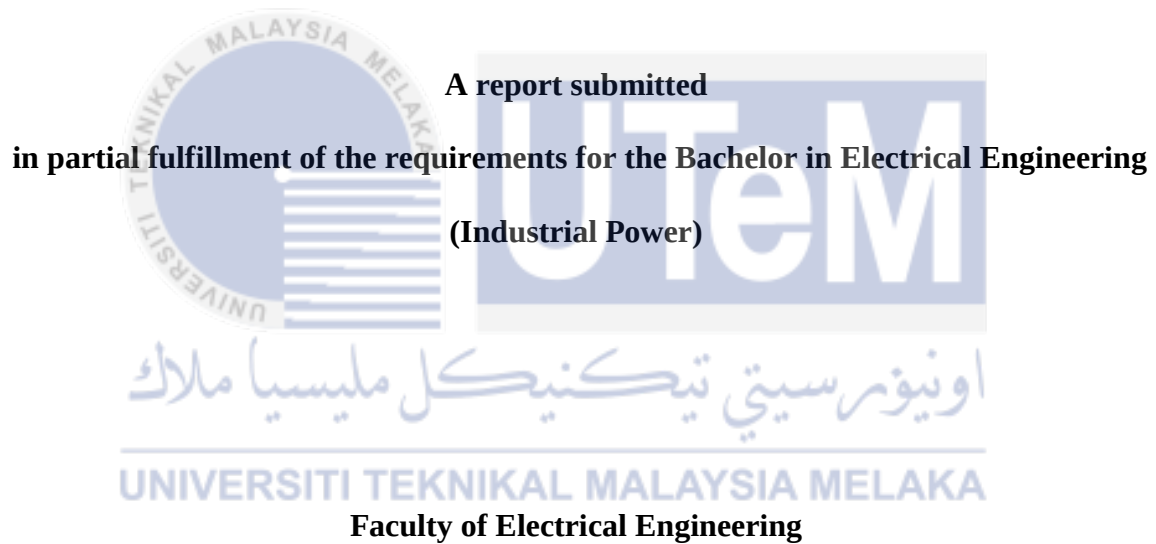


A SMART POWER QUALITY (PQ) CLASSIFICATION VIA GUI

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2015

DECLARATION

I declare that this report entitle “*A Smart Power Quality (PQ) Classification via GUT*” is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in the candidature of any other degree.



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ABSTRACT

Power quality (PQ) is among the main things that is emphasized and is taken into consideration by utilities in order to meet the demands. At each passing day this issue has becoming more serious and at the same time the user's demand on power quality also gets more critical. The increased of power electronics equipment that are more sensitive to minor voltage really give a huge impact on PQ. Therefore, system that has a good and understandable interface should be developed to detect and classify the quality level of voltage in distribution system for recovering process. In order to achieve that, a technique that called phase space has been developed in matrix laboratory (MATLAB) graphical user interface (GUI) as presented in this thesis. Twelve different types of PQ disturbances under different conditions have been tested using the proposed scheme to detect and classify the disturbances. The results indicate that the proposed PQ detection method can effectively detect, classify and display the types of occurred disturbances through GUI.

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ABSTRAK

Kualiti kuasa (KK) adalah antara perkara utama yang ditekankan dan diambil kira oleh utiliti untuk memenuhi permintaan pelanggan. Sejak kebelakangan ini, isu KK telah menjadi lebih serius dan pada masa yang sama permintaan pengguna terhadap kualiti kuasa juga menjadi lebih kritikal. Peningkatan peralatan elektronik kuasa yang lebih sensitif kepada voltan kecil benar-benar memberi kesan yang besar terhadap KK. Oleh itu, satu sistem yang mempunyai antara muka yang baik dan mudah difahami perlu dibangunkan untuk mengesan dan membezakan tahap kualiti dalam sistem pengagihan untuk proses membaik-pulih. Untuk menjayakannya, satu teknik yang dipanggil ruang fasa telah dibangunkan dalam makmal matriks (MATLAB) grafik antara muka pengguna (GUI) seperti yang dinyatakan dalam tesis ini. Dua belas jenis gangguan KK di bawah keadaan yang berbeza telah diuji menggunakan teknik yang dicadangkan dan keputusan membuktikan bahawa teknik tersebut berfungsi dengan baik dalam mengesan dan mengklasifikasikan KK. Hasil kajian menunjukkan bahawa kaedah pengesanan KK yang dicadangkan berhasil untuk mengesan, mengelaskan dan memaparkan jenis gangguan yang berlaku melalui GUI.

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CHAPTER 1

INTRODUCTION

1.1 Research Background

Power Quality (PQ) has becoming a very important even to be concerned by customers especially industrial sectors nowadays. The load variations, load switching, system faults motor starting and non-linear loads are usually will create disturbances in power quality [1]. Flicker, interruptions, sag, swell, under voltage and over voltage are some of electrical disturbances due to the phenomenon above.

For utility companies, power quality really makes a huge impact if it is not controls well. The quality level of voltage is the most importance before it can be supplied to customers. To make sure the quality level of voltage is acceptable, the utilities should recognize first the level of voltage that will be used by customers and if the voltage level is unacceptable, the voltage treatment should be done by detecting and classifying type of PQ.

In this thesis, it shows how PQ disturbances are being detected and classified using the phase space technique. By implementing the technique in MATLAB, the disturbances including sag, swell, interruptions, under voltage and over voltage will be processed and then displayed through the interface that has been developed via GUI.

1.2 Problem Statement

Power Quality problems has been a source of major concern in recent years due to extensive used of power electronic devices and non-linear loads in electrical power system which have led to large growth in the number of voltage disturbances. To monitor the disturbances, many techniques have been implemented and a common way to detect and classify the disturbances is based on frequency-based approach such as discrete Fourier transform (DFT) and wavelet transform (WT). However, these techniques have some limitations. Even DFT has a great application to periodic signals but it fails to track a transient signal due to the limitation of a fixed length window length [2]. So, DFT cannot be used successfully for high frequency components. For WT, it is able to identify the details of localized transient but it required a sampling window of a certain length to perform integral calculations which increases the computational burden and impairs its attraction [2]. Besides that, artificial intelligence-based algorithms also has been proposed for disturbances detection. This technique can provides a satisfactory classification results but it relies on massive data for training which greatly limits the practical application [3]. It seems that phase space technique is the best choice for monitoring the disturbances due to this technique can be used to classify all the PQ events just by analyse the shape (ellipse) of the voltage signal that has been transformed from original voltage waveform [3].

Meanwhile, a lot of software are applicable in displaying the detected disturbances through an interface such as common line interface (CLI) and menu-driven user interface. CLI is flexible in completing an interface task even for a complicated one. However, due to a lot of syntax should be remembered to perform a task, it will caused human error that can affects the results [4]. For menu-driven user interface, user is provided with a hierarchically organized set of choices but if the structure of menu is complex, users will fail to correctly perform a task on a menu [5]. Development on interface software has been improved from time to time and MATLAB GUI is one of them. It is the best graphical user interface due to the guidance of menu-based that has installed in MATLAB GUI which has reduced the difficulty of remembering the syntax. So that the system has easier users to perform a task and at the same time will reduces human error [4].

1.3 Objective

The objectives of this project are listed below:

- i. To develop system that will detect and classify the quality level of voltage in distribution system in Malaysia for single phase and three phase via phase space technique.
- ii. To develop an easy interface to read by customers via MATLAB GUI for power quality disturbances (voltage quality level).

1.4 Scope of Project

This project monitored the quality level of voltage in distribution system where MATLAB GUI processed the voltage signals through phase space technique. The voltage signals data that obtained from Tenaga Nasional Berhad (TNB) are saved in text format (.txt) first before processed by a system (MATLAB GUI). The system only specialized to classify the quality of voltage level for 230V (+10% -6%) and 400V (+10% -6%) according to standard that has been decided by TNB for single phase and three phase system in Malaysia. Apart from that, this system is built to only locate, identify and classify normal voltage and twelve voltage disturbances which are instantaneous short duration variations (interruption, sag and swell), momentary short duration variations (interruption, sag and swell), temporary short duration variations (interruption, sag and swell) and long duration variations (interruption, under voltage and over voltage).

1.5 Report Outline

There are 5 chapters in this research project. For **Chapter one**, it is discussed about the introductory of this project. Then for **Chapter two**, the parameters of literature reviews which are power quality (PQ), technique in classifying power quality interruption and previous research are discussed. Methodology is in **Chapter three** where the steps in

achieving the objectives of this research is detailed discussed. Starting with locate the voltage signal, transform the voltage signal through phase space technique and process the voltage signal via GUI. In **Chapter four**, the result of the tested voltage signals are explained in there. For the last chapter (**Chapter five**), conclusion on this project is literally pointed out.



CHAPTER 2

LITERATURE REVIEW

2.1 Power Quality (PQ)

Power Quality (PQ) is a term used that can disrupted or damaged sensitive electronic device [5]. Ideally, the best electrical supply would be a constant magnitude and frequency sinusoidal voltage waveform. However, because of the non-zero impedance of the supply system, of the large variety of loads that may be encountered and of other phenomena such as transients and outages, the reality is often different. If the PQ of the network is good, then any loads connected to it will run satisfactory and efficiently. Installation running costs and carbon footprint will be minimal. If the PQ of the network is bad, then loads connected to it will fail or will have a reduced lifetime, and the efficiency of the electrical installation will reduce. Installation running costs and carbon footprint will be high and/or operation may not be possible at all.

2.2 PQ Characterization

Power Quality can be characterized into several types based on the amplitude and duration of occurrence (frequency) of the voltage signal. Some of types of PQ have the same amplitude but differ in the duration of occurrence. Apart from that, there are also types of PQ that have the same duration of occurrence but differ in the amplitude. The types of PQ characterization based on amplitude and duration of occurrence is shown in Table 2.2.

Table 2.2: Typical PQ characters [6]

Item	Categories	Typical Duration	Typical Voltage Magnitude
1.0	Short Duration Variation (Instantaneous) - Interruption - Sag (dip) - Swell	0.5 – 30 cycles 0.5 – 30 cycles 0.5 – 30 cycles	<0.1 p.u 0.1 - 0.9 p.u 1.1 – 1.8 p.u
2.0	Short Duration Variation (Momentary) - Interruption - Sag (dip) - Swell	30cycles – 3s 30cycles – 3s 30cycles – 3s	<0.1 p.u 0.1 - 0.9 p.u 1.1 – 1.4 p.u
3.0	Short Duration Variation (Temporary) - Interruption - Sag (dip) - Swell	3s – 1min 3s – 1min 3s – 1min	<0.1 p.u 0.1 - 0.9 p.u 1.1 – 1.2 p.u
4.0	Long Duration Variation - Interruption sustained - Under voltages - Over voltages	>1min >1min >1min	<0.1 p.u 0.1 – 0.9 p.u 1.1 – 1.2 p.u

2.2.1 Voltage Sag

Voltage sag is one of the common disturbance in voltage signal. Typically, large loads such as an electric motor or an arc furnace can create a voltage sag [7]. By definition, voltage sag is an event that can last from half of a cycle to several seconds depends on the types of voltage sag whether short instantaneous, momentary or temporary. The magnitude of voltage sag is lower than the normal (pure) voltage signal. Figure 2.2 shows the voltage signal during sag event.

