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IMPLEMENTATION OF NEURAL NETWORK IN CLASSIFYING THE TYPES OF DISTURBANCE AND ITS LOCATION

NOR HASYIMAH BINTI ALI

A thesis submitted in fulfillment
of the requirements for the award of the degree of
Bachelor of Electrical Engineering (Electric)

Faculty of Electrical Engineering
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To my beloved parents, brothers, sisters

and all my friend for their support

and encouragement

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Lastly, for my beloved family and friends, thank you for encourage me while doing this report because with you guys, I feel like I have many supporters that are still with me to continue this project.

ABSTRACT

Power quality is become a popular issue in the power industry since the late 1980's. It can cause the electrical equipments to malfunctions and it also could effect on total power lost for days. Therefore, this project is going to introduce a new way which could identify the location and type of disturbance in a faster and simpler way by using automated recognition system using software. The approach used for development of this project is Wavelet Transform Analysis and Artificial Neural Network. From PSCAD, the circuits for disturbances were created according to their types which are voltage sag, voltage swell, capacitor switching, harmonic and outage. The simulation results will show that each of disturbances will produce different waveforms from the pure sinusoidal and therefore, Wavelet Transform will be used to produce the characteristics of the disturbance. Then, ANN will be applied to detect the type of disturbance and also its location in the transmission lines. Finally, a program named "Power Quality Disturbance and Location Detector Using ANN" was introduced which include involvement of Wavelet Toolbox, Neural Network Toolbox, and GUI builder from MATLAB.

ABSTRAK

Kualiti kuasa telah menjadi isu popular di dalam industri kuasa semenjak tahun 1980. Ia boleh menyebabkan peralatan elektrik menjadi rosak dan ia juga mampu menyebabkan kehilangan bekalan kuasa selama beberapa hari. Oleh itu, projek ini memperkenalkan cara terbaru untuk mengenal pasti lokasi dan jenis gangguan dengan lebih cepat dan mudah dengan menggunakan system pengesanan automatic yang menggunakan perisian. Pendekatan yang digunakan dalam membangunkan projek ini ialah Discrete Wavelet Transform Analysis dan Artificial Neural Network. Dari PSCAD, litar akan direka berdasarkan jenis gangguan iaitu kenaikan voltan, kejatuhan voltan, pengsuisan kapasitor, harmonic dan outage. Hasil simulasi akan menunjukkan bahawa setiap jenis gangguan akan menghasilkan gelombang yang berlainan dari gelombang sinus yang asal dan oleh itu, Wavelet Transform akan digunakan untuk menghasilkan ciri-ciri gangguan. Seterusnya, ANN akan mengesan jenis gangguan dan lokasi di talian penghantaran. Akhirnya, program yang dinamakan ”Power Quality Disturbance and Location Detector Using ANN” diperkenalkan di mana ianya melibatkan penggunaan Wavelet Toolbox, Neural Network Toolbox, dan GUI dari MATLAB.

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CHAPTER 1

INTRODUCTION

1.1 Project Background

The usage of electronic equipments is important in our lives nowadays and the development of this technology is growing rapidly days by days. This newer-generation load equipment was created to be more sensitive than the electronic devices before and this will increase the power quality problems. As things now are interconnected in a power grid, therefore disturbance from load will give huge impact on the power system that will brings side effects to the other consumers too.

Power quality can be defined as any power problem manifested in voltage, current, or frequency deviation that can results in failure or misoperation of customer equipment. So, it also means that power quality problems can cause the load to malfunction as the load was connected to the power system supplied by power utilities.

Although several methods had been introduced to detect this disturbance, but it is expensive and took a long time to solve it. Time is very important because the longer time taken, the higher the affects on power system. Suitable problem solving should be taken to restore the system as soon as possible to avoid it from become worse which could affect on total loss of power for days.

The usage of artificial neural network is popular these days and it is widely used in different field as its ability to provide a simpler and faster way than what we already used now. It is computer software that is under artificial intelligence which also includes fuzzy logic. This neural network is easy to use and it also has lots of advantages if compared to other intelligent methods.

1.2 Problem Statement

The intelligent technology that is created lately demands power that is free from interruption or disturbance. However, a recent study carried out in USA shows that business sectors losing a lot sum of money every year due to this power quality problems. For an industrial sector that used 24-hours machine to operate, this phenomenon will give them big impacts especially for the machines that required a long start-up time.

The common causes of this problem can be divided into two groups which are internal and external causes which include weather conditions such as lightning, ice storm, and wind, heavy startup loads, faulty distribution components and major switching operations.

This disturbance can cause on economic value which for power supply utilities, they will have to bear the loss that comes from consumers and also from their own power system. Besides that, when power quality problems happen such as blackout, some company might ask for compensation as this situation will cause their machine to lose synchronization and this will bring them to lots of losses. Residential consumers also will have less faith in them if this problem of poor services occurred frequently and if there are many choices of power qualities, they will prefer to change to the best supplier.

Loads are interconnected in power grid. Thus, any disturbance caused by load at other location will give impact on the stability of the power system. This requires the power supply utilities to be more concern on the location of where disturbance originated as less times taken to detect, less cost will be needed. In order to have high accuracy of detection, therefore neural network is introduce in giving more faster and simpler method in this new-advanced technology.

1.3 Project Objectives

The main objective of this project is to create a program that is able to classify the types of disturbance and its location using Artificial Neural Network and Wavelet Transform Analysis while the general objectives of this project are:

1. To utilize ANN technique in order to detect type of disturbance that occurred and its location
2. To develop a user friendly guide as an interface for user to the created software by using MATLAB.
3. To create characteristics for each type of disturbance by using Wavelet Transform

1.4 Project Scope

Based on the classification under IEEE 1159, the disturbances can be categorized under seven categories and for more accurate categorization, each category will have their sub-categories which depends on amplitude, frequency, spectrum, modulation and others to identify them. Therefore, studies on type of disturbance and the software that are going to use is needed for this project.

For this project, only certain types will implemented which are:

a) Sag
b) Swell
c) Harmonic
d) Outages
e) Capacitor Switching

This project also covered on circuit designation and simulation using PSCAD and it involved the usage of Discrete Wavelet Transform, which is a type of wavelet transform, to extract the characteristics of each disturbance based on the waveforms produced via simulation. After that, Probabilistic Neural Network will be applied to identify the types of disturbance and its location on the transmission lines.

CHAPTER 2

LITERATURE REVIEW

2.1 Power Quality

Power quality is defined as any power problem occur involving voltage, current, or frequency deviation that results in failure or misoperation of customer equipment while disturbance is temporary deviation from steady-state waveform. Therefore, power quality disturbance can be described as a phenomenon which can cause the output voltage to be not in purely sinusoidal.

It is easily to react with sensitive equipments which can cause it to malfunction and as the power system is interconnected to each other, it can also affect on other end-load users. So, it is important to everyone to give concern about this problem. From a survey carried out by the Electric Power Research Institute, 80% of all disturbances come from inside the homes and business. Therefore, most of the disturbance comes from household equipments and appliances such as refrigerator, air conditioner, vacuum and so on. Weather conditions like lightning, ice storms, and high winds are also another factors for disturbance to occur.

This power quality problem could give a big impact on economic value either to power supply utilities, residential consumers or industry. For power supply utilities, it will effect on gaining the level of confidence from their consumers and this also will reflect on their number of customers to competing power supplier. Residential consumers now, for example, usually depend on internet for making their business easier either for paying bills, online shopping, or to communicate with their family and friends which lives far away from them. So, without computer, it will make their life quite difficult as they need to go to the office to settle down their needs.

2.1.1 Types of Disturbance

There are different types of disturbance that usually occurred in power system such as overvoltage, undervoltage, harmonic, voltage sag, voltage swell, and so on that can be categorized based on their length and magnitude. Each type can be differentiating by its waveform.

a) Voltage Sag

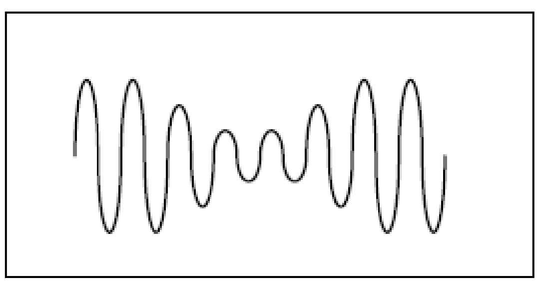

Figure 2.1 Sag

Voltage sag is a decrease of 10-90% of AC voltage and it usually occurred between the duration of 0.5 cycles to 1 minute’s time at a given frequency. The common causes for sag are heavy startup loads and remote clearing faults performed by utility equipments.

b) Undervoltage

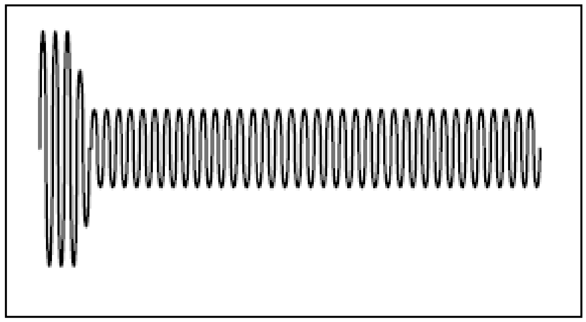

Figure 2.2 Undervoltage

Undervoltage is also usually known as brownouts and it is the result for the longer time problems of voltage sags. It is closely related with increase in currents as the motor starting required six times or more than its normal running current. It could give effects on incorrect operation of control devices, computer system crash, speed variation or stopping of motors and so on. For example, it can create overheating in motors and also could cause to the failure of nonlinear loads such as computer power supplies.

c) Voltage Swell

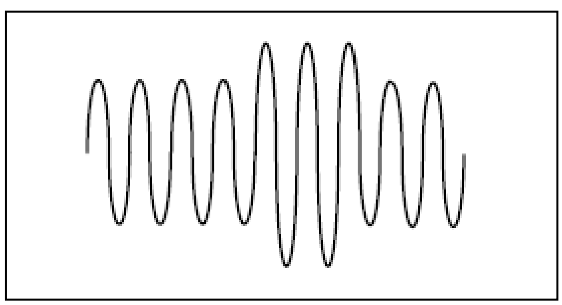

Figure 2.3 Voltage Swell

Voltage swell is an increase of AC voltage for 10-90% of rms voltage for duration of 0.5 cycles to 1 minute. Usually, the sources that could bring to voltage swells are sudden load reductions with a poor damaged regulator, high-impedance neutral connections and a single-phase fault on a three-phase system. Swells effects is able to disturb electric controls and motor drives, mainly on adjustable speed-drives, which can be trip because of their built-in protective circuitry.

d) Overvoltage

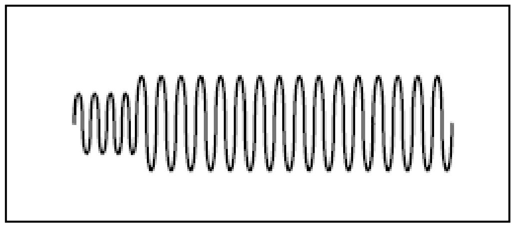

Figure 2.4 Overvoltage

Overvoltage is the consequences for the long-term problem of swells. It usually occurred when transformer supply tap settings are set incorrectly and loads have been reduced. It can cause overheating, unnecessary tripping of downstream circuit breakers and putting stress on equipments.

e) Harmonic

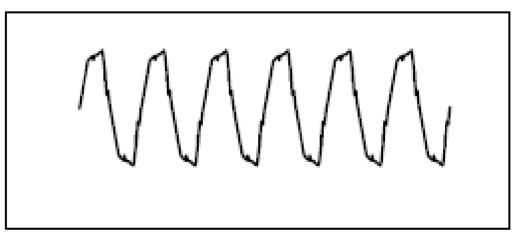

Figure 2.5 Harmonic

Harmonics can be categorized under waveform distortion. There are five primary types of waveform distortion which are DC offset, harmonics, interharmonics, notching, and noise. Harmonics can be defined as a distortion of waves from a pure sinusoidal at multiples of fundamental frequencies. The contributors to harmonics are high-power types of equipments using phase-angle control and uncontrolled rectification, and saturation of transformers core during energization with the increasing use of FACTS from power utility equipment. It can give effects on transformers heating and system halts.

f) Momentary Interruptions

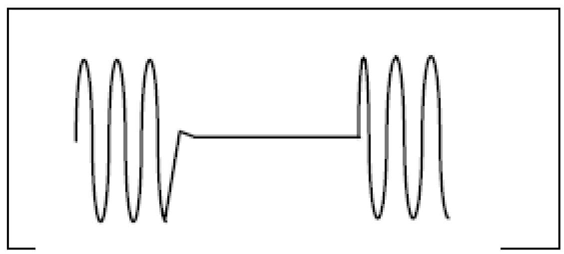

Figure 2.6 Momentary Interruptions

Momentary interruption is a state where the voltage will be zero for 30 cycles to 2 minutes. It is almost like a temporary blackout which can be experienced when the power supply suddenly did not operate and the common causes for this problem are equipment failure, circuit breaker tripping and damaged of electricity supply grid. When someone use computer and suddenly this interruptions happened at that time, it will cause computers to lose data. There are four types of interruptions which are instantaneous, momentary, temporary and sustained which each of them can be classified according to the time taken for the situation to happen and heal.

2.1.2 Power Quality Solutions

a) Uninterruptable Power Supply (UPS)

UPS is a device that is put between power supply and a device to protect devices from disturbance that could directly affect the performance of the device.

There are three types of UPS that commonly used which are Standby Power Supply (SPS), hybrid (or ferroresonent) UPS system, and online UPS. The UPS has internal battery which also acts as an emergency power supply that could be as a backup power supply when power failure happened. This feature is very important especially to the computer as the users can prepare to shutdown the computer when there is no power supply so that the data is not lost due to the power loss.

b) Power Conditioner

Power conditioner is an electrical device that improves the power quality and it is used to provide AC power supply that is free from disturbance to sensitive electrical equipments. It is also used between the device and power supply such as wall outlet and it is able to protect the equipments from surge, brownout, noise and other power quality problems.

c) Transient Voltage Surge Suppression (TVSS)

TVSS is used to protect sensitive electrical equipments from harmful surge energy and it is a voltage-sensitive switch, which monitors the AC voltage input and output waveforms. It is similar to the surge arrester and surge diverter. When the surge is detected, it provides short circuit which will send the surge flow to the earth between the power line and ground.

