinusoidal signal to determine frequency range of the fundamental component is carried out using Matlab M-Files (refer to Appendix 4). Figure 16, Figure 17 and Figure 18 exhibit different level of wavelet transform coefficients over some frequency range of the system for phase-A fault, phase-B fault and phase-C fault respectively. The signal in the range of power frequency is given to the Mann and Morrison algorithm which is then used to obtain the amplitude and phase angle of the resultant waveform (refer to appendix 5). The duration of the voltage dip is determined at instance of beginning of the dip when at least one of the RMS voltages is below the threshold limit.

4.2.4 Determining Amplitude and Phase Angle of Waveform Using the Mann and Morrison Algorithm

Three consequent points of the waveform are used to calculate the amplitude as well as the phase angle of the system voltage using the following equations

$$V_p \sin\theta = V(t)\,|_{t=0} \tag{11}$$

$$V_p \cos\theta = \frac{V(t)\,|_{t=+\Delta t} - V(t)_{t=-\Delta t}}{2\omega_0 \Delta t} \tag{12}$$

$$\omega_0 = 2\Pi\left(\frac{1}{2(t_2 - t_1)}\right) \tag{13}$$

$$V^2 = (V_p \sin\theta)^2 + (V_p \cos\theta)^2 \tag{14}$$

$$\theta = \tan^{-1}\left(\frac{V_p \sin\theta}{V_p \cos\theta}\right) \tag{15}$$

The amplitude of the power system voltages (three voltage phasors) for each type of fault are summarized in Table 6.

Table 6 : Amplitude of power system voltages

Amplitude	Phase-A Fault	Phase-B Fault	Phase-C Fault
Phase-A	0.81	0.95	0.98
Phase-B	1.11	0.86	0.97
Phase-C	0.90	0.94	0.79

4.2.5 Determining Phasor Values and Dip Type Using Symmetrical Component Algorithm

The phasor values of the amplitude and phase angle of the power system voltages are calculated using symmetrical component algorithm to obtain voltage dip characteristics (refer to Appendix 1). The three sequence components of a three-phase signal (V_1, V_2 and V_0) are computed as follows:

$$V_0 = \frac{1}{3}(V_a + V_b + V_c) \tag{16}$$

$$V_1 = \frac{1}{3}(V_a + aV_b + a^2V_c) \tag{17}$$

$$V_2 = \frac{1}{3}(V_a + a^2V_b + aV_c) \tag{18}$$

where

V_0, V_1, V_2 are zero sequence, positive sequence and negative sequence components of phasor value respectively

$a = e^{j2\pi/3} = 1\angle 120^{o}$

Table 7 summarizes the classification of voltage dip for all the fault conditions done by applying the symmetrical component algorithm. For one of the available measurements, the dip type, characteristic voltage and the PN-factor were calculated. Example of dip-characterization by the characteristic voltage for phase-A fault:

i. The dip is classified as type C_b,,a single drop in phases a and c.

$$k = \frac{1}{60} \times \arg\left(\frac{V_{neg}}{1 - V_{pos}}\right) \quad \textbf{(19)}$$

ii. The voltage components were calculated for each time instant as well as the characteristic voltage. The remaining voltage during the dip event changes with time which will also affects the characteristic voltage. The lowest characteristic voltage during the dip was 0.84 p.u. and the duration of the dip was 0.065s.

$$V_{characteristic} = V_{positive} - V_{negative} \quad \textbf{(20)}$$

$$e^{(-i*k*\pi/3)} \quad \textbf{(21)}$$

iii. The PN-factor is calculated and the lowest value obtained during the dip was 0.89 p.u.

$$Pn - factor = V_{positive} + V_{negative} \quad \textbf{(22)}$$

Table 7 : Voltage dip characterization

	Phase-A Fault	Phase-B Fault	Phase-C Fault
V_0	0.940	0.917	0.913
V_1	-0.0649+j0.0606	0.0167-j0.0231	0.0333+j0.5196
V_2	-0.0649-j0.0606	0.0167+j0.0231	0.0333-j0.5196
Type	C_b	D_b	D_c
|V|	0.84	0.85	0.82
P_n factor	0.89	0.96	0.94

4.2.6 Voltage Dip Characterization

The simulation data showed that the characterization of voltage dips by using RMS voltage magnitude can be a good measure to predict severity of a dip in term of less complex approach. The two methods used for characterization of voltage dips gives almost similar results. The method with application of the Mann and Morrison algorithm was proven to give quicker response as well as successful in determining frequency approximation of the system. Furthermore, this method which was applied together with characteristic voltages can give more information such as phase angle and how it changes during the event. However, the algorithm cannot provide accurate information on location of the source of voltage dip.