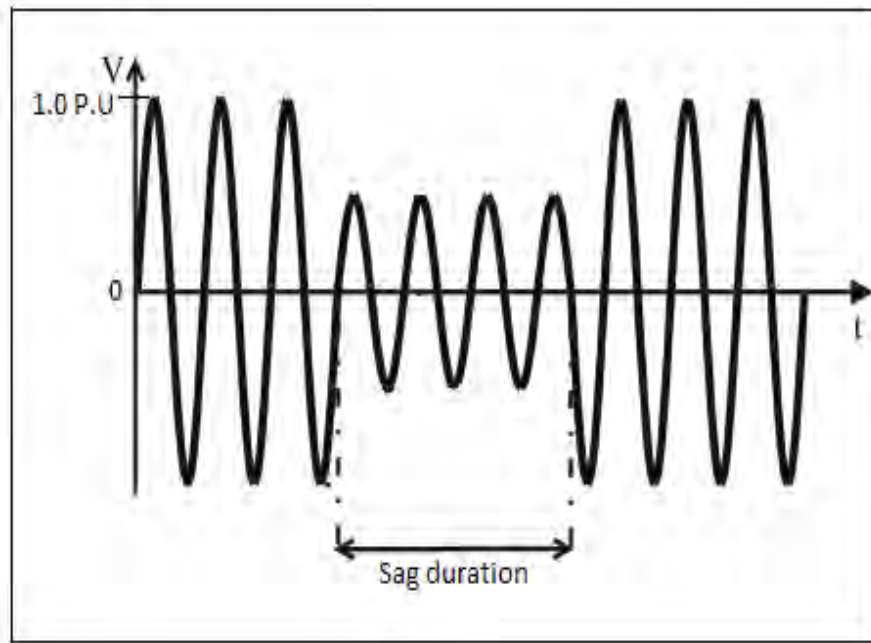


Figure2.2: Voltage sag signal

2.2.2 Voltage Swell

Swell normally related to system fault conditions but is not as common as voltage sag. Energizing a large capacitor bank and switching off a large load can caused swell [8]. Differ with sag, swell is the increment of voltage signal above than normal. A different types of swell category will have a different value of voltage magnitude and the duration as stated in Table 2.1. Instantaneous swell is the shortest duration followed by momentary swell and the longest swell event is temporary swell. Figure 2.3 shows the signal of voltage during swell event.

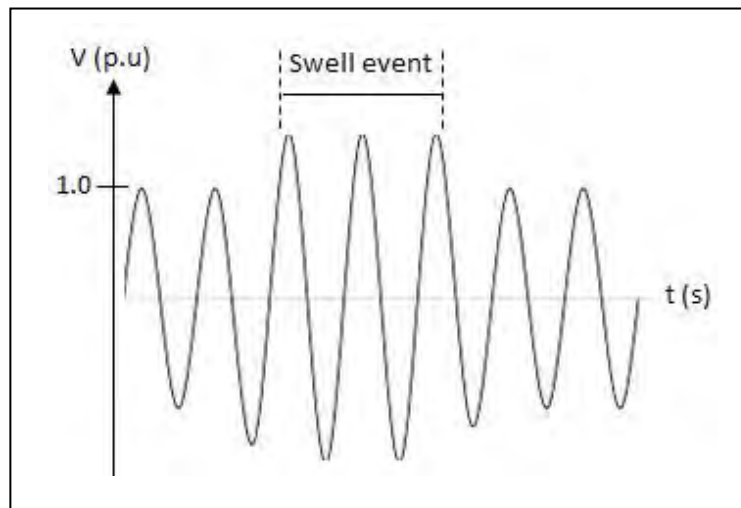


Figure 2.3: Voltage swell signal

2.2.3 Interruption

Interruptions can be the result of power system faults, equipment failures, and control malfunctions [8]. During interruption, the voltage magnitude is always below ten percent of nominal while the duration is specified according to the types of interruption whether instantaneous, momentary, temporary or interruption sustain. Figure 2.4 shows the signal of voltage during interruption.

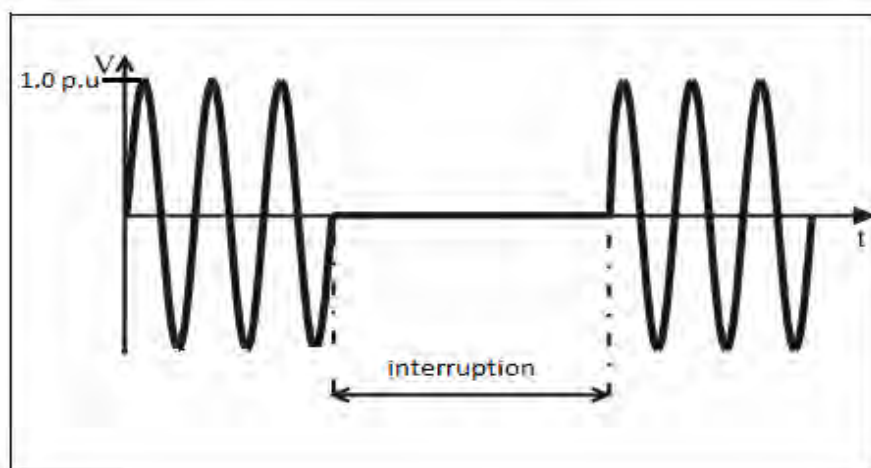


Figure 2.4: Interruption signal

2.2.4 Undervoltage

An under voltage is a decrease of ninety percent of voltage amplitude from nominal. Even has the amplitude as sag, however the duration of undervoltage more than one minute. Undervoltages are the result of switching events that are the opposite of the events that cause overvoltages. A load switching on or a capacitor bank switching off can causes an undervoltage until voltage regulation equipment on the system can bring the voltage back to within tolerances [8]. The signal of undervoltage is shown in Figure 2.5.

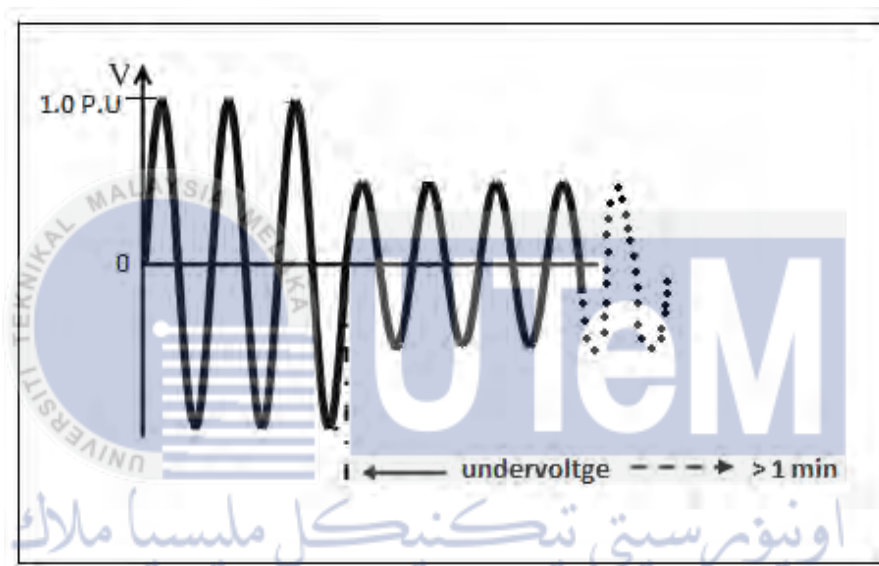


Figure 2.5: Undervoltage signal

2.2.5 Overvoltage

An overvoltage is an increase by ten percent of voltage magnitude from nominal for a duration longer than one minute. Overvoltage usually due to energizing a capacitor bank or switching off a large load [8]. The overvoltage result because either the system is too weak for the desired voltage regulation or voltage controls are inadequate [8]. Incorrect tap settings on transformers can also result in system overvoltage [8]. The example of overvoltage signal is shown in Figure 2.6.

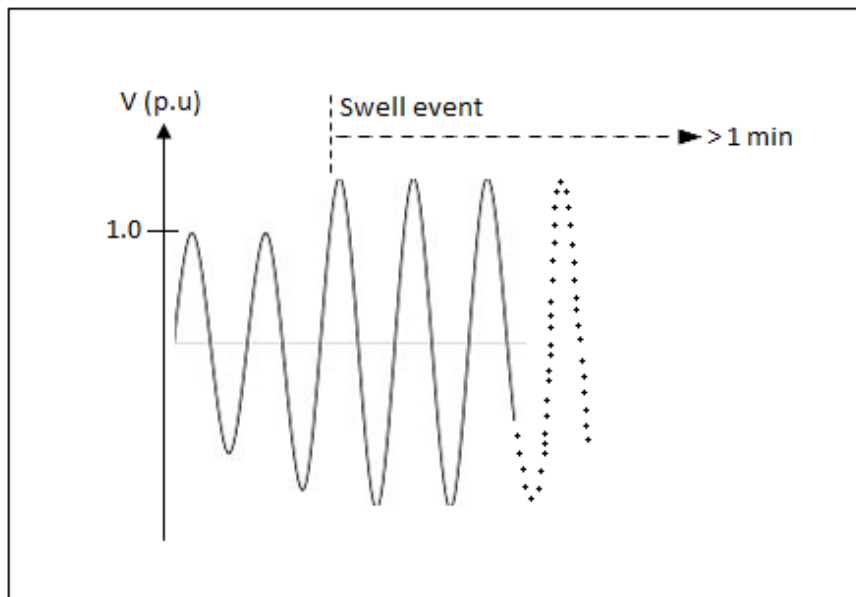


Figure 2.6: Overvoltage signal

2.3 Power Quality Costs Evaluation

Any organizations that related to power quality problem while handling their electrical power systems will face the increment of their costs. During disturbances in power quality, costs can be divided into:

- a) Direct costs, which are the costs that relate to the disturbances directly. Salary costs, restart costs, loss of raw materials, damage in equipment and loss of productions are all included in direct costs. Sometimes, during disturbances may be it will not imply production stoppage but other costs may relate to the events like reduction of equipment life and reduction of equipment efficiency [9].
- b) Indirect costs. These costs are hardly to evaluate but by taking a situation, a company may not be able to accomplish the delivery on the deadlines due to power quality interruptions. It will be even difficult situation when the company will lose future orders. So that, the investments to prevent power quality problems can be considered as indirect costs [9].

2.4 Costs of Momentary PQ Interruption

Interruptions in power quality will create a huge impact on facilities even just momentary. The costs presented are different for different customers and they are without major investments. The values are based on Electrotek Concept and publish service with individual studies [10]. Table 2.3 below summarizes costs that consumers will face during momentary interruptions [11].