2.2 Wavelet Transform

Wavelet transform is a transformation to basis function which is represented in scale and time. It transforms a waveform or a signal into its frequency component and this gives a faster and effective way to analyze non-stationary voltage and current waveforms. Wavelet transform can be classified into Continuous Wavelet Transform (CWT) and Discrete Wavelet Transform (DWT)

2.2.1 Continuous Wavelet Transform

Continuous Wavelet Transform transforms a signal into wavelets that has small oscillations and highly localized in time. It produces a time-frequency with a good time and frequency localization. CWT can be defined as:

$$W_n(s) = \sum_{n'=0}^{N-1} x_{n'} \sqrt{\frac{\delta t}{s}} \Psi_0^* \left[\frac{(n'-n)\delta t}{s} \right]$$

…Equation 2.1

The equation 2.1 shows that the convolution is used directly as CWT is a convolution of data sequence with a scaled and translated version of the mother wavelet, the psi function while the equation 2.2 is alternative way by using the FFT-based fast convolution.

$$W_n(s) = FFT^{-1}\left[\sum_{k=0}^{N-1} \hat{x}_k \left(\sqrt{\frac{2\pi s}{\delta t}}\hat{\Psi}_0^{\,*}(s\omega_k)e^{i\omega_k n\delta t}\right)\right]$$

…Equation 2.2

where

$$\hat{x}_k = \frac{1}{N}\sum_{n=0}^{N-1} x_n\, e^{-2\pi i k n}$$

…Equation 2.3

and

$$\omega_k = if\left(k \le \frac{N}{2}, \frac{2\pi k}{N\delta t}, -\frac{2\pi k}{N\delta t}\right)$$

…Equation 2.4

with x = discrete data series

N = data series length

s = wavelet scale

n = localized time index

δt = sampling interval

ω = angular frequency

2.2.2 Discrete Wavelet Transform

The CWT is a costly process and most of the signal data were stored in discrete in computer to process. The low pass digital filter is the scaling function of the Wavelet, $g_n(n)$ while high pass digital filter is wavelet function of the Wavelet, $h_n(n)$.The low frequency content is very significant as it can give the characteristics of the signal for many signals.

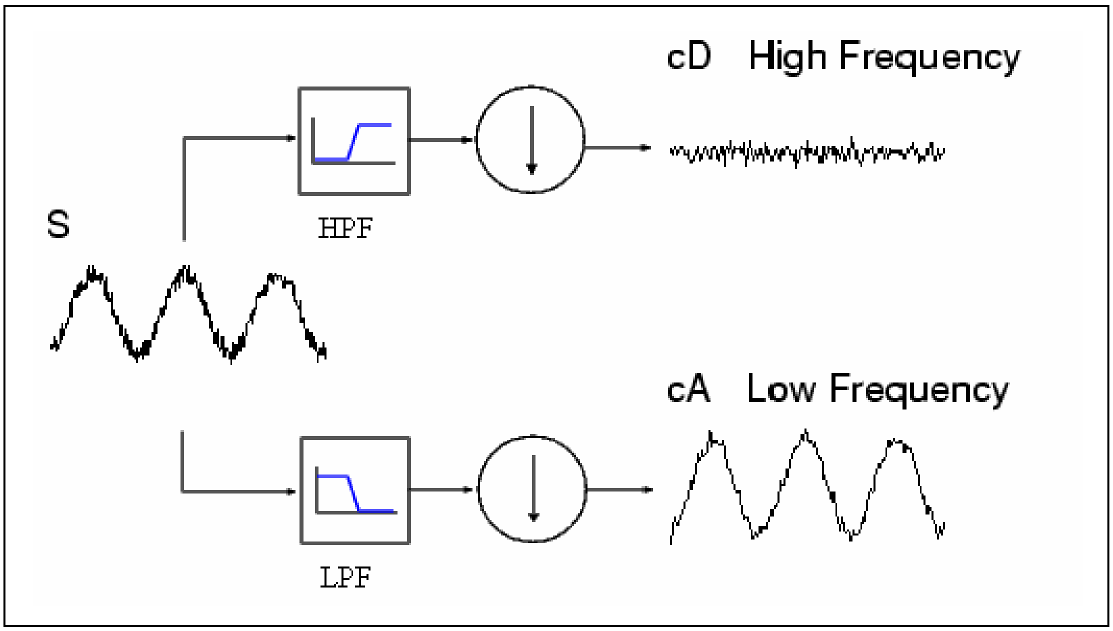

Figure 2.7 Sub-band Filtering of DWT

The signal will pass through two filters which are low pass filter and high pass filter and it will produce two other signals which are details, and approximation. Details are the low scale, high frequency components while approximations are high scale, low frequency component.

The signals also will be down sampling by eliminating half of the signal when it passes through the filters in order to maintain the number of data we had in our signals. This is indicated by ↓ in Figure 2.7.

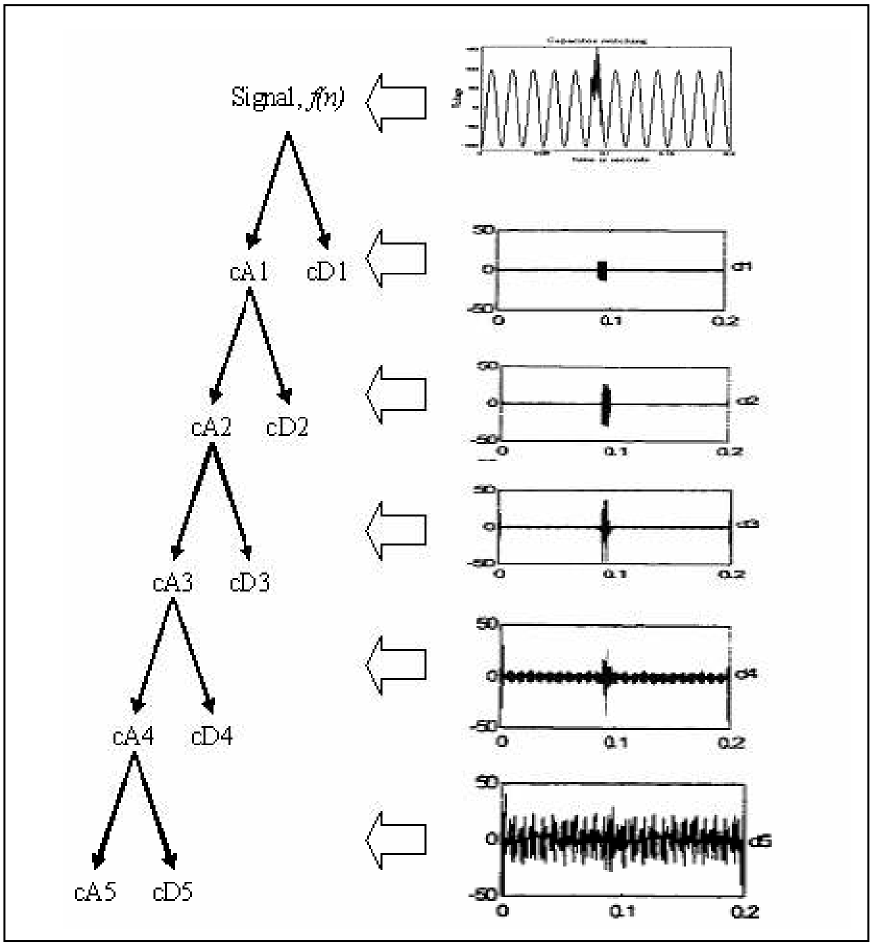

Figure 2.8 Wavelet Decomposition Process

For multiresolution analysis using DWT process, a signal is decaying into a discrete number of arithmetic frequency bands. In the first level of decomposition, the entire high frequency is filtered out. The Wavelet is shifted along the signal in convolution and all the component in the signal that matched the Wavelet's frequency will result in high amplitude of the coefficients. In the second level of decomposition, half of the signal will be removed. As a result, the frequency band of the signal now is half of the original signal. The process will continue and the level needed depends on the sampling frequency or the highest cutoff frequency set in the analysis. The amplitude of coefficients increased as the level of decomposition increased until it reached certain level to start decreased. The drop of coefficient's amplitude shows that the signal is completely decomposed.

2.2.3 The Advantages of Wavelet Transform

1. The Wavelet Transform is a time-frequency analysis which its coefficients contains information on successive bands or frequency. Therefore, it would be an advantage for the users who did not sure about the frequency that produced the signal which it is really well-suited for disturbance signal with rapid changes.

2. For comparison between Wavelet Transform and the popular Fourier Transform, Wavelet provides different windows in order to isolate signal discontinuities such as if we would like to have some very short basis functions and on the same time too, to have some very long basis functions which it will gives detailed frequency analysis. Unlike Fourier Transform, the resolution of the analysis is same for all frequencies as it needs to fit the window's width.

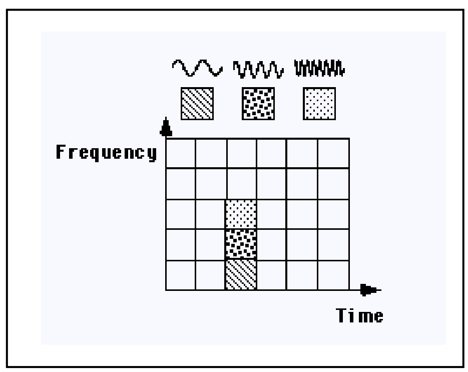

Figure 2.9 Fourier Basis Functions

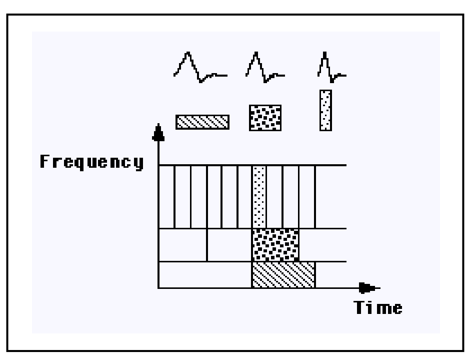

Figure 2.10 Deubechies Wavelet Basis Functions

2.3 Artificial Neural Network (ANN)

Artificial neural network is a model that was created based on biological brain and it consists of neurons that were interconnected with each other. These processing signals produced output from input signals it received to solve certain problems. Therefore, the input signals will be processed and then from the tasks that have been trained, output will be produced.

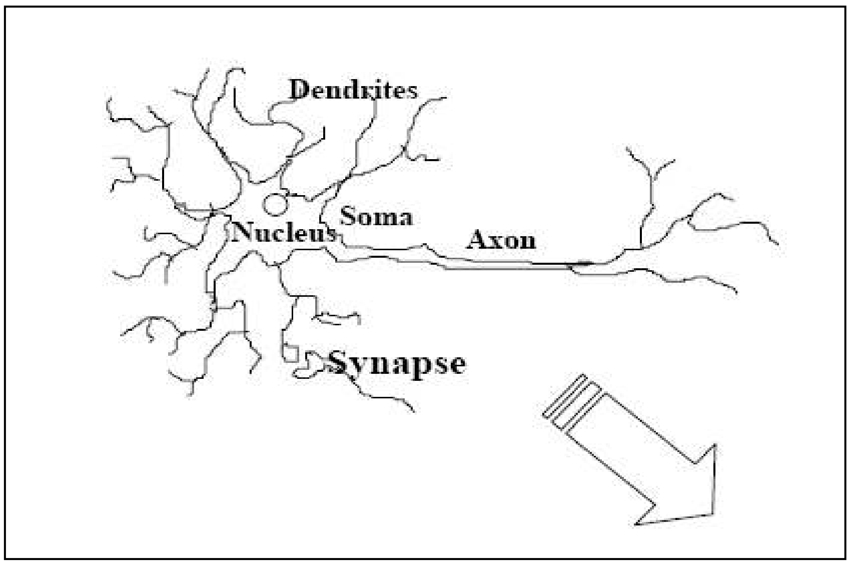

Figure 2.11 Neuron

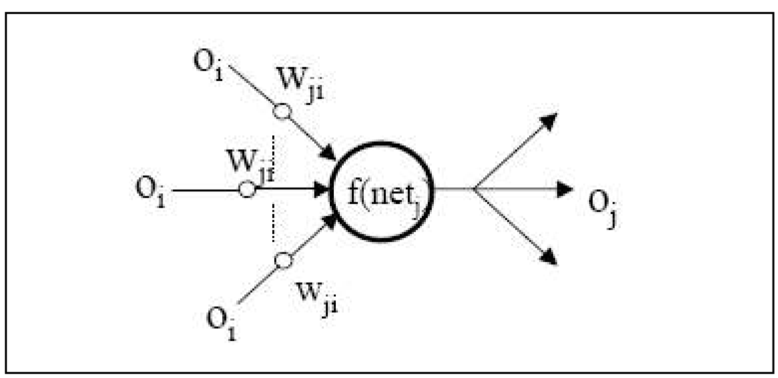

Figure 2.12 An Artificial Neuron

There are a few terms that have been used to explain how to implement this ANN. Figure 2.13 above showed an artificial neuron that is used in neural network. Each neuron are activated by activation functions and for each interconnection, there is an associated weight which is Wji. The signals sent then will be processed by multiplying the activation signals with its weight.

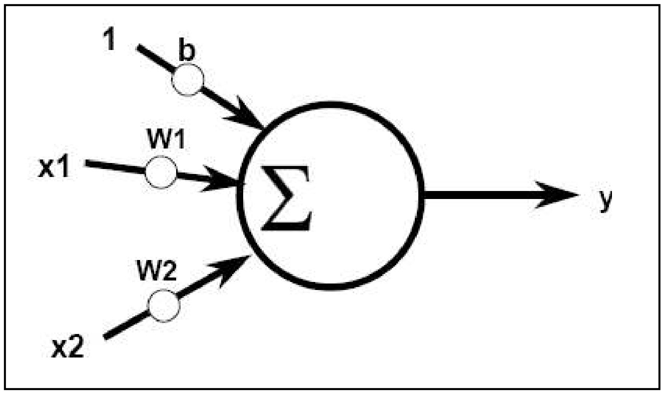

Figure 2.13 An Artificial Neural Network

Some ANN used bias signals, b and it acts same with weights. The only difference is that bias will always have activation equals to 1. This connection will be treated equally with weights and then will be adapted according to the learning rule of ANN. It can increase the signal levels which will also improve the union.

Neural network input, S = $b + \sum x_i w_i$

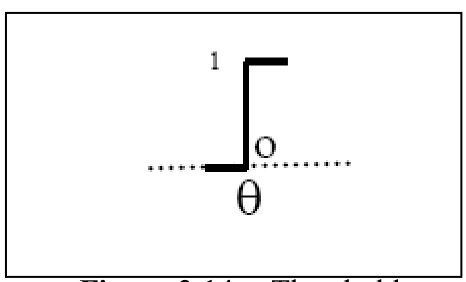

Figure 2.14 Threshold

The threshold is quite similar with the bias but it is not adapted and its value will be used to make decisions in ANN such as either ANN will fire or unfire. The separating line the will be

$$b + x_1 w_1 + x_2 w_2 = \theta \qquad \text{…Equation 2.5}$$

The ANN can be categorized into 3 models which are feedforward, feedback and cellular and each model can be either in supervised or unsupervised mode.