Table 8 : Comparison of two algorithms (voltage amplitude)

Fault	RMS voltage	Characteristic voltage	Difference
Phase-A	0.81	0.84	-0.03
Phase-B	0.86	0.85	0.01
Phase-C	0.79	0.82	-0.03

Table 9 : Comparison of two algorithms (duration)

Fault	RMS voltage	Characteristic voltage	Difference
Phase-A	0.063	0.065	-0.002
Phase-B	0.083	0.082	0.001
Phase-C	0.079	0.077	0.002

4.2.7 Reducing Voltage Dip Effects

Very few utilities and interfaces in the world escape voltage dip. Even those with total underground systems in a small geographic area suffer from this phenomenon. There are several steps that can be taken to reduce the voltage dip effects since they cannot readily be eliminated from regular utility systems. The steps are inclusive of:

a) Identifying the problem
   i. Equipment identification.
   ii. Voltage dip identification

b) Measuring the problem
   i. Installation of metering
   ii. Record unplanned production failure

c) Choosing a solution
   i. Changing of sensitive equipments
   ii. Using electronic voltage regulator
   iii. UPS solution

However, this work will only concentrate on methods for extracting data and information from voltage dip event itself. The general procedure of analyzing and characterizing the dip event is summarized in the following figure

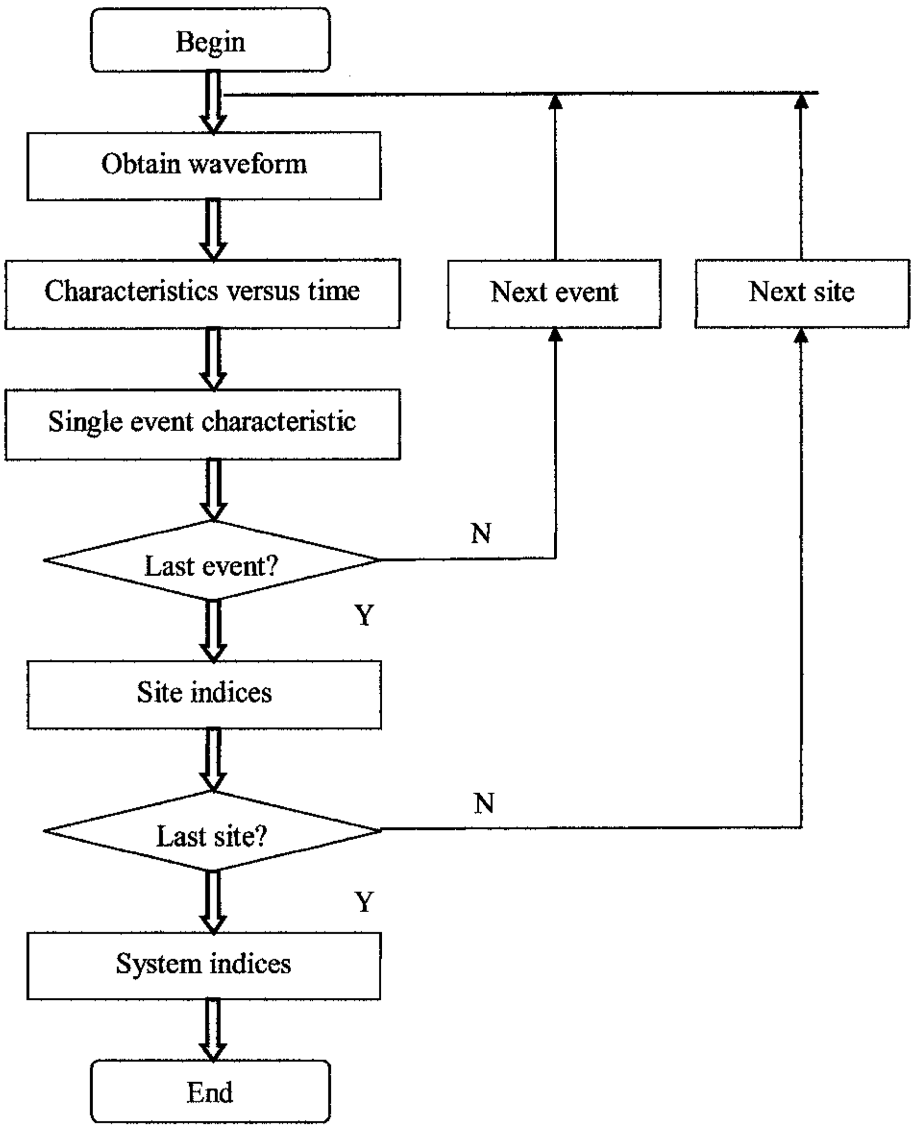


Figure 27 : General procedure for calculating event characteristics and indices

It is crucial to know on the probability distribution of the number of voltage dip events per year for interpreting accurate results for power quality monitoring purposes. An often method which is usually performed is by collecting voltage dip statistic and assuming that the average dip frequency in the previous event is almost equal to the expected value for the future.

Collecting voltage dip statistics that occur in three-phase systems needs the choice of phase-to-phase or phase-to-ground measurements. Studies have shown that the phase-to-phase measurements at medium and higher level of voltage give better information and observation of the voltage dip occurrence happened in the equipment compared to phase-to-ground measurements. To get accurate results and ensure better performance, it is recommended to perform phase-to-phase measurements to detect the voltage dip event.

Some voltage dip is said to be very sensitive to threshold settings. Hence, it is required to clearly indicate the threshold setting used when analyzing the result. The standard value of threshold setting recommended for voltage dip characterization is 90%.

4.2.8 Parameters to Measure Voltage Dip Occurrences

Parameters are attributes of a voltage or current signal that can be used to identify and analyze power quality disturbance. These parameters will then being combined into power quality indices, given an example of the RMS voltage as an index for voltage variation. Basically, voltage dips are characterized by determining some important parameters including voltage magnitude, phase angle jump and the duration of the dip occurrence.

a) Voltage magnitude

The IEC power quality measurement standard 61000-4-30 [1] defined a very precise approach for determining the voltage magnitude as in time domain. In order to determine the magnitude, it is crucial to obtain the RMS voltage value over a window which is exactly equal to one cycle of the normal frequency. The window is shifted one half-cycle in time that will result in a discrete function with a time step equals to one-half cycle of the frequency.