Table 2.3: Typical costs of momentary interruptions [11]

	Cost of momentary interruptions (\$/kW demand)	
	Minimum	Maximum
Industrial		
Automobile manufacturing	5.0	7.5
Rubber and plastics	3.0	4.5
Textile	2.0	4.0
Paper	1.5	2.5
Printing (newspapers)	1.0	2.0
Petrochemical	3.0	5.0
Metal fabrication	2.0	4.0
Glass	4.0	6.0
Mining	2.0	4.0
Food processing	3.0	5.0
Pharmaceutical	5.0	50.0
Electronics	8.0	12.0
Semiconductor manufacturing	20.0	60.0

2.5 PQ Classification Technique

During PQ interruptions, current or voltage waveforms are recorded in order to determine type of PQ. The waveforms are continuously recorded by using power

monitoring instruments where digitized time series of sampled data will generate. Based on previous researchers, discrete Fourier transform (DFT), wavelet transform (WT) and analysis of root-mean-square (RMS) of voltage are the common ways in accessing and monitoring the recorded data. DFT is good to apply for periodic signals but it will not tracks transient signal due to the limitation that it must performed in a window of a fixed length [12]. Meanwhile, WT is a technique to construct a string of time-frequency representations of a signal and the representations are in different solutions which means it is more suitable in identifying details of localized transients. However, sampling window of a certain length is required for WT to perform integral calculations, which increases the computational burden and impairs its attraction. Apart from that, time domain which is essential for the analysis of some particular distorted portion of power system signals is not capable by using WT [13]. The analysis of RMS value of voltage is a good approached but by detecting RMS voltage only is not enough to recognize and classify PQ events due to frequency also changes during interruptions [13]. In this project, PQ classification are rely on the shape information of a power system signal. Compare to the above techniques, analysing the signal data by using phase space technique (used in this project) is more capable in classifying PQ events [14]. Refer to Table 2.1, TNB has stated that voltage magnitude (voltage) and typical durations (frequency) are the two main items in classifying PQ. So that, by monitoring voltage and frequency through phase space technique is enough to classify PQ events in this project.

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2.6 Graphical User Interface (GUI)

A graphical user interface (GUI) is a graphical display in one or more windows that enable a user to perform interactive tasks. The development of GUI software applications has made a good improvement in programming field where the difficulty of remembering syntax and semantic has been eliminated by providing the guidance of menu-based interactive properties it delivers [15]. A task can be completed by just create a script and type the commands at the command line of GUI. The components in user interface including menus, toolbars, push buttons, radio buttons, list boxes, and sliders as shown in Appendix A.

MATLAB is one of the software that provide GUI for user to perform any type of read and write data files, communicate with other user interface and display data as table or as plot [16] which means that it is applicable to test the voltage signal by displaying the desired output through table or plot.



CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

This chapter describes the development of the proposed power quality classification technique based on phase space feature extraction. Apart from that, development of will be discussed further in this chapter.

3.2 Phase Space Technique

A dynamical system normally described by a state space where each orthogonal coordinate represents the variable needed to clarify the state of a system [17]. So that all the possible states of the dynamical system are represented in the state space and each possible state corresponds to a unique point. Normally, it is impossible to measure the variables of a dynamical system but Takens in [18] has proved that it can be reconstructed from a time series of a collection of the states using the embedding theorem.

The solution of this equation $\mathbf{s} \in \mathfrak{R}^D$, is a state in the corresponding phase space where $\mathfrak{R}$ indicates the Euclidean space. The measured function $\mathbf{x} = h(\mathbf{s})$ transform a collection of $\mathbf{s}$ state to a scalar time series. The ‘delay’ of the time series is denoted by a positive number of τ . The evolutions of the state $\mathbf{s}$ at time i is defined by the function $\mathbf{F}_\tau(\mathbf{s}_i) = \mathbf{s}_{i+\tau}$. So, the embedding $\Phi: \mathfrak{R}^D \rightarrow \mathfrak{R}^{DE}$ which is called the delay-coordinate is defined as

$$\begin{aligned}\Phi(h, F, \tau)(s_i) &= \{h(s_i), h(s_{i+\tau}), \dots, h(s_{i+(d_E-1)\tau})\} \\ &= \{x_i, x_{i+\tau}, \dots, x_{i+(d_E-1)\tau}\} = x_i\end{aligned}\quad (3.1)$$

So, a trajectory matrix of dimension d_E and delay τ is can be constructed in the following way,

$$\begin{aligned}X &= \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_M \end{bmatrix} = \begin{bmatrix} x_1 & x_{1+\tau} & \cdots & x_{1+(d_E-1)\tau} \\ x_2 & x_{2+\tau} & \cdots & x_{2+(d_E-1)\tau} \\ \vdots & \vdots & \ddots & \vdots \\ x_M & x_{M+\tau} & \cdots & x_{M+(d_E-1)\tau} \end{bmatrix} \\ &= [\dot{X}_1 \quad \dot{X}_2 \quad \cdots \quad \dot{X}_{d_E}]\end{aligned}\quad (3.2)$$

where, τ is the delay, $\dot{X}_i (i = 1, 2, \dots, d_E)$ are column vector that form the coordinate of each d_E dimension, and the row vectors $x_i (i = 1, 2, \dots, M)$ represent individual point in the phase space. The correlation dimension is defined as

$$C(r) = \lim_{N \rightarrow \infty} \frac{1}{N^2} \sum_{i=1}^N \sum_{j=1}^N \theta(r - |x_i - x_j|) (i \neq j) \quad (3.3)$$

where, x_i and x_j are two arbitrary points, and $\theta(a)$ is the Heaviside step function with a value of zero for negative algorithm and one for positive algorithm.

$$\theta(a) = \begin{cases} 0, & \text{if } a < 0 \\ 1, & \text{if } a \geq 0 \end{cases} \quad (3.4)$$

The number of pairs (x_i, x_j) calculated by Eq. (3.3) satisfies $|x_i - x_j| < r$. A small r suppose that $C(r)$ behaves as $C(r) \propto r^{d_c}$, such that d_c is the correlation dimension and estimated by

$$d_c = \lim_{r \rightarrow 0} \frac{\log C_r}{\log r} \quad (3.5)$$

The embedding dimension is defined by $2d_E = [2d_c + 1]$. In the proposed method, the delay is selected to demonstrate the geometric data of the perturbation signal. In the sinusoidal waveform is given by $F(t) = A \sin(\omega t + \varphi)$, the sample signal can be expressed by $F(k) = A \sin(\omega k \Delta t + \varphi)$. In this case, $Ns = 2\pi/(\omega \Delta t)$ is the sampling rate in each period. Embedding the signal to phase space of $d_E = 2$ with a delay of quarter of its period, $\tau = Ns/4$ shows that the embedded signal is an ellipse. Using x, y to represent the coordinates of phase space, x_1 and x_2 , respectively the embedded signal in the phase space can be defined by the following equations:

$$\begin{cases} x + y = 0 \\ x^2 + y^2 = A^2 \end{cases} \quad (3.6)$$

Eq. (3.6) in the xy -plane constitute a circular waveform with radius that is the amplitude of the original signal and centre that is the source of the plane. The Euclidean norm of each point on xy -plane will be obtained through the following equation:

$$E(k) = \sqrt{x_k^2 + x_{k+\tau/4}^2}, \quad k = 1, 2, 3, \dots \quad (3.7)$$

Euclidean norm for points belonging to the normal part of the signal should be within the range of $[A(1 - \gamma), A(1 + \gamma)]$, where γ is the threshold introduced to tolerate the noise corruption. Points in which E falls out of this range are detected as disturbances. The beginning to ending samples of the disturbances are recorded using detection scheme. In this project, E_k is utilized to extract special features to classify PQ events.

3.3 Disturbances Classification

As stated in Table 2.2, the characters of each type of disturbances are differ to each other. From Eq.(3.7), the amplitude of voltage signal can be recognized but it is not enough to claim the type of PQ disturbances just by their amplitude. The typical duration (T_d) of the events should be compared too with voltage amplitude in order to get the exact type of

PQ disturbances. T_d is varied for different types of disturbances. The value of T_d is affected by frequency (f) and total number of selected point in one complete cycle (N).

The illustration in Figure 3.1 shows how the features extraction is obtained through phase space technique. Based on Eq.(3.7), it shows that the value of E_k will be obtained from the values of x_k and $x_{k+\tau/4}$. According to Figure 3.1 (a), X1 represents the value of x_k while X6 represents the value of $x_{k+\tau/4}$. So, as the voltage signal keeps flowing, there is increasing value of k which means that the next E_k value is obtaining from X2 and X7 and so forth. Meanwhile, Figure 3.1 (b) represents the ellipse form of the Euclidean norm. The shape of ellipse will determine whether the Euclidean norm belongs to the normal part of the signal or not. If it is within the range of $[A(1 - \gamma), A(1 + \gamma)]$, will be classify as normal but if falls out of the range detected as disturbances.

The next step is to determine the duration of events, T_d . As illustrated in Figure 3.2, there are several numbers of N for a complete cycle, T . In this project the number of N is fixed by the value of 128 for one complete cycle which means $T = 128$ (number of N). So, by using $f = \frac{1}{T}$, for one second duration of event can be determined by multiply the number of N in one complete cycle with the value of frequency. By having both values of Euclidean norm and duration of events, PQ can be classified and Table 3.3 shows the classification of PQ based on the value of Euclidean norm, E_k and duration of events, T_d .

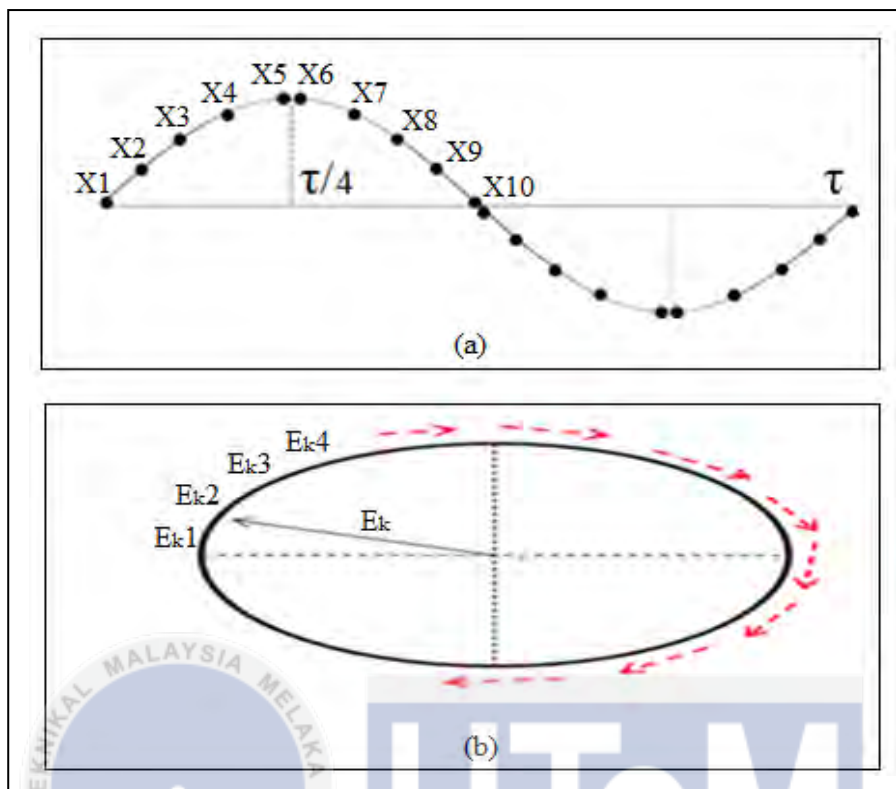


Figure 3.1: E_k figure (a) Original waveform (b) Phase space (ellipse)