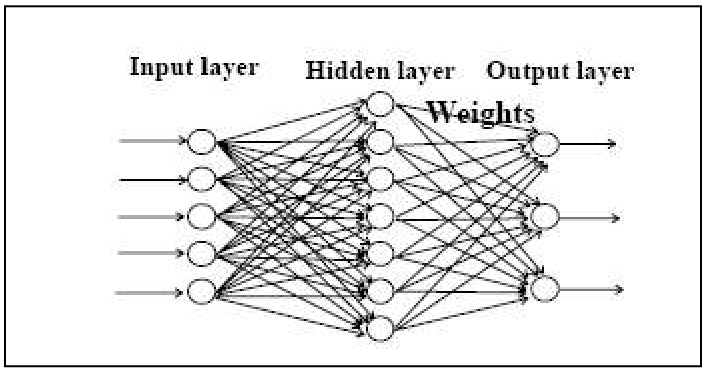

Figure 2.15 Feedforward Propagation

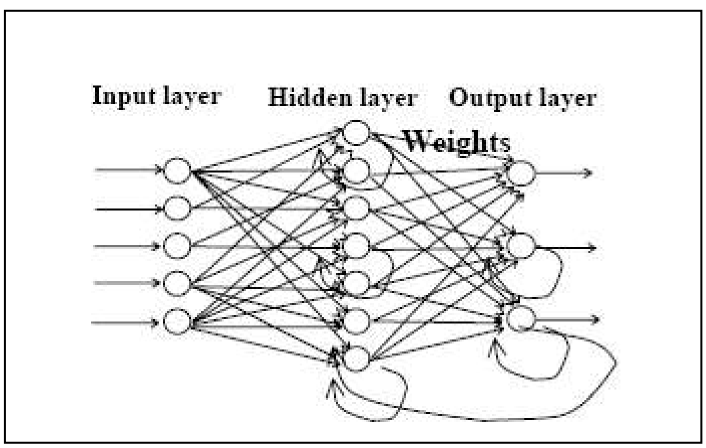

Figure 2.16 Feedback Propagation

2.3.1 Learning Phase

Learning means using a set of observations that is used to solve the task such as to find

$$f^* \in F$$

where F is a class of functions

There are three major learning paradigms which are supervised learning, unsupervised learning and reinforcement learning. The cost function, C is used to determine how close the problem from the optimal solution.

In supervised learning, the main objective is to gather the mapping that is used indirectly by the data. The mismatch on cost function contains information about the problem domain and it is happened between mapping and the data. For unsupervised learning, the cost function is dependent and can be minimized by any function of the data, x and the network's output, f. Meanwhile, in reinforcement learning, the data is regenerated by an agent's interactions with the environment.

2.3.2 Training Phase

In the training phase, the model needs to be trained and correct training patterns should be determined so that they can perform the correct task. Here, an incorrect selection, which is wrong training patterns, will produce wrong results. There are four initializations that need to be considered in this training phase which are:

a) Choose correct number of iterations (stopping criteria)
b) Learning parameter / momentum parameter
c) Randomize the weight correctly
d) Minimum error (stopping criteria)

2.3.3 Types of Neural Network

There are many types of neural network which are:

a) Feedforward neural network
b) Radial Basis Function (RBF) network
c) Kohonen self-organizing network
d) Recurrent neural network
    i. Simple recurrent network
    ii. Hopfield network
    iii. Echo state network
    iv. Long short term memory network
e) Stochastic neural network
    i. Boltzmann machine
f) Modular neural network
    i. Committee of machine
    ii. Associative neural network (ASNN)

2.3.4 Feedforward Neural Network

The feedforward neural network is the first and simplest method for artificial neural network. In this network, the information moves to the forward where is from the input nodes, to the hidden layer and lastly to the output. The information that was sent did not creating loops in the network.

2.3.5 Radial Basis Neural Network

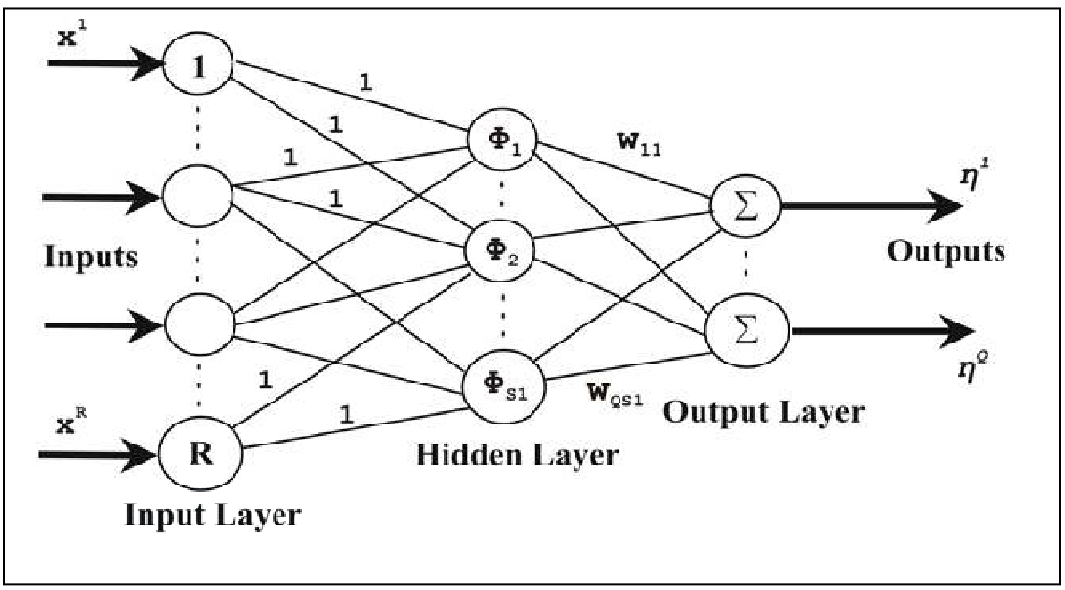

Figure 2.17 Radial Basis Function (RBF) Network

The network consists three layers which are input layer, hidden layer and output layer. This network provides good technique for interpolation in dimensional space and compared to the Multi Layer Perceptrons (MLP), it is better where it can be trained using 2 fast stages of training algorithm without the need for time consuming non-linear optimization techniques.

2.3.5 The Advantages of Artificial Neural Network

1. Non-linearity
    a) Neuron is a nonlinear device
    b) With a proper trained of neural network, it will performed highly non-linear mapping
2. Learning
    a) The neural network is learn from the interaction with environment
3. Generalization capability
    a) Generalize the training information to similar situations which never experienced before
4. Complex mapping
    a) Can synthesize complex mappings which maybe difficult or impossible if in mathematical form
5. Robust and fault tolerance
    a) if the input data is incomplete or noisy, the ANN still can produce satisfactory result
    b) due to the distribution of computational load across many processing units, the network gained same degree of fault tolerance with respect to processor failures
6. High speed
    a) Can solve the mapping problem much faster than conventional methods and other intelligent methods such as expert system.

CHAPTER 3

METHODOLOGY

Generally, the methodology involved for this project can be divided into gathering information on modeling circuit for disturbance and then simulating it to collect the data, extracting characteristics for each types of disturbance, classify the types and location for every each and lastly, developing the graphical user friendly interface for the user easier to use the program.

The software used for this project is

1. PSCAD
2. MATLAB

PSCAD is used to design circuit that is able create disturbances characteristics such as voltage sag, voltage swell, outage, harmonics, and capacitor switching. The data that was generated from each signal that was produced then will be analyzed for further use in MATLAB.

By using MATLAB, the signal created before then will be characterized using wavelet transform analysis and a few data then will be obtained which is very useful to determine the input layer for neural network to be able to classify the location and types of disturbance that occurred. Then, a user friendly approach will be created to interface the user with the program.

Software for Project Development

PSCAD

Figure 3.1 The PSCAD Software

PSCAD (Power System CAD) provides features for the user to schematically construct a circuit, run a simulation, analyze the results, and manage the data in a completely integrated, graphical environment. It is a powerful and flexible graphical user interface to the EMTDC solution engine. EMTDC is most suitable software that can be used for simulating the time domain instantaneous responses which is also known as electromagnetic transients of electrical systems.

PSCAD completely provide users with a library of pre-programmed and tested models, which includes from simple passive elements and control functions, to more complex models such as electric machines, FACTS devices, transmission lines and cables. If a certain desired model does not exist, PSCAD provides the flexibility of building custom models, either by assembling it graphically using existing models, or by utilizing an intuitively designed Design Editor.

3.1.2 MATLAB

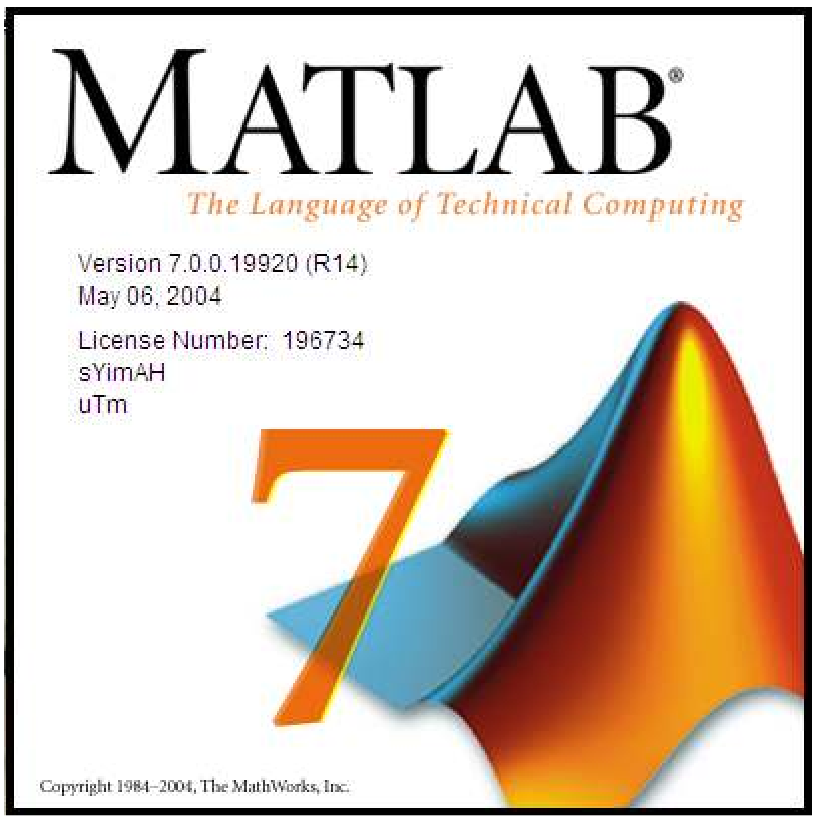

Figure 3.2 The MATLAB Software

MATLAB stands for matrix laboratory. It is a high-performance language for technical computing which combines computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation. Typical uses include

a) Math and computation
b) Algorithm development
c) Data acquisition
d) Modeling, simulation, and prototyping
e) Data analysis, exploration, and visualization
f) Scientific and engineering graphics
g) Application development, including graphical user interface building

MATLAB is a system that does not require dimensioning as the basic data element is an array and this allows users to solve many technical computing problems, especially those with matrix and vector formulations, in a fraction of the time it would take to write a program in a scalar noninteractive language such as C or Fortran.

a) Wavelet Toolbox

The Wavelet Toolbox is a collection of functions built within the MATLAB® Technical Computing Environment. It offered tools for the analysis and synthesis of signals and images, and tools for statistical applications, using wavelets and wavelet packets within the framework of MATLAB.

The Wavelets Toolbox provides two categories of tools:

1. Command line functions
2. Graphical interactive tools

The first category of tools is made up of functions that users can call straight away from the command line or from their own applications. Most of these functions are M-files, sets of statements that implement specialized wavelet analysis or synthesis algorithms. The second category of tools is a type of graphical interface tools that afford access to extensive functionality. For this project, the first category was chosen to perform the Wavelet analysis which consists of Wavelet decomposition, determination of the Wavelet coefficients and Wavelet extraction.

b) Neural Network Toolbox

Neural Network Toolbox is a set of established procedures that are known to work well. It is a useful tool for industry, education and research, which will help users find what works and what doesn't, and a tool that will help develop and extend the field of neural networks.

The Neural Network Toolbox also provides two alternatives for users either to access it using command line or graphical interactive tools that are provided within MATLAB. Both of it can be used to create, train and testing the neural network. For neural network, the command line approach also was chosen for this project.

c) GUI Builder (GUIDE)

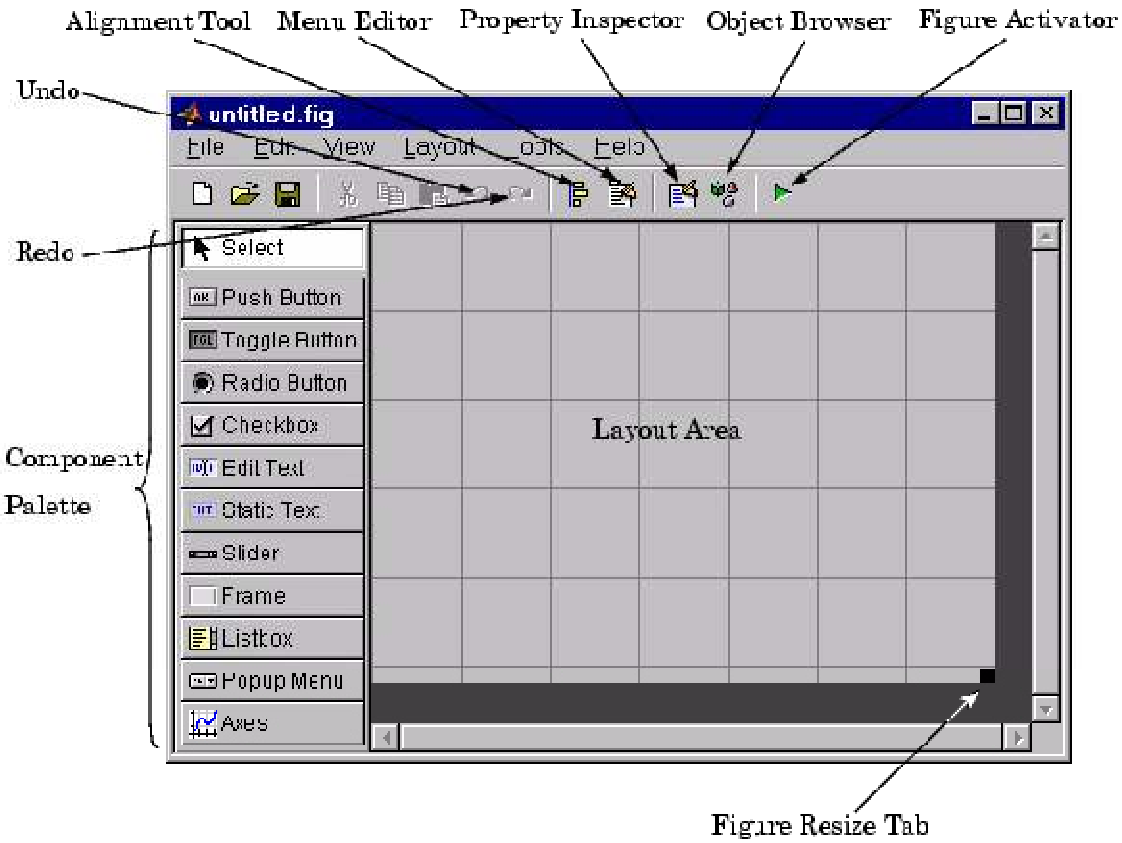

Figure 3.3 The Layout Editor of GUI Builder

GUIDE, the MATLAB Graphical User Interface Development Environment, provides a compilation of tools for creating graphical user interfaces (GUIs). These tools greatly help to simplify the process of designing and building GUIs. Users can use the GUIDE tools to:

1. Lay out the GUI Using the GUIDE Layout Editor
2. Program the GUI

By using the GUI builder, users can create layout for their program easily by clicking and dragging GUI components such as panels, buttons, text fields, sliders, menus, and so on into the layout area. To program the GUI, GUIDE automatically generates an M-file that is able to controls how the GUI operates. The M-file initializes the GUI and contains a set of outline for all the GUI callbacks, the commands that are executed when a user clicks a GUI component. Using the M-file editor, users can add code to the callbacks to perform the functions they want them to.