b) Phase angle jumps

Most voltage dip events are closely related with phase angle jump [12]. This means that the voltage signal does not only experience drop in magnitude but also get affected for the phase angle. This phenomenon is visible in the waveform as a shift in the zero voltage crossings and it is caused by two reasons which are:

i. The difference between the X/R ratio of the source and of the faulted feederwill result in phase angle jump within three phase supply system.
ii. The voltage dip events which are caused by nonsymmetrical faults have higher potential of phase angle jumps occurrence.

Phase angle jump is not a main concern in voltage dip event since it only affects certain equipment such as power electronics converters that uses phase angle information for switching purpose.

c) Duration of voltage dip event

The approximate time duration where the system is affected by voltage dip can be easily determined from the shape of the RMS sequence itself. The duration of a disturbance is the time when at least one of the RMS voltages is below the threshold limit. Although the RMS sequences can determine the triggering points, it also has limitation where the triggered points may have low accuracy regarding their exact time position.

d) Unbalance of dip

Faults in power systems are classified into two types which are symmetrical and unsymmetrical faults. Voltage dip can also be divided as symmetrical or unsymmetrical depending on the type of fault. Three phase fault will cause symmetrical dip while single phase, double phase or double phase to ground faults will result in unsymmetrical or unbalanced dip.

4.2.9 Factors Affecting Voltage Dip Characteristics

Several factors which affect voltage dip characteristics are:

a) Type of fault

Type of fault in power system distribution is the main factor that affect dip characteristic. Voltage dip may be balanced or unbalanced in all of the three phases depending on the type of fault. This factor can also affect the magnitude as well as phase angle of voltage dip event. Examples of faults that can cause voltage dip event are single-phase fault, phase-to-phase fault and two-phase-to-ground fault.

b) Location of fault

The location of fault will definitely affect on the magnitude and the phase angle jump of the voltage dip event. The sensitive load is located at distribution level but the fault at distribution level and transmission level will have an influence on both magnitude as well as phase angle jump.

c) Point on wave of dip initiation

The point on wave of dip initiation is the phase angle of the fundamental voltage at the beginning of voltage dip occurrence. This angle is defined as the angle at which the short circuit fault occurs. The change in point in wave of dip initiation will cause the phase angle jump to change more as compared to the magnitude of the dip.

d) Single/double circuit transmission

The purpose of having double circuit transmission in the power system is mainly to improve reliability. Any of the transmission line can be maintained as a double circuit to study on the influence of disconnection of lines on the dip magnitude and phase angle. Changing the transmission configuration will also change X/R ratio of impedance that will definitely affect characteristic of voltage dip.