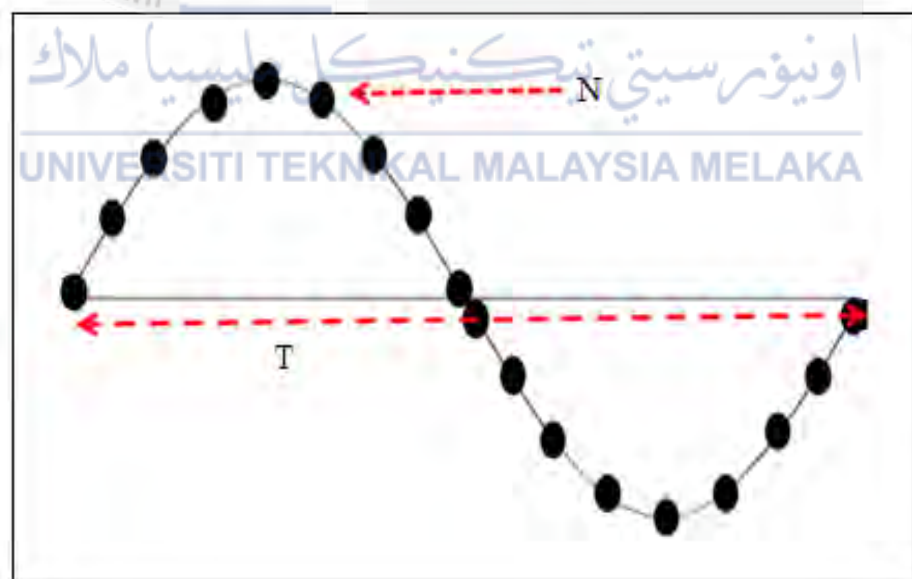


Figure 3.2: Duration of event

Table 3.3: Determination of PQ type

Item	Categories	Typical Duration (T_d)	Typical Voltage Magnitude (P.U)
1.0	Normal	-	$0.9 < E_k < 1.1$
1.0	Short Duration Variation (Instantaneous) - Interruption - Sag (dip) - Swell	$0.5N \leq T_d \leq 30N$ $0.5N \leq T_d \leq 30N$ $0.5N \leq T_d \leq 30N$	$E_k < 0.1$ $0.1 \leq E_k \leq 0.9$ $1.1 \leq E_k \leq 1.8$
2.0	Short Duration Variation (Momentary) - Interruption - Sag (dip) - Swell	$30N \leq T_d \leq (3fN)$ $30N \leq T_d \leq (3fN)$ $30N \leq T_d \leq (3fN)$	$E_k < 0.1$ $0.1 \leq E_k \leq 0.9$ $1.1 \leq E_k \leq 1.4$
3.0	Short Duration Variation (Temporary) - Interruption - Sag (dip) - Swell	$(3fN) \leq T_d \leq (60fN)$ $(3fN) \leq T_d \leq (60fN)$ $(3fN) \leq T_d \leq (60fN)$	$E_k < 0.1$ $0.1 \leq E_k \leq 0.9$ $1.1 \leq E_k \leq 1.2$
4.0	Long Duration Variation - Interruption sustained - Under voltages - Over voltages	$T_d > (60fN)$ $T_d > (60fN)$ $T_d > (60fN)$	$E_k < 0.1$ $0.1 \leq E_k \leq 0.9$ $1.1 \leq E_k \leq 1.2$

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3.4 Designing of PQ Classifier Using GUI

The classification process begins by inserting the voltage signal into GUI system. Next, features extraction is obtained through phase space techniques where T_d and E_k of voltage signal are recognized. According to the features extraction, the system will make the decision to classify the PQ events. The summary of PQ classifier is shown in Figure 3.4.

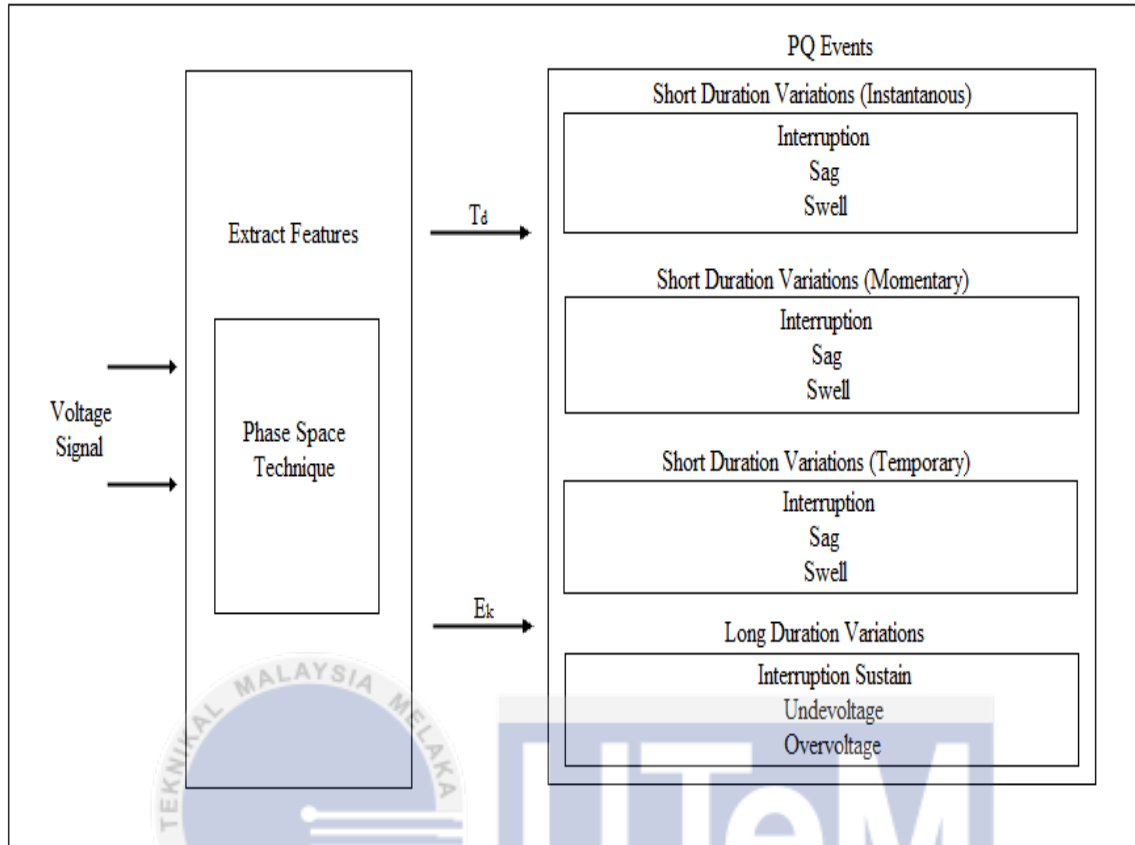


Figure 3.4: Summary of PQ classifier

The overall implementation step of the proposed method illustrated above can be described as follow and in a flowchart shown in Figure 3.5 respectively:-

Step 1: Insert test voltage base (V), frequency (Hz) and number of N.

Step 2: Transfer the voltage signal data that will be tested.

Step 3: Euclidean norm, E_k and duration of events, T_d recognition.

Step 4: Type of PQ events classification.

Step 5: Checking for normal voltage signal. If values in **Step 3** according to normal character, then the system will classify the test voltage as normal. If it is not, then the system will continue checking for abnormal events (PQ).

Step 6: The same procedure as in **Step 5** but the checking process is now for short duration variations (instantaneous) PQ. The system will recognize the test voltage signal as interruption, sag and swell, well if the values in **Step 3** according to them but if none then system will check for the next PQ events.

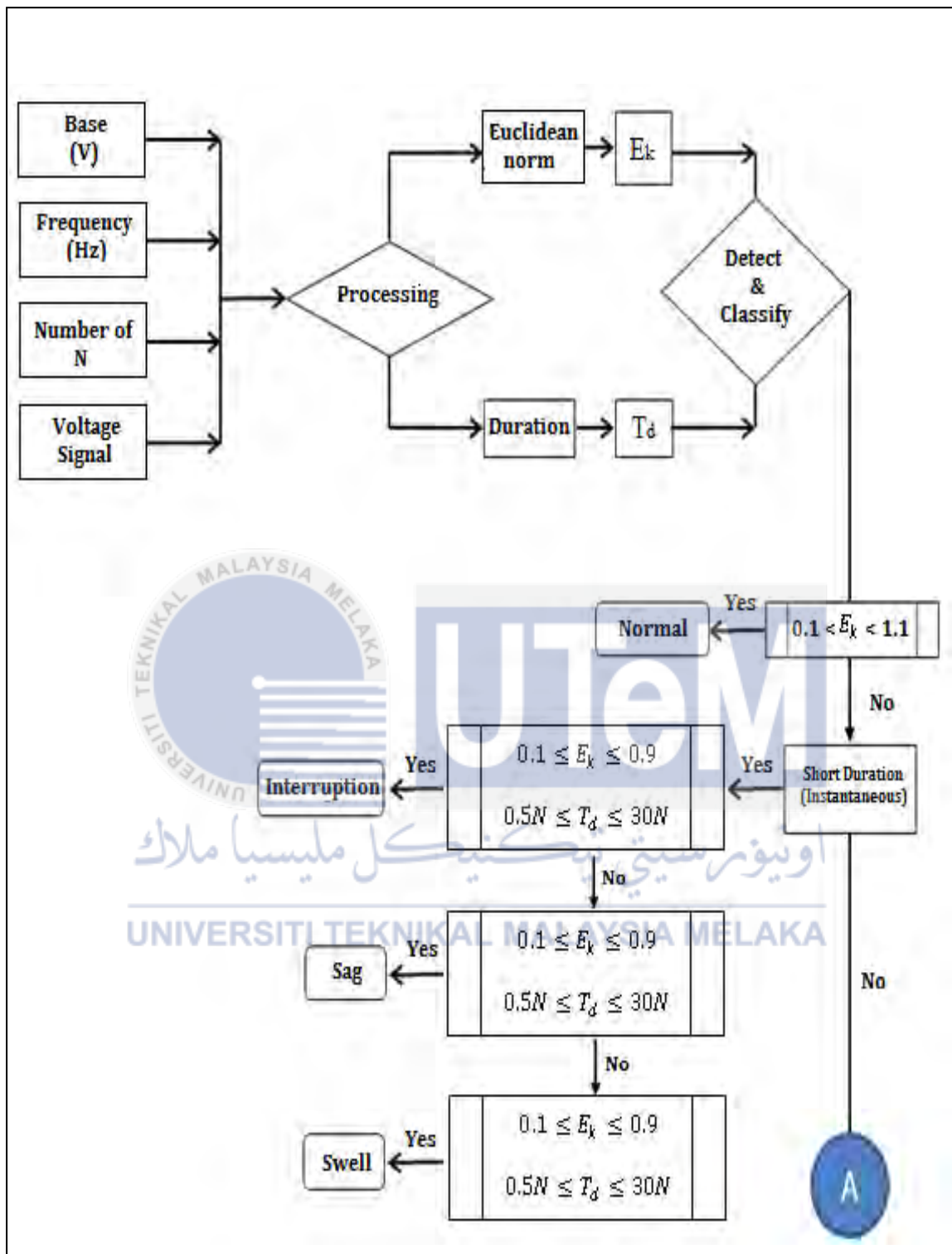
Step 7: Checking for short duration variations (momentary) PQ and the procedure is the same as in **Step 6**. If none values in **Step 3** according to the events then the system will check for another PQ events.

Step 8: Checking for short duration variations (temporary) PQ. The same procedure as in **Step 7**.

Step 9: Checking for the last event, long duration variations PQ with the same procedure as in **Step 8**.

Step 10: End.