All the programs created before was compiled using the GUI for users to access, simulate, and can simply modify their data whenever they want, So anyone without the knowledge of the wavelet transform and neural network can handle the program easily.

However, before designing the GUI, the programmer should know the detail features of the GUIDE. For example, each button has its own callback which is a function definition line and by using this function, we can relate the button with the command that we created before in M-file. So, the button will function according to our desire by adding the code that we already specified as the name of our M-file. Below is the example of function callbacks that is used for this project.

```
% --- Executes on button press in pushbutton3.
function pushbutton3_Callback(hObject, eventdata, handles)
decompose(handles);
% --- Executes on button press in pushbutton4.
function pushbutton4_Callback(hObject, eventdata, handles)
extraction(handles);
```

As the users press the button with tag named pushbutton 3, then the GUIDE automatically will be linked with the M-Files named decompose. Therefore, the program created will functions as the desired scripts writing in the M-File. Handles is used to share data between callback and the users can access the data in the handles structure in any callback because hObject and handles are input arguments for all the callbacks generated by GUIDE.

There are two ways to access the template, either by entering guide at the MATLAB prompt, or if GUIDE is already open, select New from the File menu in the Layout Editor.

GUIDE provides several templates, which are simple examples that users can easily modify it to create their own GUIs. The templates are fully functional GUIs and their callbacks are already programmed. Users can view the code for these callbacks to see how they work, and then modify the callbacks for their own purposes. GUIDE provides four templates, which are:

- Blank GUI
- GUI with Uicontrols
- GUI with Axes
- Menu Modal Question Dialog

Besides that, command **function** also was used for this project which is inside the M-File and the name of the function, which defines in the first line of M-File, should be in the same name as the M-File. It is use for the MATLAB to search when the users try to use the script or function.

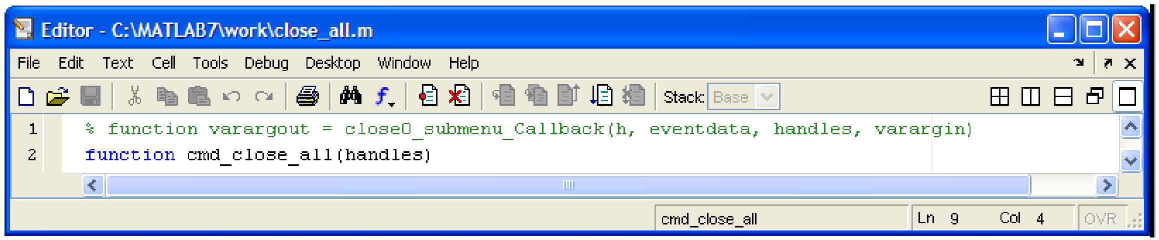

Figure 3.4 Script Writing

3.2 Wavelet Transform Analysis.

The Wavelet Toolbox is a set of functions built on the MATLAB which provides tools for the analysis and synthesis of signals and images, and tools for statistical applications, using wavelets and wavelet packets within the environment of MATLAB.

The Discrete Wavelet Transform was chose for this project, using Deubechies as the type of wavelet and wavelet extraction is perform based on Parseval's Theorem approach. By using the wavelet decomposition of wave, the extracted value and pattern of the disturbances can be obtained. In a signal, lower frequency is more significant than the higher frequency. It is because it is able to show the signal's identity and in wavelet transform, two filters are used which are low pass and high pass filter.

Therefore, the disturbance signal then will be passed through two complimentary filters and emerges as two signals. There are five level involved for wavelet decomposition and it is depends on the sampling frequency or the highest cutoff frequency set in the analysis. The first level of the wavelet decomposition is filtering out the high frequency component and the wavelet then is shifted along the signal in convolution. All the components in the signal that matched the Wavelet's frequency will be resulting in high amplitude of the coefficient. On the second level of the decomposition, the frequency of the wavelet is half decreased as the band of the signal now is half of the original signal.

The amplitude of the coefficients increased with the increasing of the level of Wavelet decomposition until it reaches certain level when it started to decrease. The drop of coefficient's amplitude implies that the signal is completely decomposed.

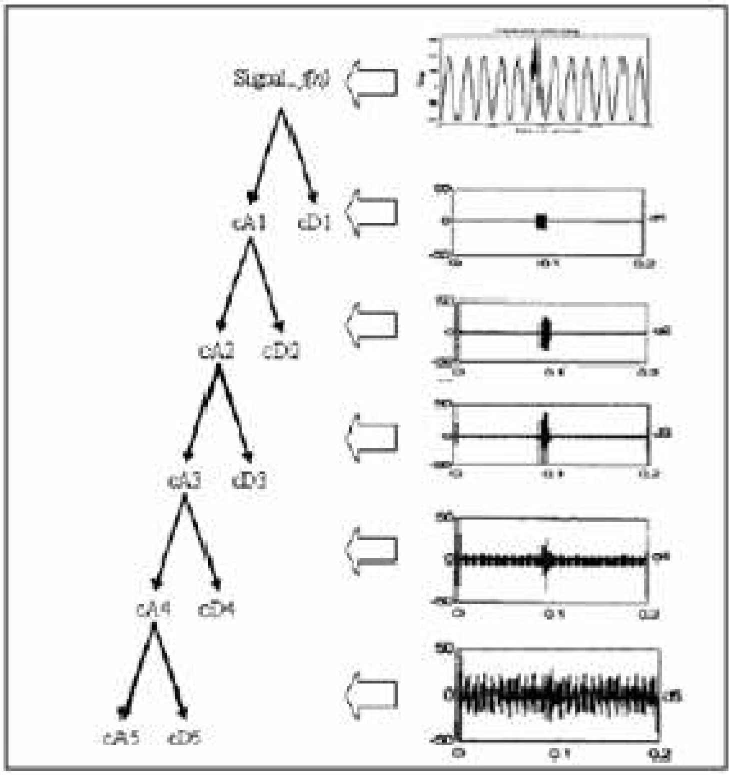

Figure 3.5 Wavelet Decomposition Tree

The approach developed for the wavelet extraction is based on the study made by Penna C., Detection and Classification of Power Quality Disturbances using the Wavelet Transform, in year 2000. By using DWT and certain features of the decomposition levels of a signal were observed, some important conclusions could be made. This information is able to detect, locate, and classify the types of disturbance. A digital program was created and implemented in the Wavelet toolbox of the MATLAB platform, through five steps as follows:

Step 1: Evaluation of the wavelet coefficients of the signal in study. The disturbance signal is decomposed by Wavelet transform in MATLAB into several levels and the coefficient of each level will be concerned.

Step 2: Evaluation of the square of the wavelet coefficients found at step 1.

Step 3: Calculation of the distorted signal energy, in each wavelet coefficient level. The "energy" mentioned above is based on the *Parseval's theorem*: "the energy that a time domain function contains is equal to the sum of all energy concentrated in the different resolution levels of the corresponding wavelet transformed signal". This can be mathematically expressed as below:

$$\sum_{n=1}^{N} |f(n)|^2 = \sum_{n=1}^{N} |cAi(n)|^2 + \sum_{j=1}^{J}\sum_{n=1}^{N} |cDi(n)|^2$$ **...Equation 3.1**

where:

f(n) :Time domain disturbance signal in study $)(nf$

N :Total number of samples of the signal

$\sum_{n=1}^{N} |f(n)|^2$:Total energy of the *f(n)* signal

$\sum_{n=1}^{N} |cAi(n)|^2$:Total energy concentrated in the level "*i*" of the approximated version of the signa

$\sum_{j=1}^{J}\sum_{n=1}^{N} |cDi(n)|^2$: Total energy concentrated on the detail version of the signal from level "1" to "*j*"

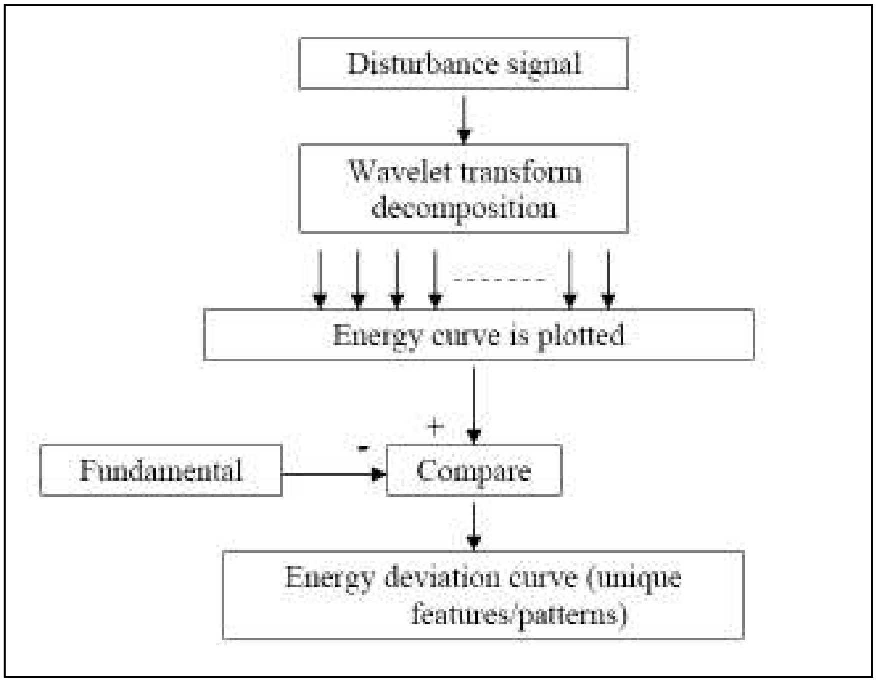

Figure 3.6 The Approach of Features Extraction to Obtain the Unique Pattern of Disturbance

Step 4: In this stage the steps 1, 2, and 3 are repeated for the corresponding "pure sinusoidal version" of the signal in study.

Step 5: The total distorted signal energy of the signal in study (found in step 3) is compared to the corresponding one of the pure signal version (evaluated in step 4). The result of this comparison is a *deviation* the will be the unique feature or pattern of the disturbance.

$$ed(i)(\%) = \left[\frac{edis(i) - eref(i)}{eref(4)}\right] \times 100 \qquad \textbf{....Equation 3.2}$$

where

i : Wavelet transform decomposition level

ed(i) (%) : Deviation between the energy distributions of the disturbance signal in study and its corresponding fundamental sinusoidal wave signal, at each Wavelet transform level

edis(i) : Energy distribution concentrated in each Wavelet transform level of the disturbance signal in study

eref(i) : Energy distribution concentrated in each Wavelet transform level of the correspondent fundamental component of the signal in study

eref(4) : Energy concentrated at the level 4 (which concentrates the highest energy) of the corresponding fundamental of the signal in study

The energy deviations (*ed(i)(%)*)curve against level of decomposition is then plotted. The deviation curve of every particular power quality disturbance has unique features that can be used to identify the problem in the voltage waveform.

3.3 Artificial Neural Network

There are many types of neural network and for this project, probabilistic neural network was chosen which is fall under type of radial basis neural network. Basically, the network can either be in single layer or in multiple layers. Multiple layers has its own advantage which it is able to give more accurate result as different function can be used for the hidden layer and output layer.

Probabilistic neural network was chose because it is easier than backpropagation neural network and besides that, the result is more accurate. In probabilistic neural network, we need to classify the group for each group of data that we defined. Compared to backpropagation, we need to determine the learning rate and how many times we want to train the data and the more we train it, the result will be more nearer to our desired target. Below is an example of backpropagation for training phase.

```
net.trainParam.show = 50;
net.trainParam.lr = 0.05;
net.trainParam.epochs = 300;
net.trainParam.goal = 1e-5;
```

Learning rate, lr should be chose wisely as if the value is too big or too small will affect the desired output. Epochs refer to how many times we train the data to reach the target stated while goal is used to minimize the error from the output and our target.

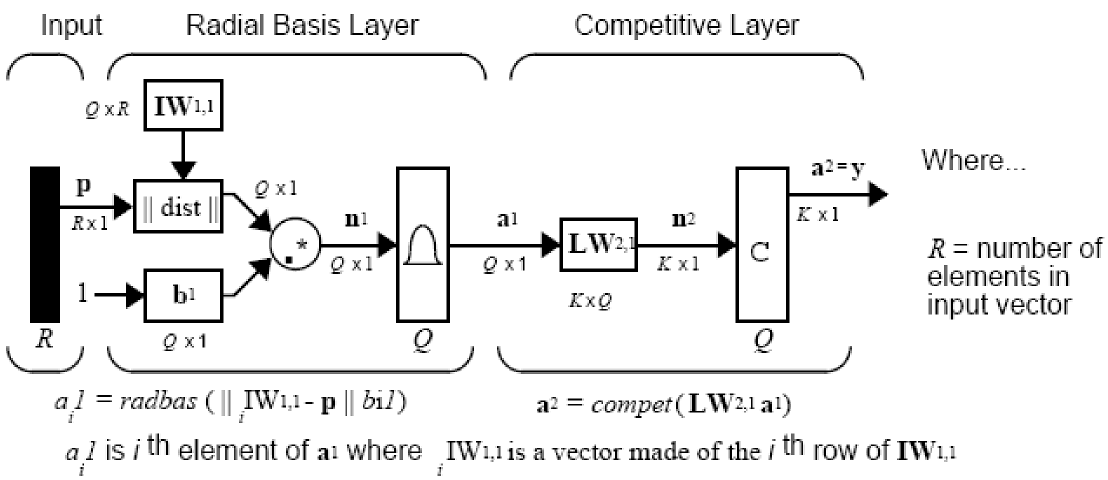

Figure 3.7 Probabilistic Neural Network

Q = number of input pairs = number of neurons in layer 1

K = number of classes of input data = number of neurons in layer 2

Figure 3.6 shows the network architecture for probabilistic neural network which consists of input, hidden layer, and output. Each input vector is associated with one of target classes. From the disturbance data from PSCad, the neuron in hidden layer will be trained. Then, Discrete Wavelet Transform analysis was applied and the energy deviation between disturbance signal and reference signal, which is pure sinusoidal, will be calculated. The data extracted from the wavelet transform will be compared with the implemented data used inside the probabilistic neural network structure and then the output will be recognized.

3.4 Software Implementation and Result Analysis

When the ‘Power Quality Disturbance and Location Detector Using ANN’ was successfully developed and functions as desired, it is used then by based on the data from circuit simulation from the PSCad. The simulation done comes from different types of disturbance such as voltage sag, voltage swell, harmonic, outage, and capacitor switching and besides that, it was done on different locations which are at 50 km, 100 km, and 200 km. The results then will be implemented towards the extracted feature which will be analyzed and evaluated.

3.5 Composition of User Manual

A user manual is created in order for the user to use the program easily and it includes the installation and setup requirements and procedures, explanation of the basic function, the features of “Power Quality Disturbance and Location Detector” Using ANN’, and examples of using the whole program. Besides that, a table of troubleshooting concerning on the simulation program is discovered as well.