CHAPTER 5
CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Detection and measurement of voltage dips must be done precisely to obtain and analyze the cause or source of the disturbances. Variety of short-time interval for power quality problem which are currently concerning on the voltage dip event detection has been discovered. Development in the area enables the effort to reduce or totally terminate the effects of power systems fault especially in the industrial area.

The processing of power quality monitoring data using signal processing have been developed through the years from the theoretical point and from the application point. From the sampled waveforms, information of voltage dip event is extracted to determine some parameters such the retained voltage and duration of dip. To extract the parameters from the waveform, it is important to apply the concept of both signal processing and power systems.

This work presents methods to discriminate between the use of wavelet-based Man and Morrison algorithm with the Root Mean Square (RMS) numerical approach. The characterization based on RMS voltage calculation might be easier to be understood. However, there are limitations present in this method which it can only predict the minimum value of the remaining RMS voltage as well as the duration of the dip during the occurrence.

The ability of wavelet-based method in segregating a signal into multiple frequency levels is undeniable since it is proven to be the best method in analyzing power quality problems. The combination of wavelet transform and the Mann and Morrison algorithm is capable of determining the amplitude and phase angle of system voltage. Although the wavelet-based algorithm produces accurate result and quickly analyzes the voltage dip characterization, the method does not succeed in determining required information for the direction of the voltage dips.

The choice of method to be implemented is a very crucial first step in developing the voltage dip characterization. The understanding on the reason and feasibility of developing the methods are also important since every method has its own benefits and disadvantages. This work is expected to provide suitable methods of quantifying performance of supply system towards voltage dip event that may result in less interruptions and higher reliability.

5.2 Recommendations

The result and discussion part concentrate only on simulation of voltage dip event using MATLAB. However, one of the most simple and suitable method for simulating voltage dip occurrence using software is by performing fault position method. For example, the software can be used to estimate number of dips due to different types of faults on different lines in the system as well as uniform distribution of fault along the lines. There is no need to perform complex programming since different types of faults can be created along the distribution lines by using MATLAB software. Since voltage dip problem usually gives impact to industries, it would be better to futher improve this work by conducting a case study based on industrial environment. The field-measured signal from power electronic equipments in Universiti Teknologi Petronas can be used in order to study the proposed methods on the real condition. Furthermore, the simulation of the system needs to be examined to determine the reason why there were errors in the estimation of the voltage amplitude and phase angle. Further algorithm development would be an advantage to locate the source of voltage dip in order to eliminate the risk.

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APPENDICES

Appendix 1: Matlab M-File for Characteristic Voltage and PN-Factor Calculations.

```
% Computes the value of the characteristic voltage
% and PN-factor during dip occurrence.
% The dimensions Vpos,Vneg,k;

function symmetry = see(Vpos,Vneg,k)


% Compute the value, but suppress printing of the result

x = (Vpos) - (Vneg*(exp((-1*k*pi)/3)))

y = (Vpos) + (Vneg*(exp((-1*k*pi)/3)))
```

Appendix 2: Matlab M-File for Mann and Morrison Algorithm Calculations.

```
% Computes the value of amplitude and phase angle
% of system voltage during dip occurrence.


function algorithm = compute(V1,V3,V4,t1,t2,delt)


% Compute the value, but suppress printing of the result

Vsine = V1;
Vcosine = V2;


omega = 2*pi(1/(2*(t2-t1)))

V2 = ((V3-V4)/(2*omega*delt))

x = sqrt((Vsine^2)+(Vcosine^2))
```

Appendix 3: Matlab M-File for RMS Voltage Magnitude Calculations.

```
% Computes the minimum value of the remaining RMS-voltage
% during dip occurrence.
% The dimensions v and N;
function rms = square(v,N)

% Compute the value, but suppress printing of the result

square = ((1/N)*(v^2))^(1/2);
```