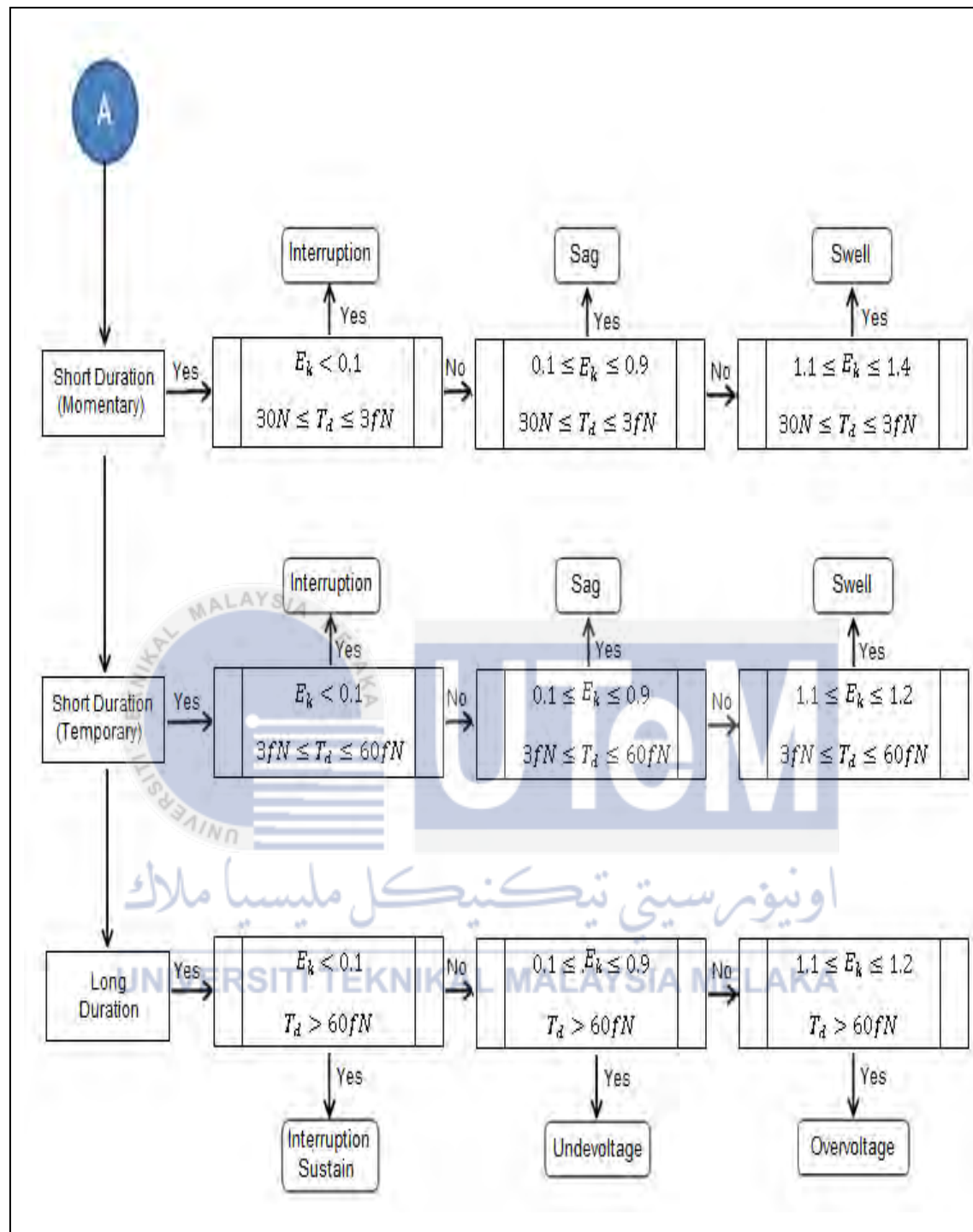


Figure 3.6: Flow of PQ detection and classification

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

All the results are tested for 230V and 400V of voltage signal data that obtained from TNB. Single interruption and multiple interruptions events are tested in this project where a constant value of 50 Hz frequency and 128 number of N are used for the entire tested voltage signal.

4.2 Case 1: Voltage Sag

A voltage sag is a reduction of voltage below than normal level that occurred for a period of time. The causes of voltage sag may be due to increased load demand, faults and starting large electrical motors. The test voltage signal for 230V is plotted in Figure 4.2. According to Figure 4.2 (a), the plot in x-y plane shows that the Euclidean norm decreases from 1 p.u and refer to Table 3.3, $0.1 \leq E_k \leq 0.9$ represents as sag event. However, it is still not enough to prove whether the event belong to instantaneous, momentary or temporary short duration variations. So, the value of T_d should be recognized to find the exact type of sag event. The original voltage signal versus Euclidean norm, E_k is plotted in Figure 4.2 (b) in order to define the value of T_d . Based on the plotted, sag event occurred from point N1 (256) until point N2 (448). As defined before, the number of N is fixed, 128 for one complete cycle of voltage signal. According to point N1 to N2, there were one and half cycles of sag signal which is $0.5N \leq T_d \leq 30N$. Based on the defined value of E_k and T_d , the test signal is classified as instantaneous short duration variation sag.

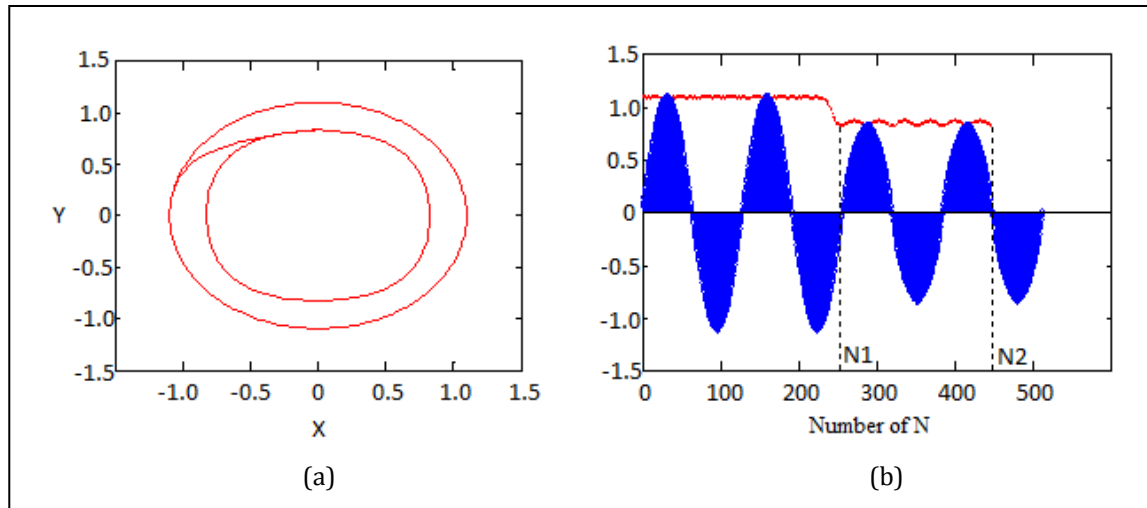


Figure 4.2: 230V Sag event (a) xy-plane (b) Original signal vs Euclidean norm

In order to verify that the system with the proposed technique can really works for sag event, sag event for 400V voltage signal is tested too as plotted in Figure 4.3. Refer to Figure 4.3 (a), the Euclidean norm decreases from 1 p.u which represents sag event due to $0.1 \leq E_k \leq 0.9$. For the duration of event as plotted in Figure 4.3 (b), sag event occurred at point N1 (128) and end at point N2 (448). Thus, the duration of sag event is defined as $0.5N \leq T_d \leq 30N$ and refer to both values of E_k and T_d will classify the event as instantaneous short duration sag. Table 4.2 represents the measured values of T_d in time (s) and E_k in per unit (p.u) for both tests of 230V and 400V.

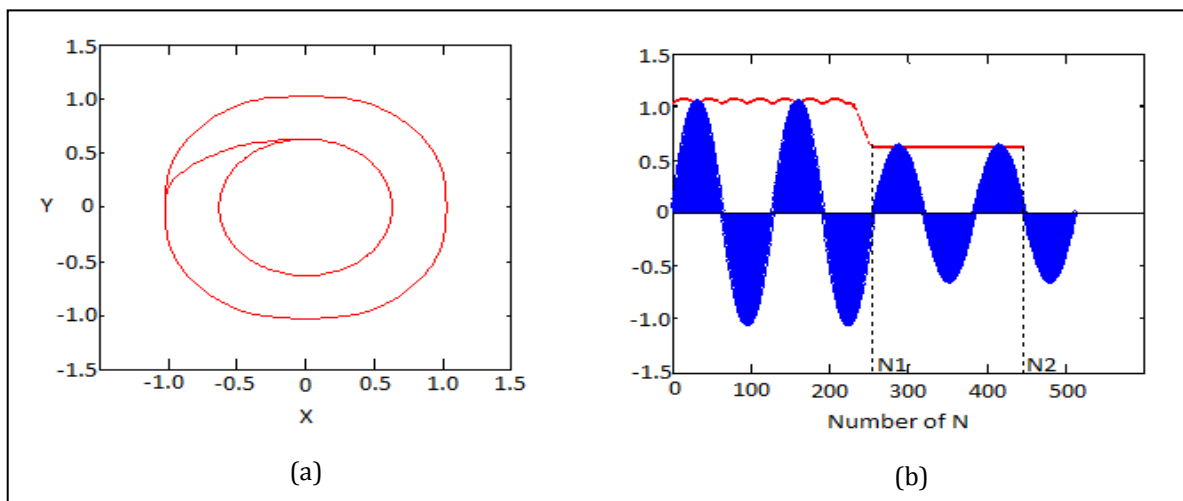


Figure 4.3: 400V Sag event (a) xy-plane (b) Original signal vs Euclidean norm

Table 4.2: T_d and E_k value for voltage sag event

Duration	230V		Type of event
	T_d	E_k	
0 - N1	$0.00015625s < T_d < 0.039688s$	$0.9 < E_k < 1.1$	Normal
N1 - N2	$0.039844s \leq T_d \leq 0.069844s$ @ $0.5N \leq T_d \leq 30N$	$0.1 \leq E_k \leq 0.9$	Instantaneous Sag
Duration	400V		Type of event
	T_d	E_k	
0 - N1	$0.00015625s < T_d < 0.036562s$	$0.9 < E_k < 1.1$	Normal
N1 - N2	$0.036719s \leq T_d \leq 0.069844s$ @ $0.5N \leq T_d \leq 30N$	$0.1 \leq E_k \leq 0.9$	Instantaneous Sag

4.3 Case 2: Voltage Swell

A voltage swell is an increment of voltage above normal level that occurred for a period of time. The causes of voltage sag may be due to increased load demand, faults and starting large electrical motors. The test voltage signal for 230V is plotted in Figure 4.4.

Figure 4.4 (a) shows that the Euclidean norm increases from 1 p.u in the xy-plane plot. The increment of E_k value from norm shows that the disturbance happened on the tested signal. Recognizing that ($1.1 \leq E_k \leq 1.8$), there are two possible events that might occurred on the signal which are swell and/or overvoltage. So, for the step, the value of event duration, T_d will be identified in order to know whether the event is swell or overvoltage. Based on Figure 4.4 (b), the event started at N1 (192) and stop at N2 (768). Four and half cycles of the event duration defines that $0.5N \leq T_d \leq 30$. So, instantaneous

swell but not overvoltage because the duration should be more than $60fN$ to claim that the event is overvoltage.