The manual for the program are compiled using Microsoft Word 2003, and all the files then are saved in PDF files. Users can also access the tutorial that already provided inside the program itself, which can be assessed when running the program. All the tutorial files including the programming and source code of the program is saved into the compact disc (CD) as a soft copy for future references and development.

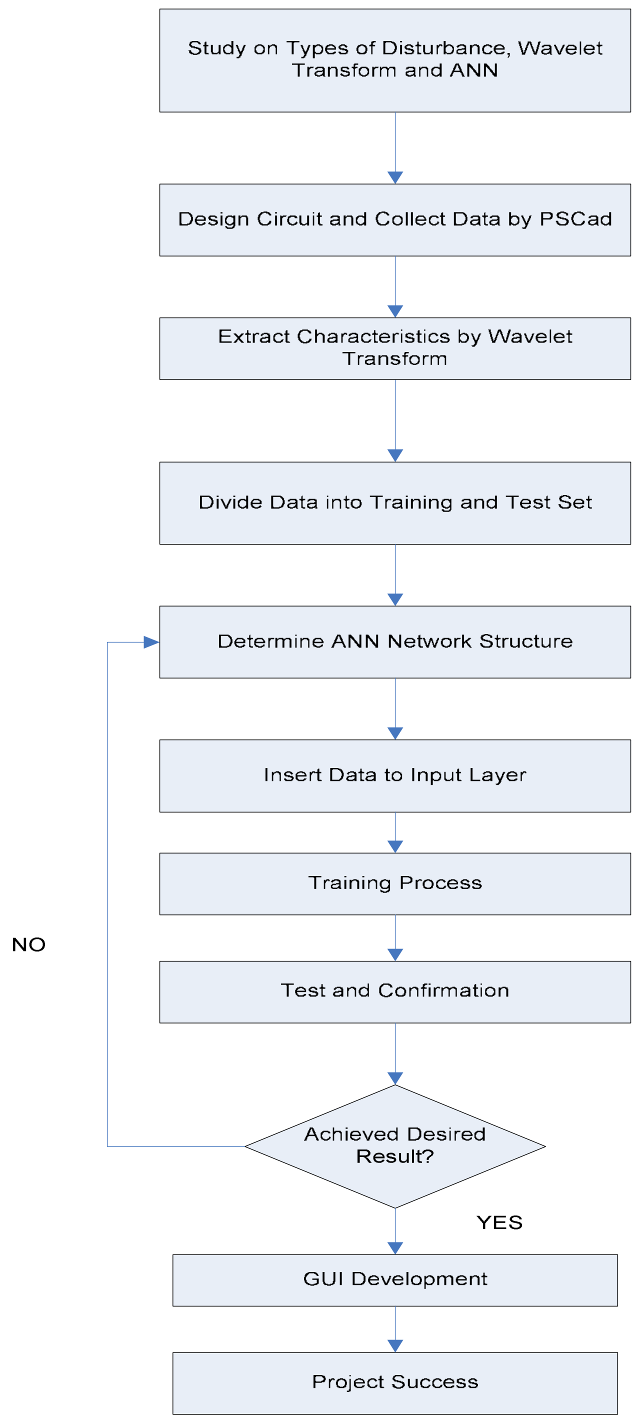

Figure 3.8 Flow Chart Process

CHAPTER 4

RESULTS AND ANALYSIS

4.1 Data Simulation

The PSCAD/EMTDC is used to perform simulation which then will create various types disturbance that is going to be studied in this project. The types of disturbance that is constructed within the PSCAD are:

a) Voltage sag
b) Voltage swell
c) Outage
d) Harmonic

The data obtained from each simulation is used for feature extraction and it was saved into a data file, *.dat for easier modification. The circuit model for each type of disturbances were created based on online dissertation, reference books, journals, power quality websites, and other paper researches.

4.1.1 Voltage Sag Simulation

For the voltage sag, the interconnected, AC system was chosen and the diagram for the desired voltage sag is shown as Figure 4.1

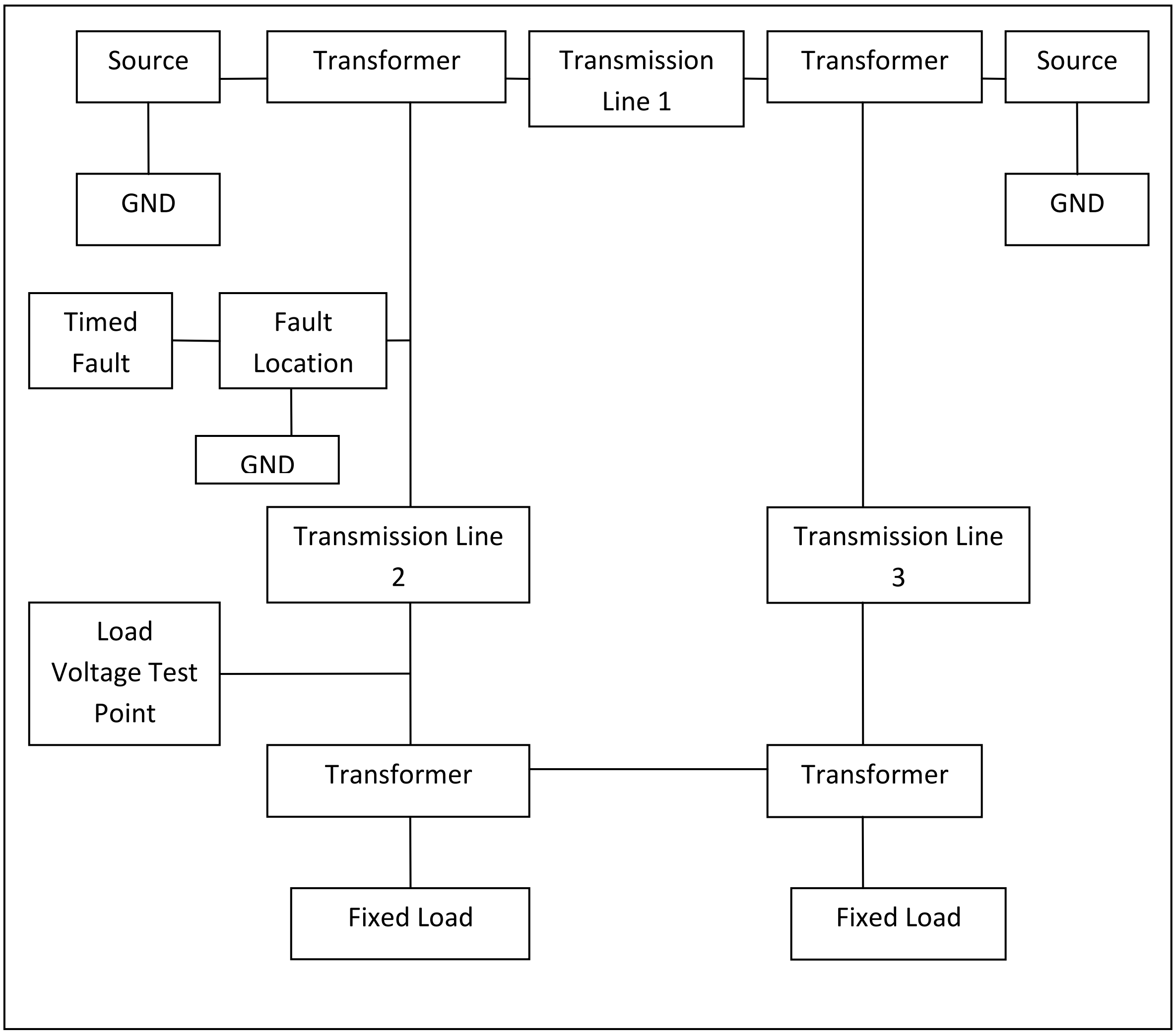

Figure 4.1 Schematic Diagram for Voltage Sag Disturbance

The fault was applied at the transmission line 2 for a duration 0.05 seconds, and start after 0.2 second. The applied fault causes the voltage drop and also causes most of the source current flow into the line. The waveform produced by this circuit run for 0.5 seconds with plot steps of 0.001 s is shown in Figure 4.2

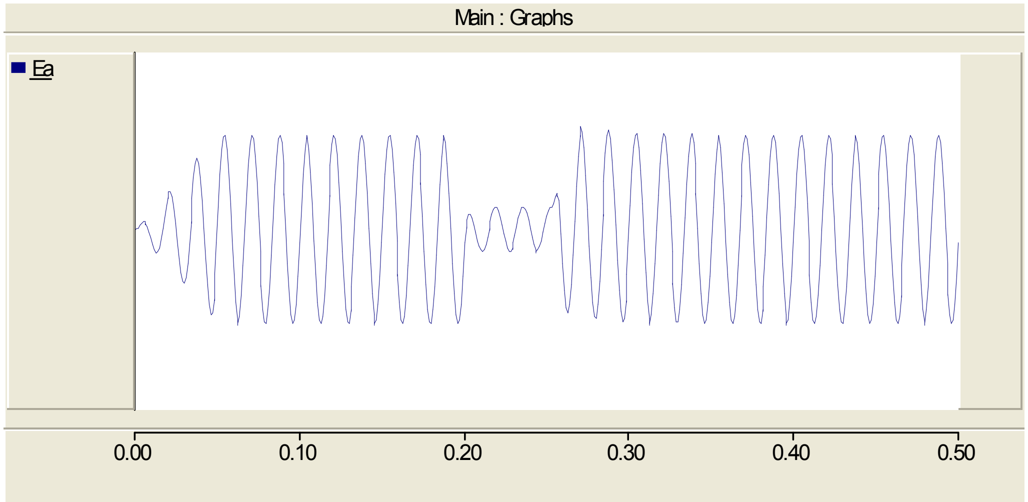

Figure 4.2 Sample of Output Voltage for Voltage Sag

The graph shows that the voltage drop at 0.2 second for duration of 0.05 seconds and then the voltage was restored back to normal. The output data from PSCad contained one time value and load voltage for phase A-C. This information was then placed in separate columns and rows for each sample.

.000000000000	.000000000000	.000000000000	.000000000000
.1000000000000E-02	.13347236731568	-.58952202309670	.45604965578102
.2000000000000E-02	.85511145167430	-1.4865670194143	.63145556774003
.3000000000000E-02	2.0367621305269	-2.2101549412142	.17339281068734
.4000000000000E-02	3.3409773217166	-2.3242928395185	-1.0166844821981
.5000000000000E-02	4.3301501951161	-1.5664802926250	-2.7636699024911
.6000000000000E-02	4.5777352436350	.10964372908882	-4.6873789727239
.7000000000000E-02	3.7768381154008	2.5162918222591	-6.2931299376599

Figure 4.3 Sample Data of Voltage Sag

Figure 4.3 shows the sample of the output data for the voltage sag. The first column shows the time and rest of the columns shows the value of voltage for phase A, B, and C at that particular time. This data file can be easily modified for use in MATLAB.

The simulation was run at different locations, which are at 50 km, 100 km, and 200 km, by varying the length of transmission line 2, to obtain the voltage sag at different distances away from the fault.

4.1.2 Voltage Swell Simulation

For the voltage swell, the effect of breaker is used to give the swell form in the voltage.

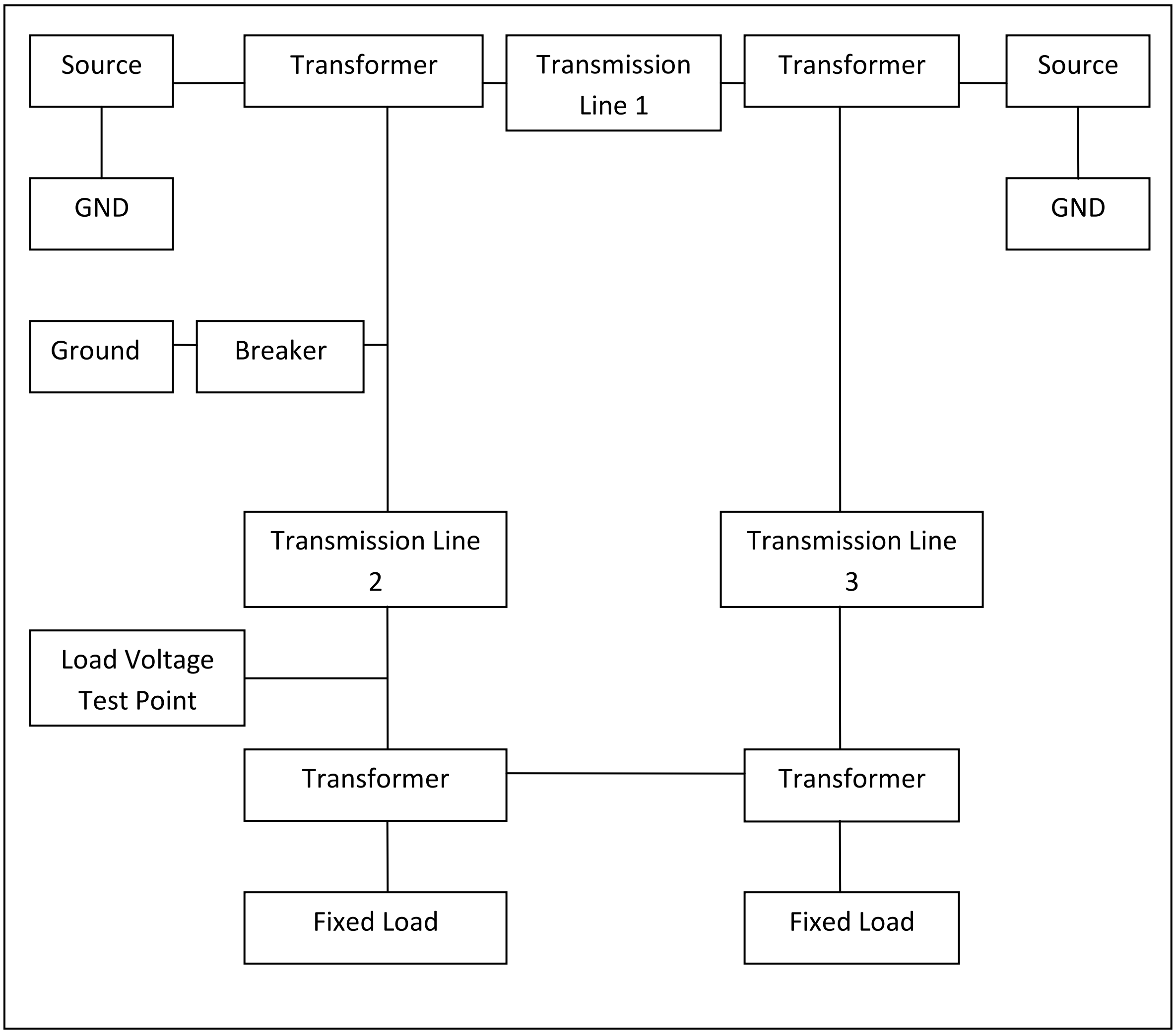

Figure 4.4 Schematic Diagram for Voltage Swell Disturbance

The voltage swell happened as the breaker was set to open at 0.2 second, and close at 0.25 second, for a duration of 0.05 seconds. The fault was applied by opening the breaker, which will make the open circuit occurred at this state. The load voltages, however, increased for this period of time. This caused the load voltage increased.