Appendix 4: Matlab M-File for 1-D Wavelet Decomposition Using Daubechies Window.

```
% The current extension mode is zero-padding (see dwtmode).

%1-D wavelet decomposition.

% Load original one-dimensional signal (phase B fault).

s= [-0.984954550551363;-0.997686747495286;-0.996384385259054;-
0.99877538226012;-1.003779374293904;-1.006084862047378;-
1.007708296793432;-1.010511438157346;-1.011368944818738;-
1.01234645728955;-1.012854837651183;-1.013518993633233;-
1.013367090227336;-1.013494436420943;-1.01254657161146;-
1.011334553250252;-1.009436141331969;-1.007746077318327;-
1.00536887350957;-1.00317497522377;-1.000303085079547;-
0.997073372567297;-0.992900947518774;-0.988901961009978;-
0.984280826906017;-0.979821262860171;-0.974739813459403;-
0.969797423232299;-0.963533140648986;-0.95729458236608;-
0.950482287967334;-0.943818968559933;-0.93659357120841;-
0.92948934873224;-0.919900672912103;-0.911991107990693;-
0.903155331097231;-0.894501421477976;-0.885340322737931;-
0.876305156907868;-0.866785700483542;-0.857153083721716;-
0.846446287037543;-0.83562145607796;-0.824391358298948;-
0.813314978502548;-0.801827797408547;-0.7904597942091;-
0.778382917153859;-0.765725141625562;-0.752611635070441;-
0.739666671139097;-0.726388410744393;-0.713249320207644;-
0.698519600478559;-0.682514064287421;-0.669039276470549;-
0.655140389436897;-0.641314140110781;-0.6276581356979;-
0.613578348620444;-0.599198776469887;-0.583424795734294;-
0.566690037234191;-0.549935580834672;-0.533964623273786;-
0.518040448988725;-0.502281058096826;-0.485898010774962;-
0.468477979341744;-0.449908177335707;-0.432195576981291;-
0.414895746138983;-0.398021663542953;-0.380566536918672;-
0.361797635843088;-0.342650815914391;-0.325497678975717;-
0.307843231393279;-0.29064071649402;-0.273275759785097;-
0.255846874229974;-0.237612346786774;-0.218389993075707;-
0.198374138633483;-0.179010769549695;-0.160193409480337;-
0.141838593722167;-0.123328955989442;-0.104369945543847;-
0.08420537249708;-0.063848008877718;-0.044242860860817;-
0.025444154993296;-
0.006841737015133;0.011660789697958;0.030707083912302;0.050322932233
812;0.070364993890041;0.090074977208268;0.109662542047148;0.12896371
5069661;0.148320256557255;0.167570793164435;0.186988357632204;0.2061
76327104446;0.22520610967964;0.243862939820805;0.262474517146406;0.2
8090502446744;0.299479335795668;0.317973757635285;0.336401328614821;
0.354393720341007;0.372245342884195;0.389910355095622;0.407757938378
974;]
% Perform decomposition at level 1 of s using db4.
[c,l] = wavedec(s,1,'db4');

% Perform decomposition at level 2 of s using db4.
[d,l] = wavedec(s,2,'db4');

% Perform decomposition at level 3 of s using db4.
[e,l] = wavedec(s,3,'db4');

% Perform decomposition at level 4 of s using db4.
```

```
[f,l] = wavedec(s,4,'db4');

subplot(311); plot(s); title('Original signal - Phase B fault');
subplot(323); plot(c); title('Approx. coef. for db4-lvl1');
subplot(324); plot(d); title('Approx. coef. for db4-lvl2');
subplot(325); plot(e); title('Approx. coef. for db4-lvl3');
subplot(326); plot(f); title('Approx. coef. for db4-lvl4');
```

Appendix 5: Matlab M-File for Computing The Value of Amplitude and Phase Angle of System Voltage During Dip Occurrence.

```
% Computes the value of amplitude and phase angle
% of system voltage during dip occurrence.


function algorithm = compute(V1,V3,V4,t1,t2,delt)


% Compute the value, but suppress printing of the result

Vsine = V1;
Vcosine = V2;


omega = 2*pi(1/(2*(t2-t1)))

V2 = ((V3-V4)/(2*omega*delt))

x = sqrt((Vsine^2)+(Vcosine^2))
```