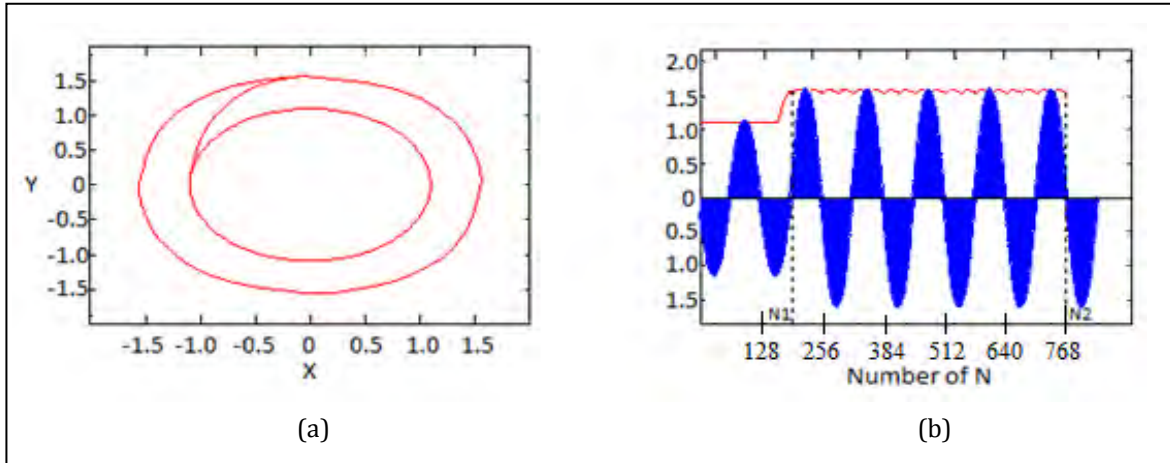


Figure 4.4: 230V Swell event (a) xy-plane (b) Original signal vs Euclidean norm

The same event also has been tested for 400V voltage signal as shown in Figure 4.5. The plot shows that the increases of E_k form norm in Figure 4.5 (a) and Figure 4.5 (b) denotes that the event happened from N1 (256) until N2 (448). Based on $(1.1 \leq E_k \leq 1.8)$ and $0.5N \leq T_d \leq 30N$ from Figure 4.5, the event is classified as instantaneous short duration variation swell. The measured values of T_d in time (s) and E_k in per unit (p.u) for both tests of 230V and 400V swell event represents in Table 4.3.

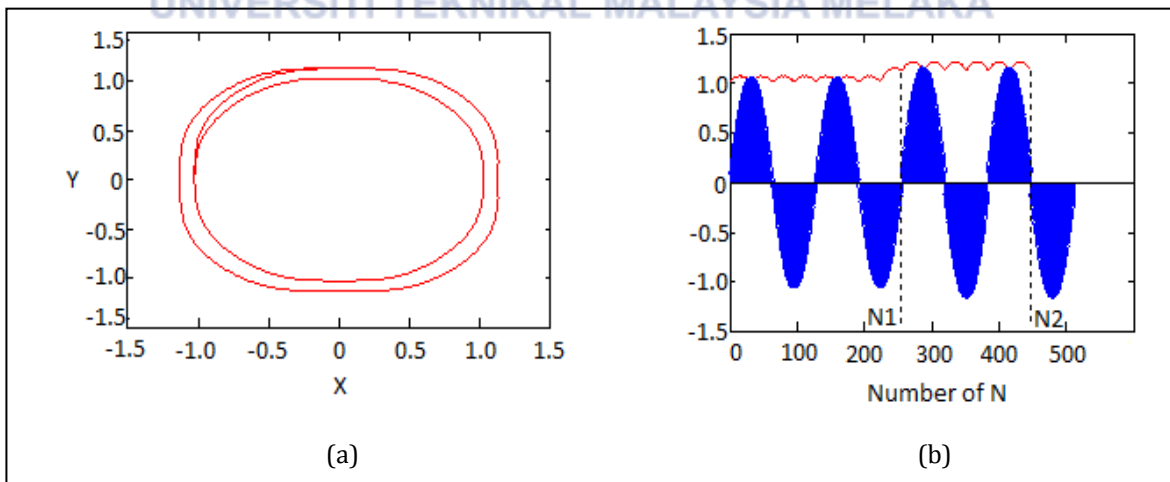


Figure 4.5: 400V Swell event (a) xy-plane (b) Original signal vs Euclidean norm

Table 4.3: T_d and E_k value for voltage swell event

Duration	230V		Type of event
	T_d	E_k	
0 - N1	$0.00015625s < T_d < 0.029844s$	$0.9 < E_k < 1.1$	Normal
N1 - N2	$0.03s \leq T_d \leq 0.12984s$ @ $0.5N \leq T_d \leq 30N$	$1.1 \leq E_k \leq 1.8$	Instantaneous Swell
Duration	400V		Type of event
	T_d	E_k	
0 - N1	$0.00015625s < T_d < 0.036406s$	$0.9 < E_k < 1.1$	Normal
N1 - N2	$0.036562s \leq T_d \leq 0.069844s$ @ $0.5N \leq T_d \leq 30N$	$1.1 \leq E_k \leq 1.8$	Instantaneous Swell

4.4 Case 3: Multiple PQ Disturbances

Multiple power quality disturbances is a situation where a lot of types of disturbances happened at a time. This event is tested to check whether the system can detect, locate and classify if in case multiple PQ disturbances happen. Figure 4.6 shows the test voltage signal data for 230V.

Based on Figure 4.6 (a), the xy-plane plot shows that there are three events occurred due to the increased and decreased of Euclidean norm from 1 p.u. The Euclidean norm has detected as $E_k < 0.1$ for the first event, $0.1 \leq E_k \leq 0.9$ for the second event and $1.1 \leq E_k \leq 1.8$ for the last event. Refer to Figure 4.6 (b), the first event occurred from 0 until N1 (256) before E_k increased and maintained until point N2 (512). Then, E_k increased again and stop at point N3 (1088). According to the number of N, all the events have the same duration which is $0.5N \leq T_d \leq 30N$. By recognizing E_k and T_d values, the

first event is classified as instantaneous short duration interruption while instantaneous short duration variation sag for the second event and instantaneous short duration variation swell for the last event.

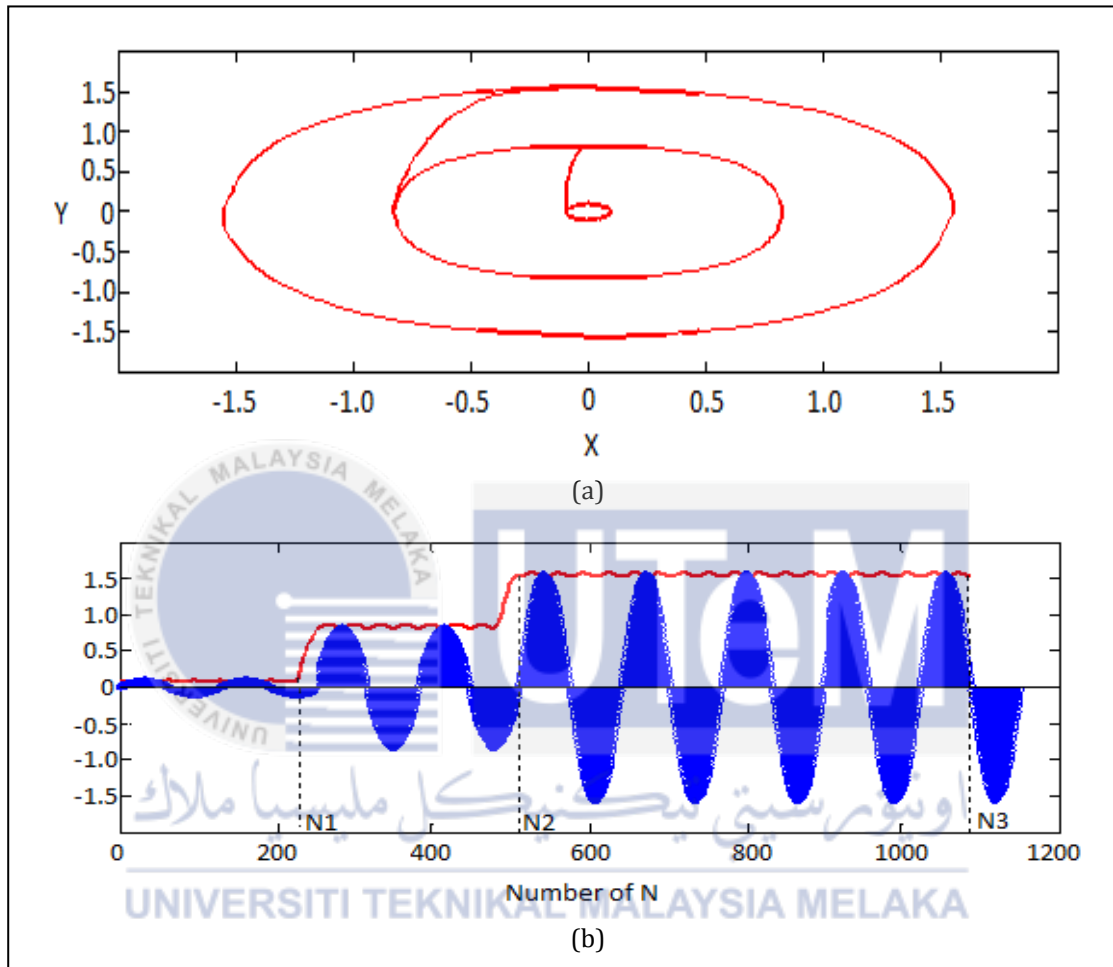


Figure 4.6: 230V multiple PQ events (a) xy-plane (b) Original vs Euclidean norm

The multiple PQ events for 400V also has been tested and result is shown in Figure 4.7. In this test, three events too have been detected through the divergence of Euclidean norm from 1 p.u in the xy-plane plot in Figure 4.7 (a). To view it more clearly, the Euclidean norm versus original voltage signal is plotted in Figure 4.7 (b). All the events are detected occurred in the range of $0.5N \leq T_d \leq 30N$. So, for the first even starting from 0 until N1 (256) is classified as instantaneous short duration variation swell due to $1.1 \leq E_k \leq 1.8$ and $0.5N \leq T_d \leq 30N$. Then, the normal condition is detected because the Euclidean norm is in the range of $0.9 < E_k < 1.1$. From point N2 (512) until N3 (768), the

Euclidean norm is decreased from normal range. Refer to the value of $0.1 \leq E_k \leq 0.9$ and $0.5N \leq T_d \leq 30N$, instantaneous short duration variation sag is classified during this duration. For the last even, N3 (768) until N4 (1280), it seems that the Euclidean norm approaching zero. Thus, comparing the Euclidean norm and durations of event, the signal is classified as instantaneous short duration variation interruption due to $E_k < 0.1$ and $0.5N \leq T_d \leq 30N$. The measured values of T_d in time (s) and E_k in per unit (p.u) for both 230V and 400V multiple PQ events represent in Table 4.4. All the tested voltage signals are summarized in Table 4.6 for single PQ event and Table 4.7 for multiple PQ events.