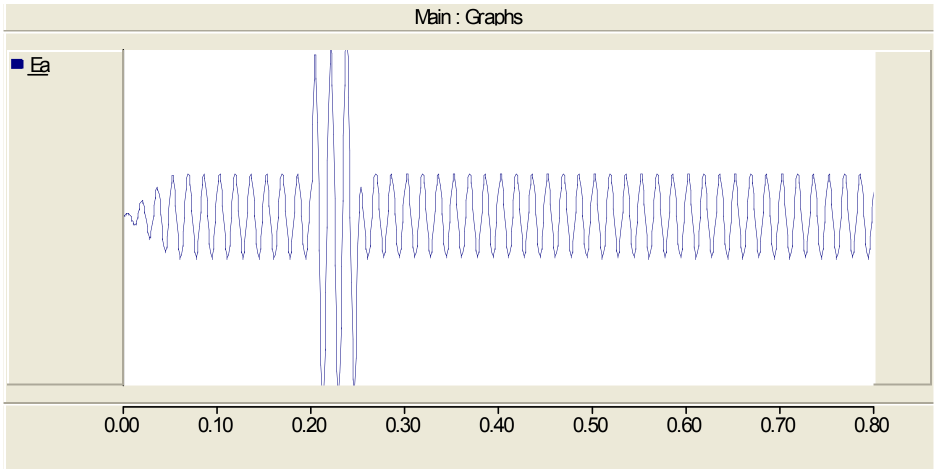

Figure 4.5 Sample of Output Voltage for Voltage Swell

As the magnitude voltage increased for duration of 0.05 seconds, therefore it shows that voltage swell disturbance occurred and the duration depends on the set time for the breaker to operate.

.000000000000	.000000000000	.000000000000	.000000000000
.10000000000000E-02	.12454308203937	-.15949874373249	.34955661693125E-01
.20000000000000E-02	.35908590369092	-.30029000862984	-.58795895061085E-01
.30000000000000E-02	.60402964182625	-.30127264831829	-.30275699350796
.40000000000000E-02	.76606678783700	-.12183925201268	-.64422753582432
.50000000000000E-02	.76342279344596	.23335700502649	-.99677979847245
.60000000000000E-02	.54540980621265	.71280606452012	-1.2582158707328
.70000000000000E-02	.10671414863474	1.2256113776101	-1.3323255262448

Figure 4.6 Sample Data for Voltage Swell

Figure 4.6 shows the sample of the output data for the voltage swell. The first column shows the time and rest of the columns shows the value of voltage for phase A, B, and C at that particular time. This data file can be easily modified for use in MATLAB. The simulation was run at different locations, which are at 50 km, 100 km, and 200 km, by varying the transmission line 2, to obtain the voltage swell at different distances away from the fault.

4.1.3 Outage Simulation

Outage occurred as there is zero voltage temporarily happened. For the outage, the breaker once again is placed in the diagram but now, it is placed at the fixed load and the voltage also was measured at load.

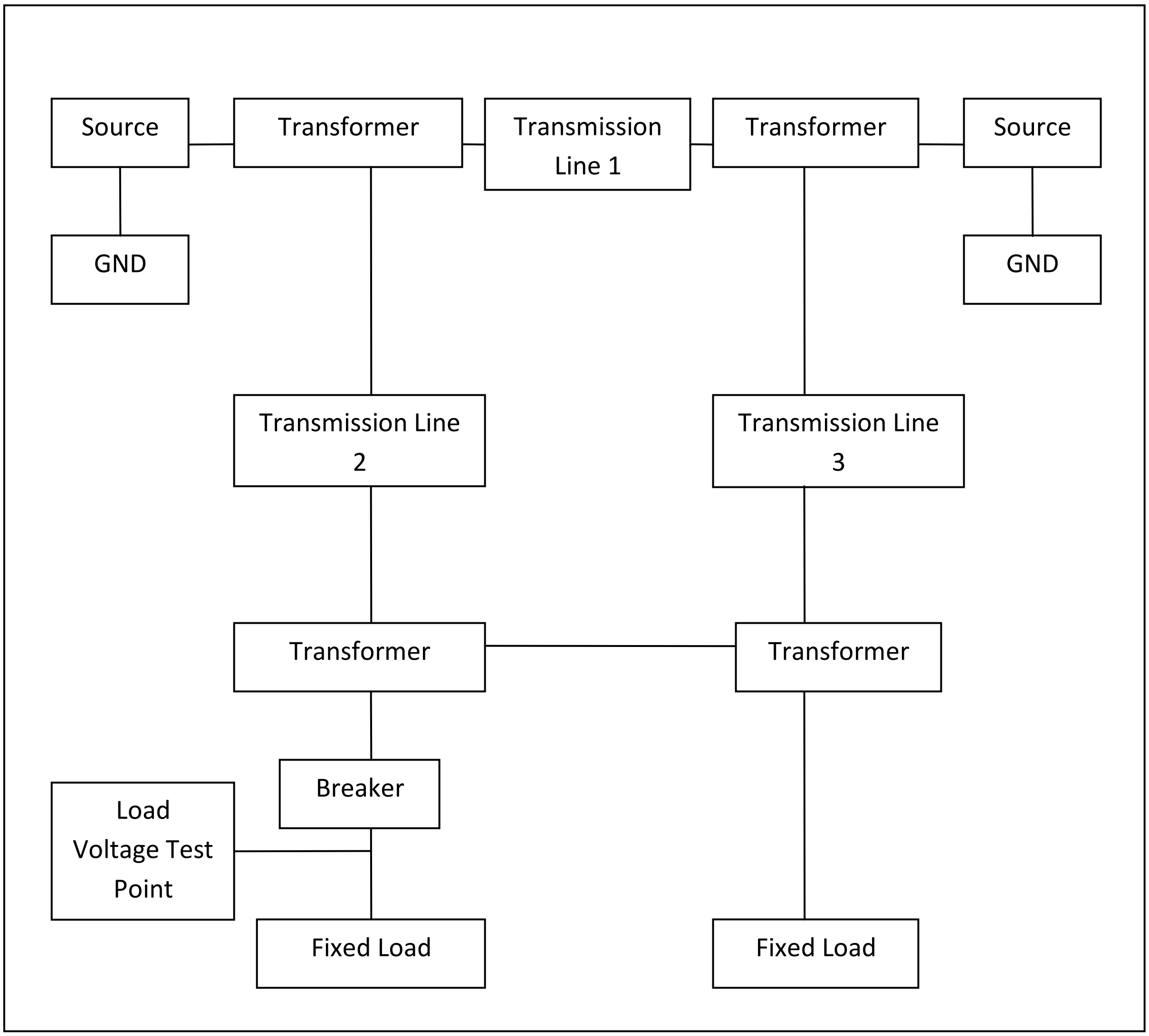

Figure 4.7 The Schematic Diagram for Outage Disturbance

The breaker was set to operate at 0.2 second for 0.05 seconds, which means it close at 0.25 second. The breaker was placed at the load to produce the effect of outage and the voltage output was measured at the load. The voltage supplied to the load will be temporarily affected which it will reduced to zero for that period. The outage simulation was run for 0.8 seconds which produced the voltage output as shown in Figure 4.8

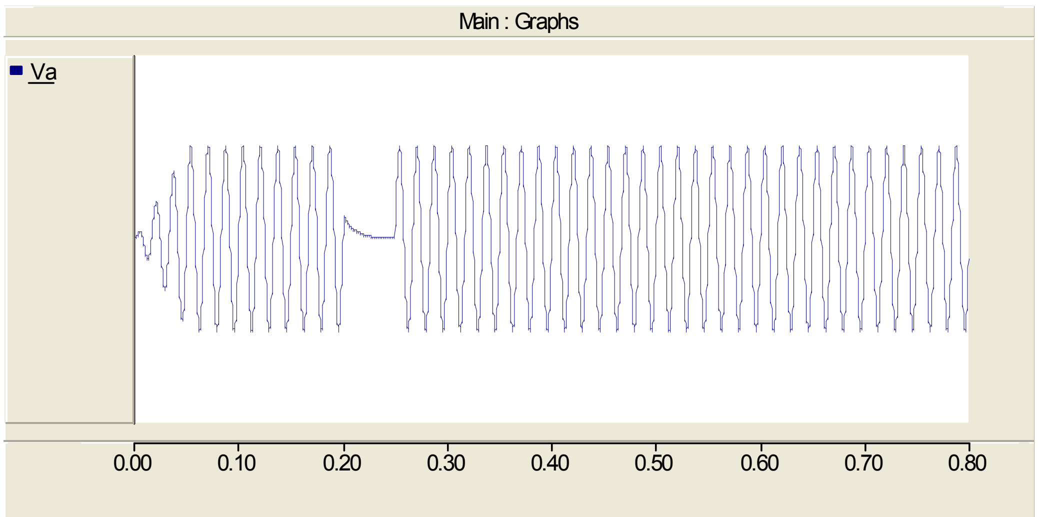

Figure 4.8 Sample of Output Voltage for Outage

The sample of data is as shown in Figure 4.9. The first column indicates the time while the remaining column shows the voltage for phase A, B and C in kV. The data was saved in .dat for easier modification and use in MATLAB. The simulation was repeated by changing the length of transmission line 2 in order to collect data at different locations, which are at 50km, 100km and 200km.

.000000000000	.000000000000	.000000000000	.000000000000
.1000000000000E-02	.13709774082808	-.89937472512597E-01	.30536218880337E-01
.2000000000000E-02	.29452031860641	-.40689160287442	.30969362914245
.3000000000000E-02	.16720925784024	-.72293172590574	.83421787230695
.4000000000000E-02	-.32367952764410	-.90725431010999	1.4661754340225
.5000000000000E-02	-1.1150107689494	-.81509378841511	2.0010044635788
.6000000000000E-02	-2.0434624666616	-.37457624048414	2.2258199660030
.7000000000000E-02	-2.8804907668905	.40089231266945	1.9733631894675

Figure 4.9 Sample Data of Outage

4.1.4 Harmonic Simulation

The harmonic simulation was done by measuring the current across the load as the total harmonic current distortion (THDI) is more significant if compared by using total current voltage distortion (THDV) which needs to measure the voltage across the load. Thyristor SCR is used to create the harmonic disturbance by switching it rapidly and for this circuit, it use resistor and inductor as the loads.

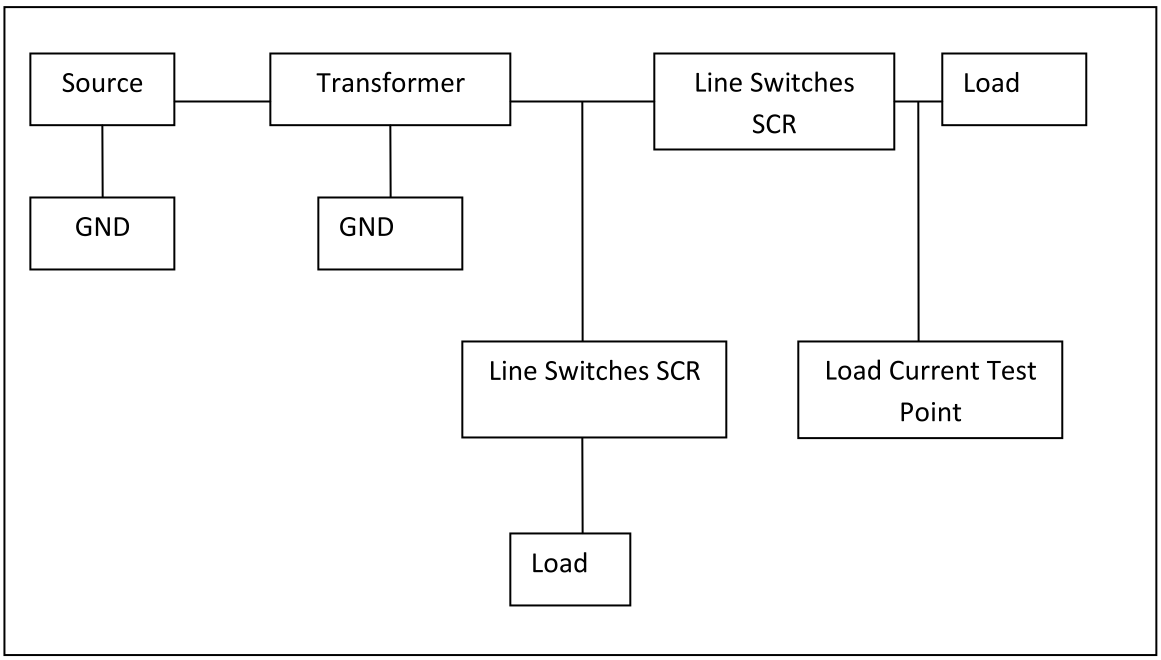

Figure 4.10 Schematic Diagram for Harmonic Disturbance:

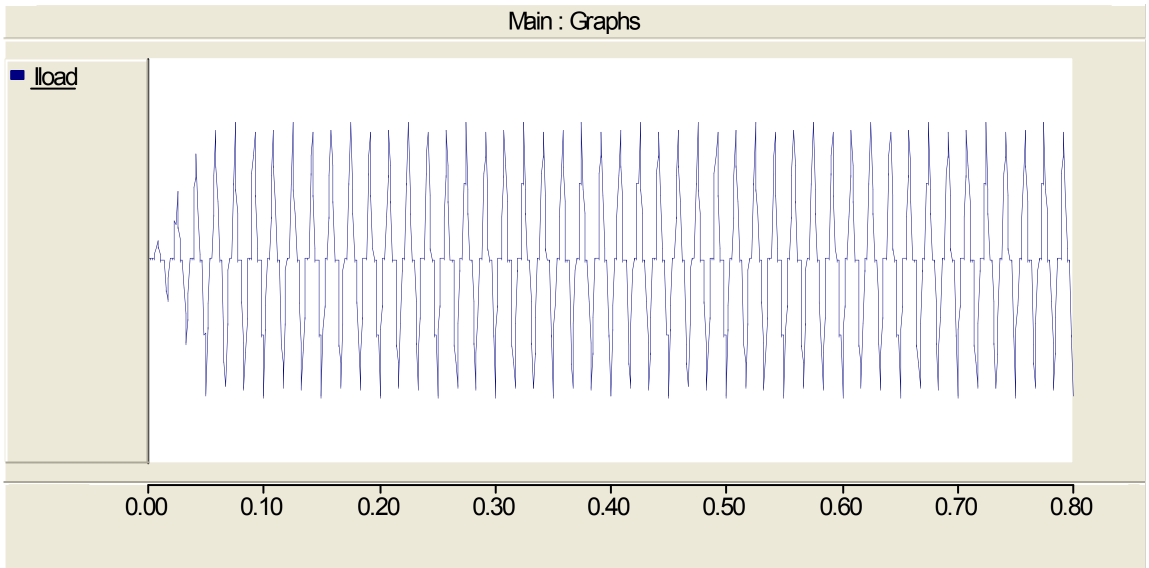

Figure 4.11 Sample of Output Voltage for Harmonic

Figure 4.11 shows the output current which was measured at the load for 0.8 seconds while Figure 4.12 shows the data generated by PSCAD which is the first column shows the value at particular runtime and the other two columns are the current that flows through the load. For this type of disturbance also, the length was varied at 50 km, 100 km, and 200km.