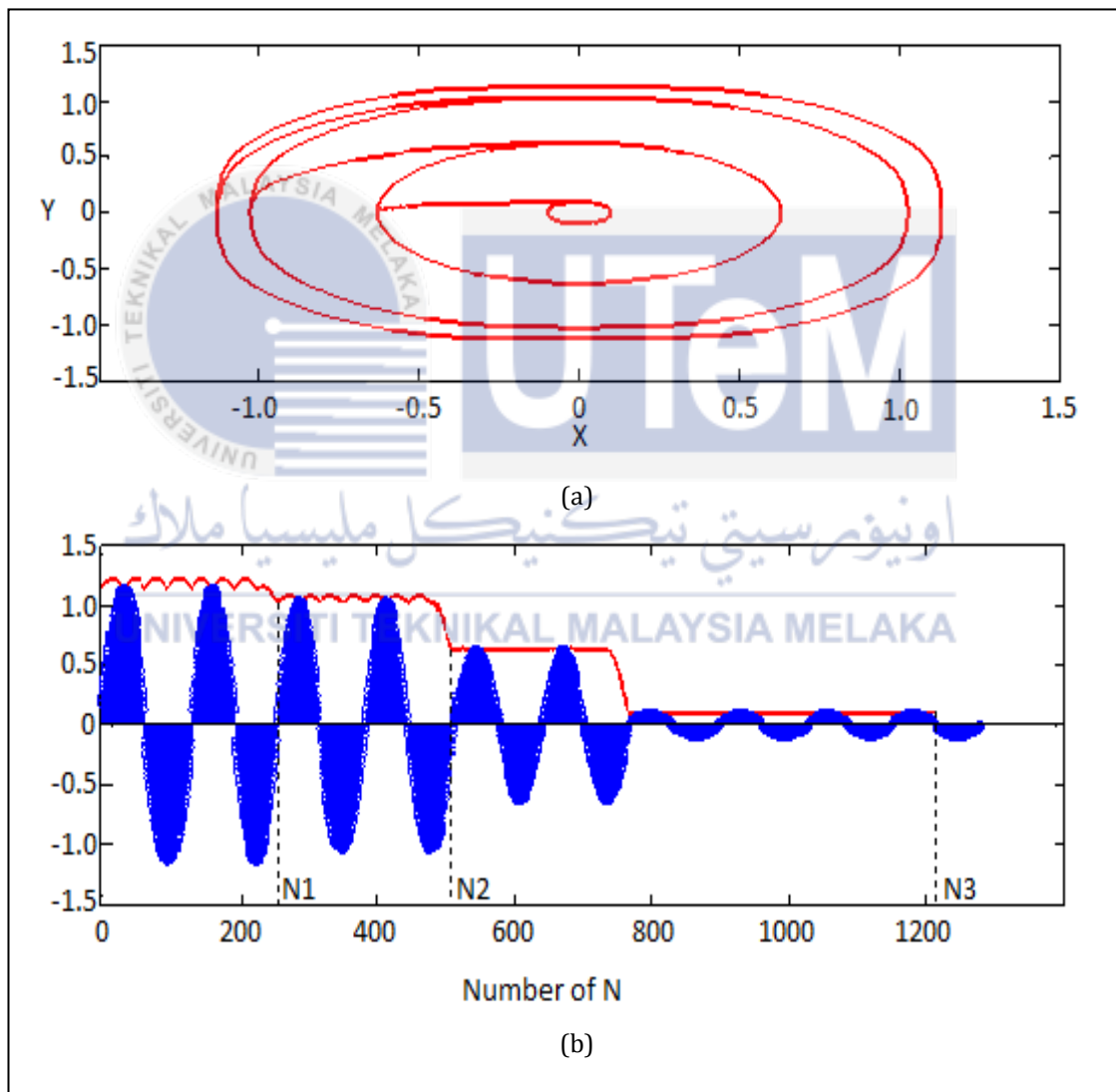


Figure 4.7: 400V multiple PQ events (a) xy-plane (b) Original vs Euclidean norm

Table 4.4: T_d and E_k value for multiple PQ events

Duration	230V		Type of event
	T_d	E_k	
0 - N1	$0.00015625s < T_d < 0.027188s$ @ $0.5N \leq T_d \leq 30N$	$E_k < 0.1$	Instantaneous Interruption
N1 - N2	$0.027344s \leq T_d \leq 0.069687s$ @ $0.5N \leq T_d \leq 30N$	$0.1 \leq E_k \leq 0.9$	Instantaneous Sag
N2 - N3	$0.076488s \leq T_d \leq 0.16984s$ @ $0.5N \leq T_d \leq 30N$	$1.1 \leq E_k \leq 1.8$	Instantaneous Swell
Duration	400V		Type of event
	T_d	E_k	
0 - N1	$0.00015625s < T_d < 0.04015s$ @ $0.5N \leq T_d \leq 30N$	$1.1 < E_k < 1.8$	Instantaneous Swell
N1 - N2	$0.040313s \leq T_d \leq 0.074844s$	$0.9 \leq E_k \leq 1.1$	Normal
N2 - N3	$0.075s \leq T_d \leq 0.012875s$ @ $0.5N \leq T_d \leq 30N$	$0.1 \leq E_k \leq 0.9$	Instantaneous Sag
N4 - N5	$0.12891s \leq T_d \leq 0.18969s$ @ $0.5N \leq T_d \leq 30N$	$E_k < 0.1$	Instantaneous Interruption

Table 4.5: Single PQ event for 230V

Voltage (v)	T_d	E_k	Type of PQ Event
230	$0.00015625s \leq T_d \leq 0.029844s$	$0.9 < E_k < 1.1$	Normal
230	$0.00015625s \leq T_d \leq 0.029844s$ @ $0.5N \leq T_d \leq 30N$	$E_k < 0.1$	Instantaneous Interruption
230	$0.039844s \leq T_d \leq 0.069844s$ @ $0.5N \leq T_d \leq 30N$	$0.1 \leq E_k \leq 0.9$	Instantaneous Sag
230	$0.00015625s \leq T_d \leq 0.089844s$ @ $0.5N \leq T_d \leq 30N$	$1.1 \leq E_k \leq 1.8$	Instantaneous Swell
230	$0.00015625s \leq T_d \leq 0.62984s$ @ $30N \leq T_d \leq 3fN$	$E_k < 0.1$	Momentary Interruption
230	$0.00015625s \leq T_d \leq 0.70984s$ @ $30N \leq T_d \leq 3fN$	$0.1 \leq E_k \leq 0.9$	Momentary Sag
230	$0.00015625s \leq T_d \leq 0.78984s$ @ $30N \leq T_d \leq 3fN$	$1.1 \leq E_k \leq 1.4$	Momentary Swell
230	$0.00015625s \leq T_d \leq 3.1898s$ @ $3fN \leq T_d \leq 60fN$	$E_k < 0.1$	Temporary Interruption
230	$0.00015625s \leq T_d \leq 3.5898s$ @ $3fN \leq T_d \leq 60fN$	$0.1 \leq E_k \leq 0.9$	Temporary Sag
230	$0.00015625s \leq T_d \leq 3.1898s$ @ $3fN \leq T_d \leq 60fN$	$1.1 \leq E_k \leq 1.2$	Temporary Swell
230	$0.00015625s \leq T_d \leq 63.9898s$ @ $T_d > 60fN$	$E_k < 0.1$	Interruption Sustain
230	$0.00015625s \leq T_d \leq 61.1898s$ @ $T_d > 60fN$	$0.1 \leq E_k \leq 0.9$	Under Voltage
230	$0.00015625s \leq T_d \leq 63.8698s$ @ $T_d > 60fN$	$1.1 \leq E_k \leq 1.2$	Over Voltage

Table 4.6: Single PQ event for 400V

Voltage (V)	T_d	E_k	Type of PQ Event
400	$0.00015625s \leq T_d \leq 0.029844s$	$0.9 < E_k < 1.1$	Normal
400	$0.00015625s \leq T_d \leq 0.029844s$ @ $0.5N \leq T_d \leq 30N$	$E_k < 0.1$	Instantaneous Interruption
400	$0.00015625s \leq T_d \leq 0.029844s$ @ $0.5N \leq T_d \leq 30N$	$0.1 \leq E_k \leq 0.9$	Instantaneous Sag
400	$0.00015625s \leq T_d \leq 0.029844s$ @ $0.5N \leq T_d \leq 30N$	$1.1 \leq E_k \leq 1.8$	Instantaneous Swell
400	$0.00015625s \leq T_d \leq 0.62984s$ @ $30N \leq T_d \leq 3fN$	$E_k < 0.1$	Momentary Interruption
400	$0.00015625s \leq T_d \leq 0.62984s$ @ $30N \leq T_d \leq 3fN$	$0.1 \leq E_k \leq 0.9$	Momentary Sag
400	$0.00015625s \leq T_d \leq 0.62984s$ @ $30N \leq T_d \leq 3fN$	$1.1 \leq E_k \leq 1.4$	Momentary Swell
400	$0.00015625s \leq T_d \leq 3.1898s$ @ $3fN \leq T_d \leq 60fN$	$E_k < 0.1$	Temporary Interruption
400	$0.00015625s \leq T_d \leq 3.1898s$ @ $3fN \leq T_d \leq 60fN$	$0.1 \leq E_k \leq 0.9$	Temporary Sag
400	$0.00015625s \leq T_d \leq 3.1898s$ @ $3fN \leq T_d \leq 60fN$	$1.1 \leq E_k \leq 1.2$	Temporary Swell
400	$0.00015625s \leq T_d \leq 63.9898s$ @ $T_d > 60fN$	$E_k < 0.1$	Interruption Sustain
400	$0.00015625s \leq T_d \leq 60.7898s$ @ $T_d > 60fN$	$0.1 \leq E_k \leq 0.9$	Under Voltage
400	$0.00015625s \leq T_d \leq 63.8098s$ @ $T_d > 60fN$	$1.1 \leq E_k \leq 1.2$	Over Voltage

Table 4.7: Multiple PQ events

Voltage (V)	T_d	E_k	Type of PQ Event
230	$(0.00015625s \leq T_d \leq 0.029844s) @ (0.5N \leq T_d \leq 30N)$ $+$ $(0.00015625s \leq T_d \leq 0.029844s) @ (0.5N \leq T_d \leq 30N)$ $+$ $(0.00015625s \leq T_d \leq 0.029844s) @ (0.5N \leq T_d \leq 30N)$	$E_k < 0.1$ $0.1 \leq E_k \leq 0.9$ $1.1 \leq E_k \leq 1.8$	Instantaneous Interruption $+$ Instantaneous Sag $+$ Instantaneous Swell
230	$(0.00015625s \leq T_d \leq 0.5301s) @ (0.5N \leq T_d \leq 30N)$ $+$ $(0.53047s \leq T_d \leq 1.2806s) @ (30N \leq T_d \leq 3fN)$ $+$ $(1.2808s \leq T_d \leq 1.4039s)$ $+$ $(1.4041s \leq T_d \leq 2.1498s) @ (30N \leq T_d \leq 3fN)$	$E_k < 0.1$ $0.1 \leq E_k \leq 0.9$ $0.9 < E_k < 1.1$ $1.1 \leq E_k \leq 1.4$	Instantaneous Interruption $+$ Momentary Sag $+$ Normal $+$ Momentary Swell
230	$(0.00015625s \leq T_d \leq 61.1566s) @ (T_d > 60fN)$ $(61.1567s \leq T_d \leq 68.3395s)$ $(68.3396s \leq T_d \leq 125.0698s) @ (3fN \leq T_d \leq 60fN)$	$1.1 \leq E_k \leq 1.2$ $0.9 < E_k < 1.1$ $0.1 \leq E_k \leq 0.9$	Over Voltage $+$ Normal $+$ Temporary Sag
400	$(0.00015625s \leq T_d \leq 0.029844s) @ (0.5N \leq T_d \leq 30N)$ $+$ $(0.03s \leq T_d \leq 0.076875s) @ (0.5N \leq T_d \leq 30N)$ $+$ $(0.081094s \leq T_d \leq 0.10984s) @ (0.5N \leq T_d \leq 30N)$	$E_k < 0.1$ $0.1 \leq E_k \leq 0.9$ $1.1 \leq E_k \leq 1.8$	Instantaneous Interruption $+$ Instantaneous Sag $+$ Instantaneous Swell
400	$(0.00015625s \leq T_d \leq 0.040156s) @ (0.5N \leq T_d \leq 30N)$ $+$ $(0.040313s \leq T_d \leq 0.074844s)$ $+$ $(0.075s \leq T_d \leq 0.12875s) @ (0.5N \leq T_d \leq 30N)$ $+$ $(0.12891s \leq T_d \leq 0.18969s) @ (0.5N \leq T_d \leq 30N)$	$1.1 \leq E_k \leq 1.8$ $0.1 < E_k < 0.9$ $0.1 \leq E_k \leq 0.9$ $E_k < 0.1$	Instantaneous Swell $+$ Normal $+$ Instantaneous Sag $+$ Instantaneous Interruption
400	$(0.00015625s \leq T_d \leq 0.040156s) @ (0.5N \leq T_d \leq 30N)$ $+$ $(0.040313s \leq T_d \leq 0.074844s)$ $+$ $(0.075s \leq T_d \leq 0.12875s) @ (0.5N \leq T_d \leq 30N)$ $+$ $(0.12891s \leq T_d \leq 0.18969s) @ (0.5N \leq T_d \leq 30N)$	$E_k < 0.1$ $0.1 \leq E_k \leq 0.9$ $0.1 < E_k < 0.9$ $1.1 \leq E_k \leq 1.8$	Momentary Interruption $+$ Temporary Sag $+$ Normal $+$ Instantaneous Swell

4.5 Interface of System

A complete interface of the PQ classification system via GUI is shown in Figure 4.8. Each of PQ events is provided with a box on the right of the interface to show the duration of every single event that occurred. User will easily classify the quality level of voltage signal by referring to the box. The normal box will light up with green colour if there is normal signal while the other boxes (disturbances) will light up with red colour according to their type when disturbances detected. Apart from that, the interface also provided the plot of Euclidean norm (ellipse) and original signal versus Euclidean norm to give a more clear view for user about the test voltage signal.



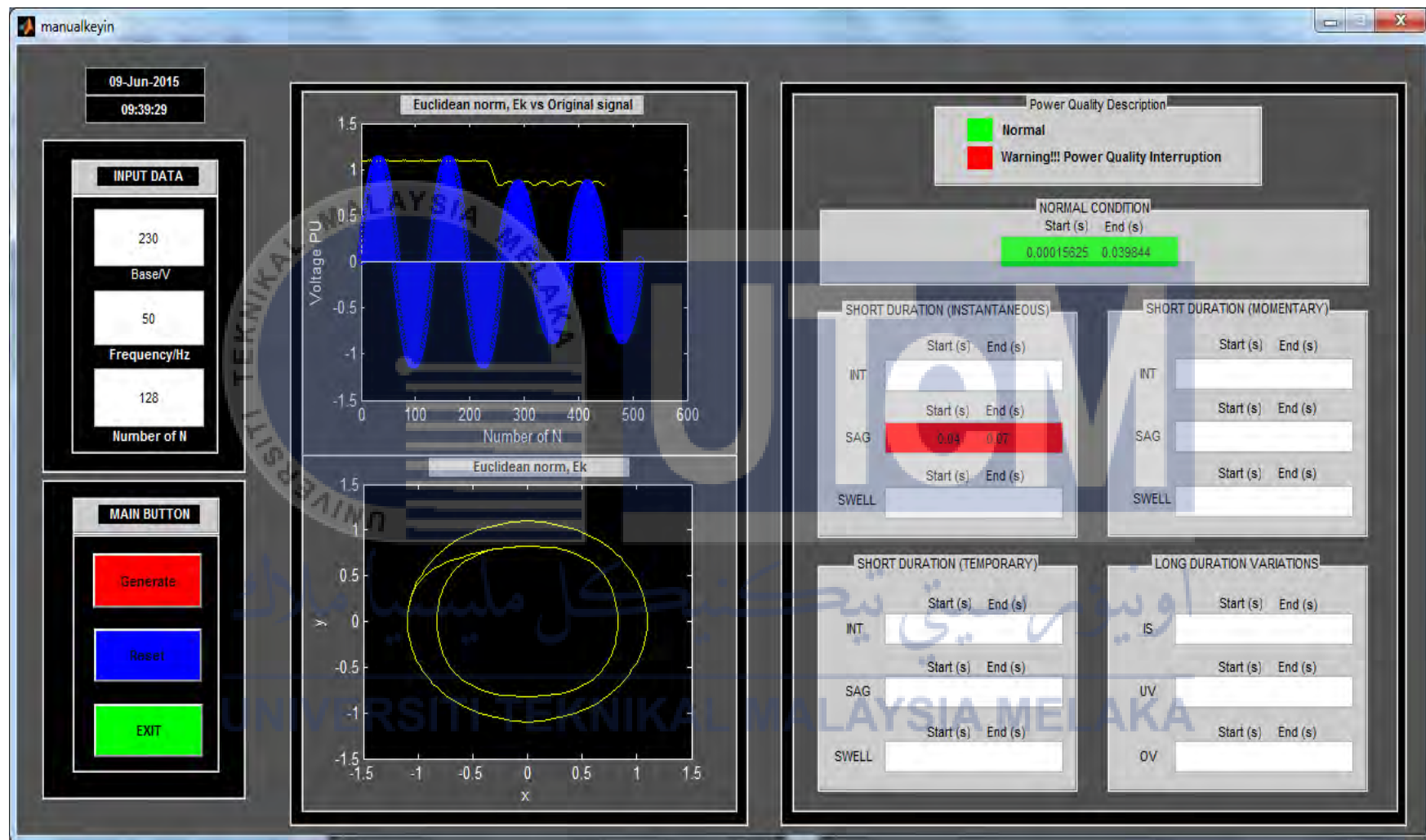


Figure 4.8: Interface of GUI

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Overall Conclusion

This thesis presents the development of A Smart Power Quality (PQ) Classification through GUI. This research has two objectives, namely, to develop a system that will detect and classify the quality level of voltage in distribution system in Malaysia for single phase and three phase and to develop an easy interface to read by customers via MATLAB GUI for power quality disturbances (voltage quality level). To accomplish the first objective, PQ detection technique based on phase space is developed. For this study, twelve cases such as sag, swell and interruption are taken from TNB. The scheme transformed a voltage signal to ellipse form in order to determine the location and classify the type of PQ. To achieve the second objective, an interface has been developed through MATLAB where user can identify the condition of the voltage signal due to the display on the interface for type of PQ.

5.2 Recommendation for Future Studies

This thesis presents a new techniques for PQ detection using GUI based on phase space technique. However, the following studies are suggested for future development:

- i. Use ARDUINO (UNO) to capture and measure voltage signal from power distribution before transfers to the GUI system for PQ classification.
- ii. Enlarge the scope of study of PQ type like transients and harmonics which were not included in this research.

REFERENCES

- [1] H. Siahkali and S. Member, "Power Quality Indexes for Continue and Discrete Disturbances in a Distribution Area," no. PECon 08, pp. 678–683, 2008.
- [2] Lu, Z., Smith, J.S., Wu, Q.H., Fitch, J.: 'Identification of power disturbances using the morphological transform', Trans. Inst. Meas. Control, 2006, 28, (5), pp. 441–455.
- [3] T. Y. Ji, Q. H. Wu, and Y. S. Xue, "Disturbances location and classification in the phase space," IEEE PES Gen. Meet., pp. 1–8, Jul. 2010.
- [4] A. Feizi, "Usability of user interface styles for learning a graphical software application," 2012 Int. Conf. Comput. Inf. Sci., pp. 1089–1094, Jun. 2012.
- [5] Robertson, O., McCracken, D., and Newell, A. "The ZOG Approach to Man-machine Communication". International Journal of HumanComputer Studies, vol. 51, pp. 279-306, 1999
- [6] Voltage Sag Solutions for Industrial Customers, Tenaga Nasional Berhad (TNB), 2007.
- [7] C.Skanran, *Power quality* © 2002. United State of America, 2002, p. 35.
- [8] H. W. B. Roger C. Dugan, Mark F. McGranaghan, Surya Santoso, *Electrical Power Systems Quality , Second Edition*, McGrawhill Company, 2004, pp. 26–28.
- [9] A. De Almeida, L. M. J. Delgado, "Power Quality Problems and New Solutions Abstract : Key words," 1992.

- [10] M. Bollen, "Understanding Power Quality Problems – Voltage Sags and Interruptions", IEEE Press Series on Power Engineering – John Wiley and Sons, Piscataway, USA (2000).
- [11] M. McGranaghan, "Costs of Interruptions", in proceedings of the Power Quality 2002 Conference, Rosemont, Illinois, pp 1-8, October 2002.
- [12] Lu, Z., Smith, J.S., Wu, Q.H., Fitch, J.: 'Identification of power disturbances using the morphological transform', Trans. Inst. Meas. Control, 2006, 28, (5), pp. 441–455.
- [13] Radil, T., Ramos, P.M., Janeiro, F.M., Cruz Serra, A.: 'PQ monitoring system for real-time detection and classification of disturbances in a single-phase power system', IEEE Trans. Instrum. Meas., 2008, 57, (8), pp. 1725–1733
- [14] Takens, F.: 'Detecting strange attractors in turbulence', Lect. Notes Math., 1981, 898, pp. 366–381
- [15] Shneiderman, B. "Designing the user interface: strategies for effective human-computer-interaction". Reading, MA: Addison Wesley, 1998.
- [16] C. Mathworks, *Creating Graphical User Interfaces R 2015 a.*, United State of America: The MathWork, Inc, 2015, pp. 20–23.
- [17] Baker, G.L., Gollub, J.P.: 'Chaotic dynamics: an introduction' (Cambridge University Press, 1990)
- [18] Takens, F.: 'Detecting strange attractors in turbulence', Lect. Notes Math., 1981, 898, pp. 366–381

Appendix A

Graphic Element	Description
Push button	A graphical component that implements a pushbutton. It triggers a callback when clicked with a mouse.
Toggle button	A graphical component that implements a toggle button. A toggle button is either “on” or “off” and it changes state each time that is clicked. Each mouse button click also triggers a callback.
Radio button	A radio button is a type of toggle button that appears as a small circle with a dot in the middle when it is “on”. Groups of radio buttons are used to implement mutually exclusive choices. Each mouse click on a radio button triggers a callback.
Check box	A checkbox is a type of toggle button that appears as a small square with a check mark in it when it is “on”. Each mouse click on a checkbox triggers a callback.
Edit box	An edit box displays a text string and allows the user to modify the information displayed. A callback is triggered when the user presses the Enter Key.
List box	A list box is a graphical control that displays a series of text string. A user can select one of the text strings by single or double clicking on it. A callback is triggered when the user selects a string.
Popup menus	A popup menu is a graphical control that displays a series of text strings in response to a mouse click. When the popup menu is not clicked on, only the current selected string is visible.
Slider	A slider is a graphical control to adjust a value in a smooth, continuous fashion by dragging the control with a mouse. Each slider change triggers a callback