.0000000000000	.0000000000000	.0000000000000
.10000000000000E-02	.42317054762302E-06	.42317054762302E-06
.20000000000000E-02	.82621980165532E-05	.82621980165532E-05
.30000000000000E-02	.21277430486846E-04	.21277430486846E-04
.40000000000000E-02	.30427371837452E-04	.30427371837452E-04
.50000000000000E-02	.37251269345432E-04	.37251269345432E-04
.60000000000000E-02	.84063115481283E-02	.84063115481283E-02
.70000000000000E-02	.14854982421947E-01	.14854982421947E-01

Figure 4.12 Sample of Data for Harmonic

4.2 Software Development

The software development can be divided into two parts which are scripts writing and GUI development (interfacing). The software was developed by using MATLAB environment which are by using wavelet toolbox, neural network toolbox, and also GUI builder.

4.2.1 Script Writing

M-file is used for the script writing which contains commands for function that we would like to execute. In order to create a program, M-file is very important because the name that contains different command is used as the callback.

The first script that is used in this 'Power Quality Disturbance and Location Detector using ANN' is for function of loading and manipulating data which was previously generated by PSCAD and saved as *.dat. Command functions, ***Load*** and ***Plot*** were used in performing those desired functions.

Then, the effort is aimed in Wavelet Decomposition analysis for the selected input signal. As the command line was chose to execute the Discrete Wavelet Transform, each of the command of the Wavelet toolbox performs various tasks required for Wavelet Analysis in signal decomposition, and Wavelet coefficients' plotting. Function, ***Wavedec*** has been used to perform the decomposition towards the input signal. ***Detcoef*** and ***Appcoef*** were used to determine the coefficients of each decomposition level.

Finally, the Neural Network command lines are created in M-File. As the Probabilistic Neural Network was chosen for the classification of types of disturbance and location, therefore command***, newpnn, ind2vec*** and ***vec2ind*** were used to design the neural network. The function ***newpnn*** creates a two layer network, with the first layer contains radbas neurons. Command ***ind2vec*** converts indices to vectors while ***vec2ind*** is vice versa. It allows indices to either be represented by themselves, or as vectors containing a 1 in the row of the index they represent.

In order to display types of disturbance and the location of where it occurred, basic structural programming language of MATLAB was used. For example, if the data from the wavelet extraction fulfills the requirement needed and match any of the target that already specified in pnn, it will give to the users the results by display the type of disturbance and location of it.

4.2.2 GUI Design

After all the scripts were written in M-File, then GUI will be used to compile all of them for easy use to the users. For the first time in designing GUI, as we choose new GUI from the file menu at MATLAB, figure as …will appeared. Users can choose the GUIDE templates they would like to start with and for this project, the Blank GUI (default) was chose.

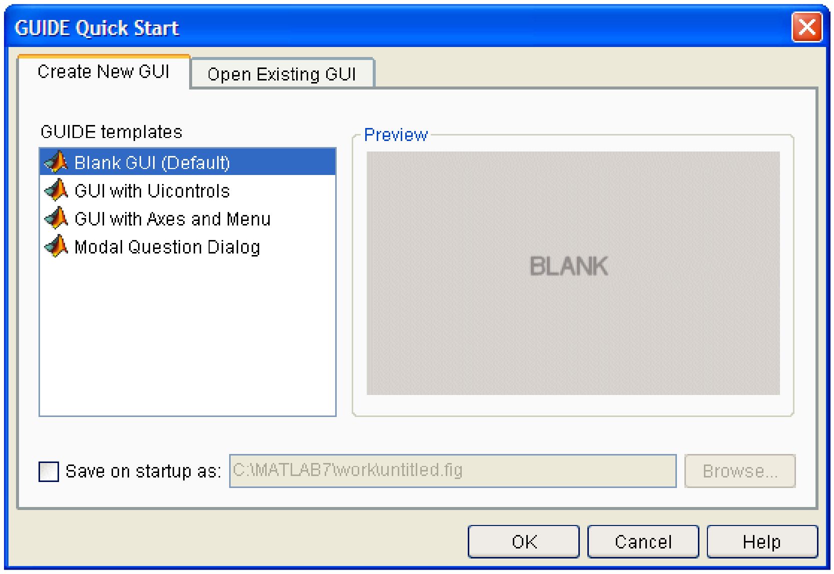

Figure 4.13 GUIDE Quick Start

For the blank GUI, component palette will be rearranged in order to perform a new layout of the created program. The component palette will be put inside the layout area which can be size-adjusted.

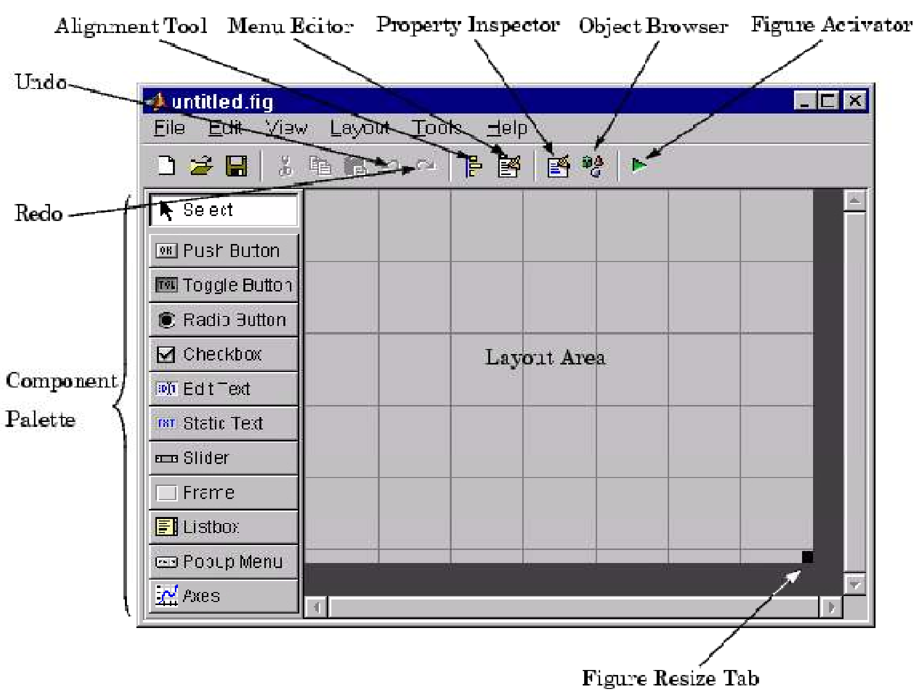

Figure 4.14 GUI Layout Editor

The process of implementing a GUI involves two basic tasks which are laying out the GUI components and programming the GUI components.

First of all, component that were selected to be use in creating “Power Quality Disturbance and Location Detector using ANN” were arranged inside the layout area. The components used for this project are push button, static text, listbox, axes and panel. Figure 4.15 shows the layout of the program and Figure 4.16 shows the activated figure for it.

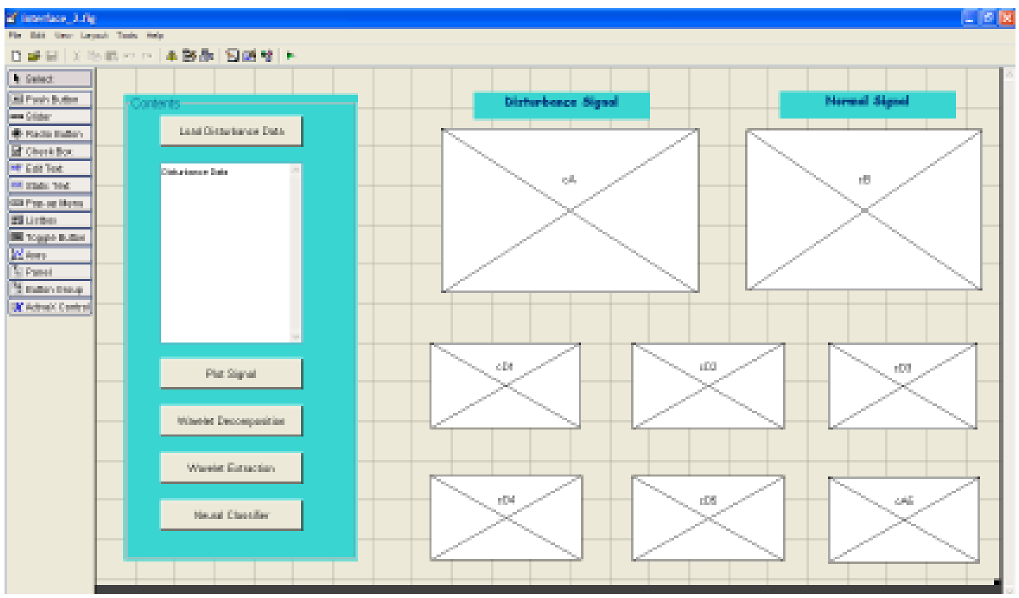

Figure 4.15 Layout of the Program

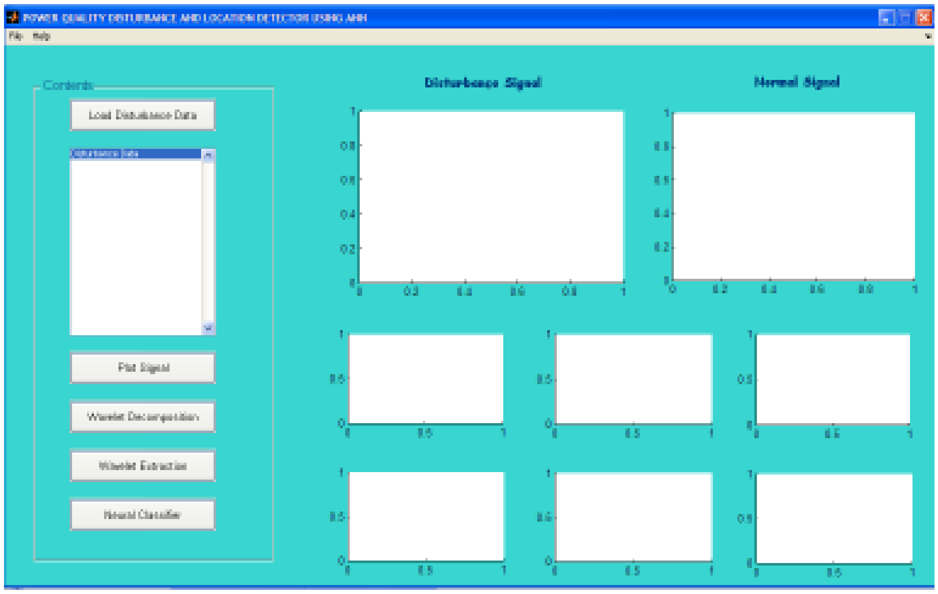

Figure 4.16 The Activated Figure for the Program

The M-Files were connected with the created GUI by using callback. Every component has its own callback and we can assign different M-File to be generated when different push button was selected.

In order to make it more like efficient, file menu and help menu were added to the program which contains different function when different command were selected. Figure 4.17 shows the Menu Editor provided in GUI for users to create their menu. Accelerator also can be used for users who would like to use their keyboard either than point to desired choose menu. The tag then will be attached to their callback to function certain command.

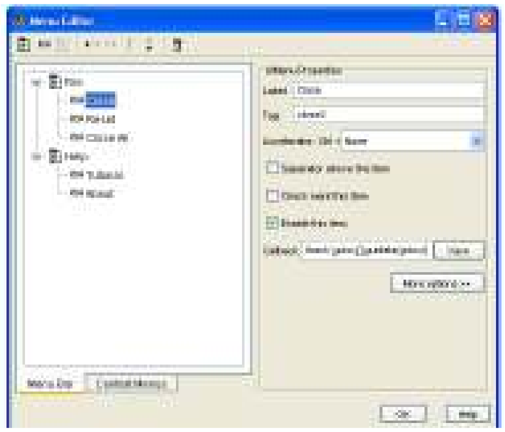

Figure 4.17 Menu Editor

The Property Inspector can be used to change fonts, size, label, tag, and so on in order to meet the best performance of the created program. This can be shown by Figure 4.18 where the programmer can easily modify it.

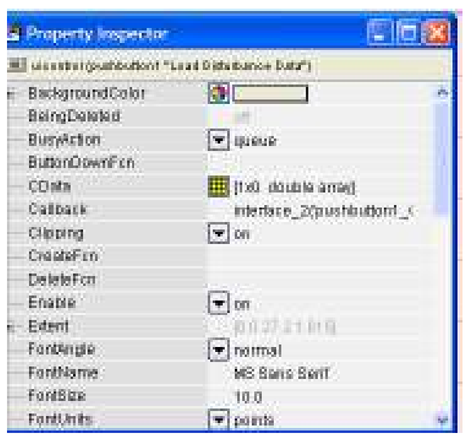

Figure 4.18 Property Inspector

Finally, the main interface for the program was introduced to connect the main page to the program that can perform the types of disturbance and location classifying.

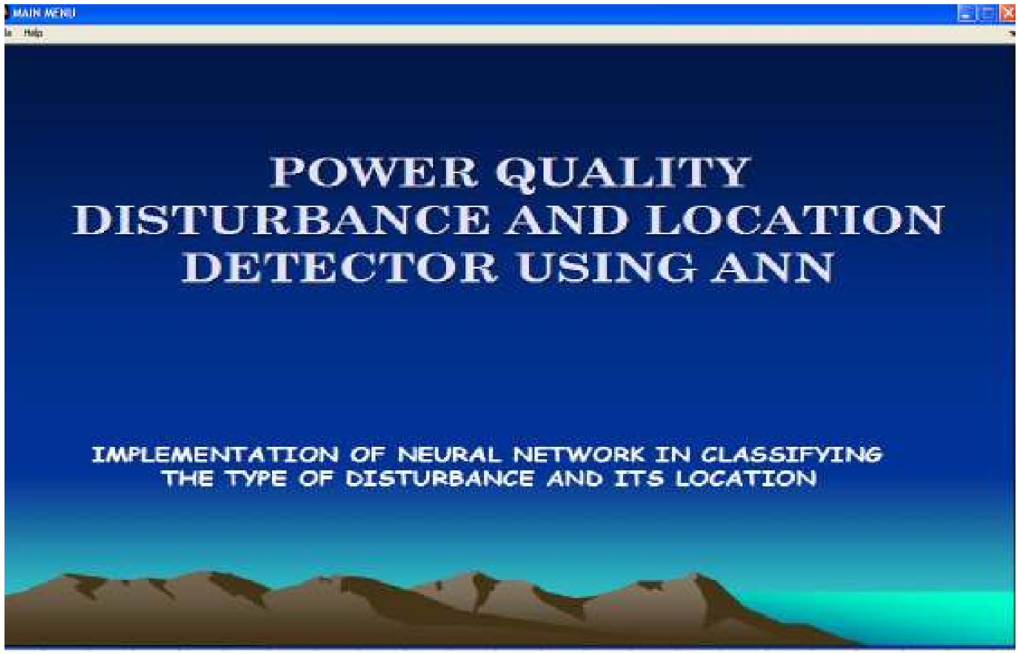

Figure 4.19 Main Page of the Program

4.2.3 Implementation of the Program

For the users that use the program for the very first time, they are encouraged to read the manual provided first. First of all, they need to copy the whole program into the MATLAB folder, and placed it inside work file. The location of MATLAB folder depends on where they locate it during installations.

Then, they can start the MATLAB window and choose to new GUI from the file menu. After that, they need to click on open existing GUI and browse the file named "interface_1". A GUI window appeared and to activate it, they can choose run from the layout editor toolbar. Figure 4.20 will come out as soon as the run button was click.

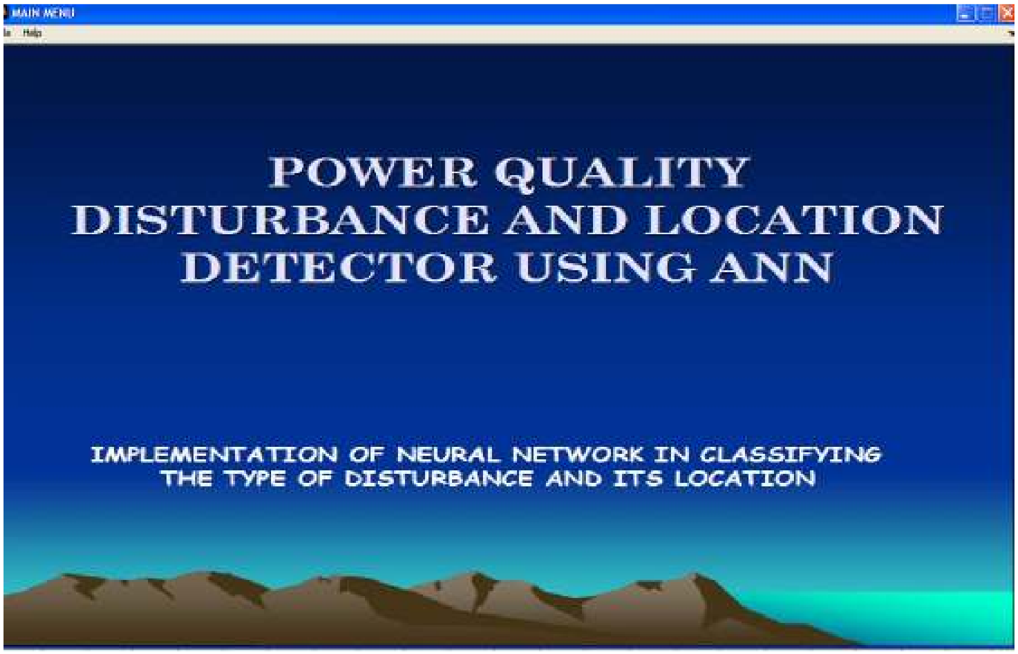

Figure 4.20 The Main Page of the Program

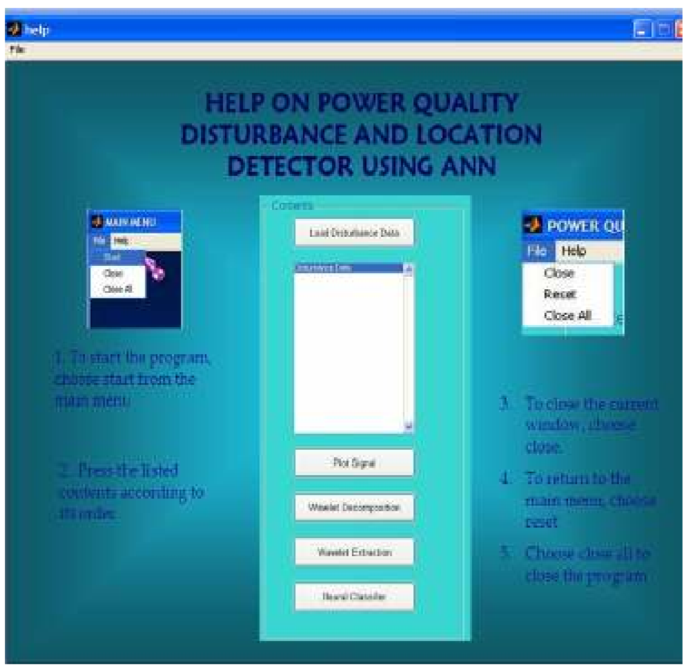

Figure 4.21 The Tutorial Page of the Program

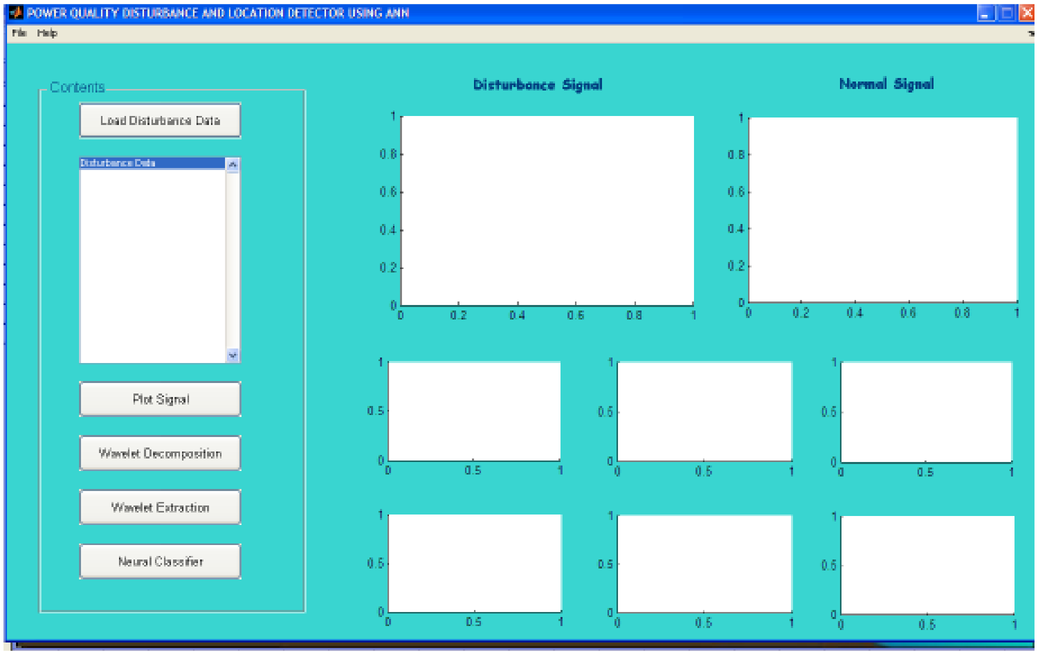

Figure 4.22 The Contents of the Program

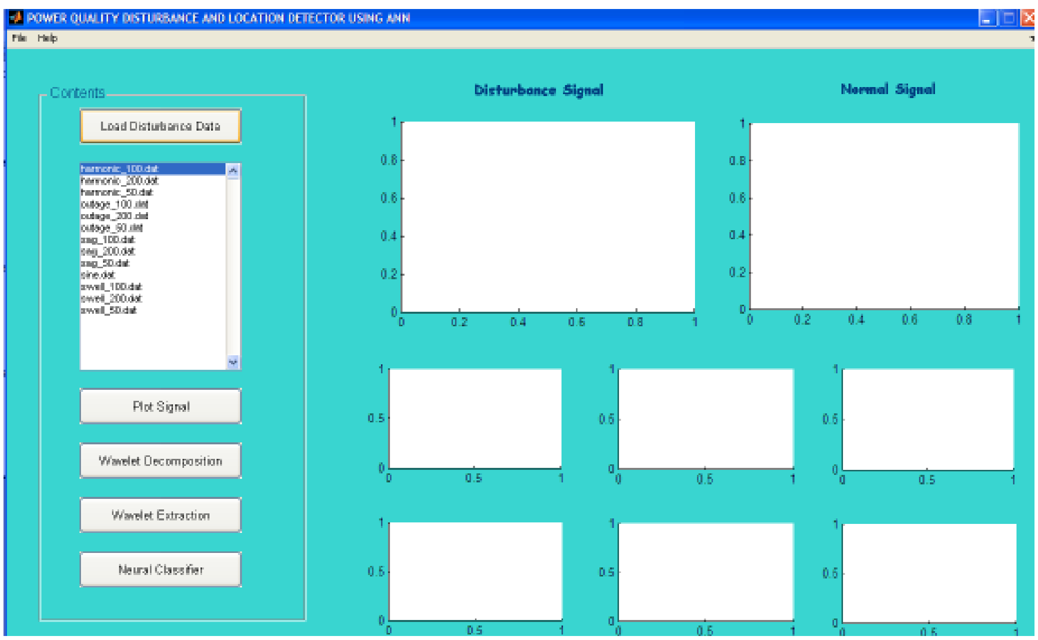

Figure 4.23 Loading Data into the Listbox

By pressing on 'Plot Signal' button the data selected then was plotted on the Disturbance Signal and Reference Signal shows the signal without disturbance.

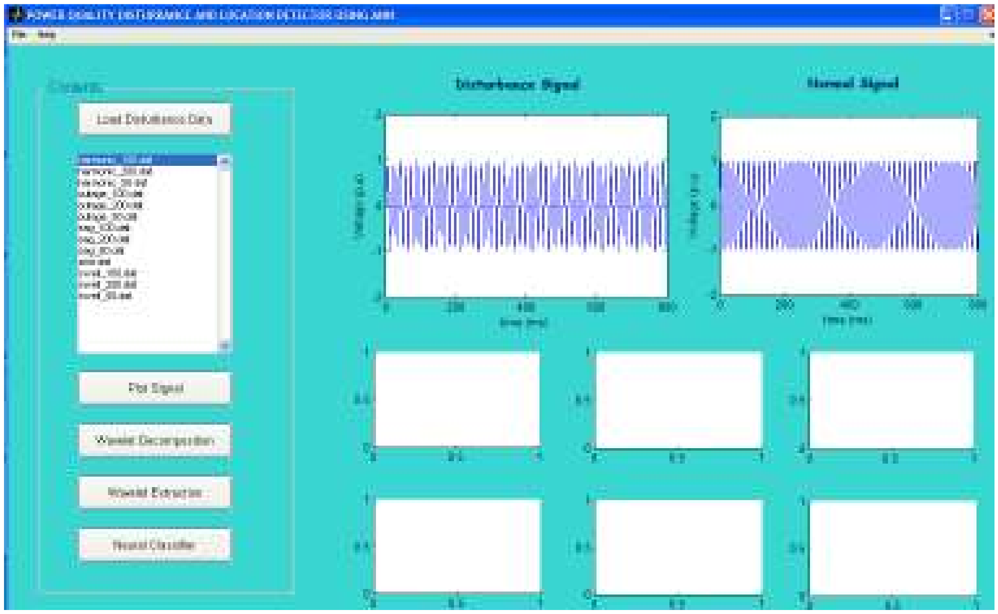

Figure 4.24 Signal Plotting for the Input Data

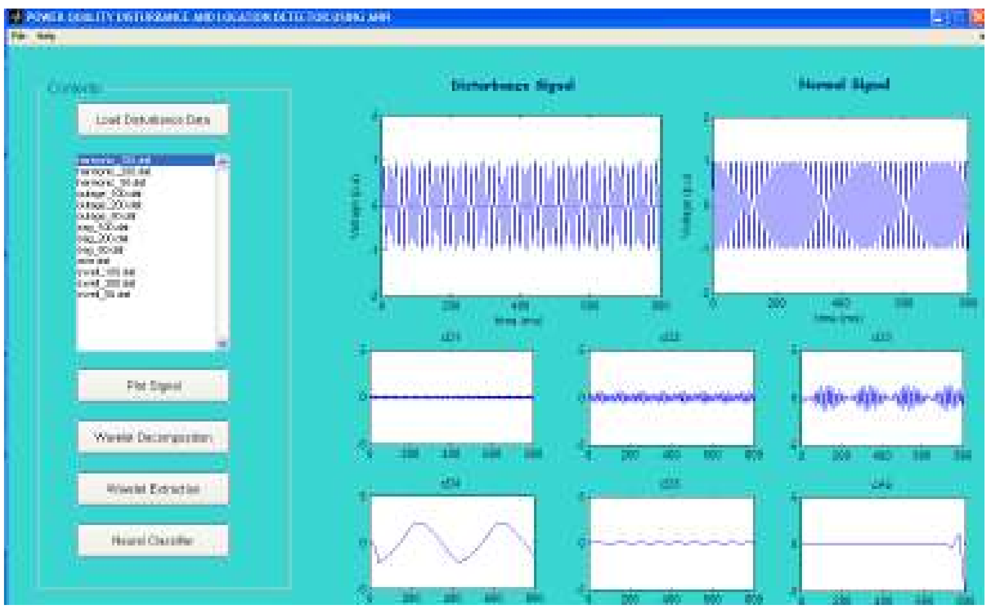

Figure 4.25 Wavelet Decomposition and Coefficients Plotting

Then, the deviation energy from the disturbance signal and reference signal was calculated to perform the wavelet extraction and the graph for the chosen type of disturbance can be obtained by clicking on the 'Wavelet Extraction' button and a new pop-up figure will appear.

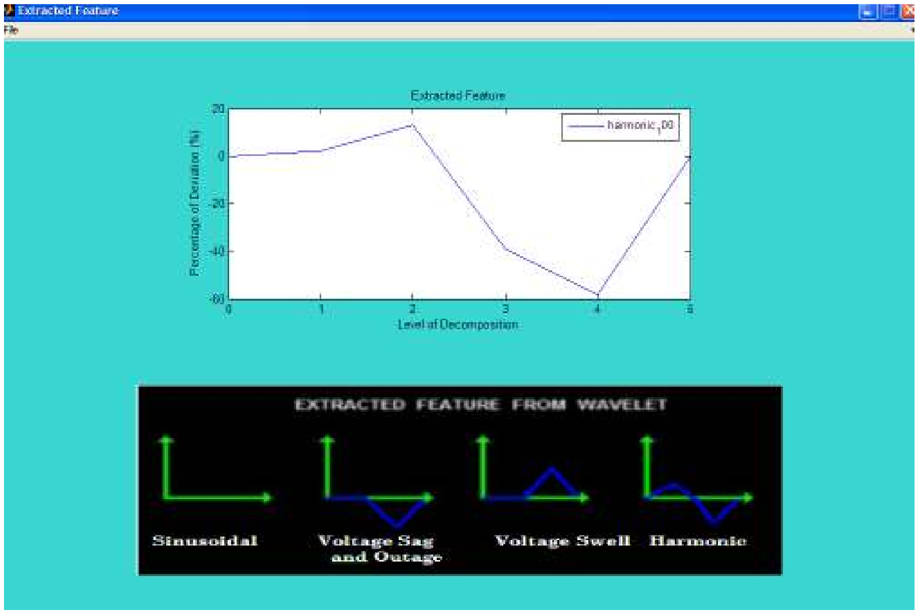

Figure 4.26 Pop-up Figure for Extracted Feature

Finally, neural network will perform classification on types of disturbance and the location of it when users select the 'Neural Classifier' button and again, a new pop-up figure appeared and display the result.

Figure 4.27 Pop-up Figure for Neural Classifier

Both of Extracted Feature and Neural Identification windows provides option for users to print out the window's display.

4.3 Simulation Result (Extracted Feature)

In this section, the extracted feature for four types of disturbance that already been studied will be discussed by performing the feature extraction analysis.

4.3.1 Voltage Sag

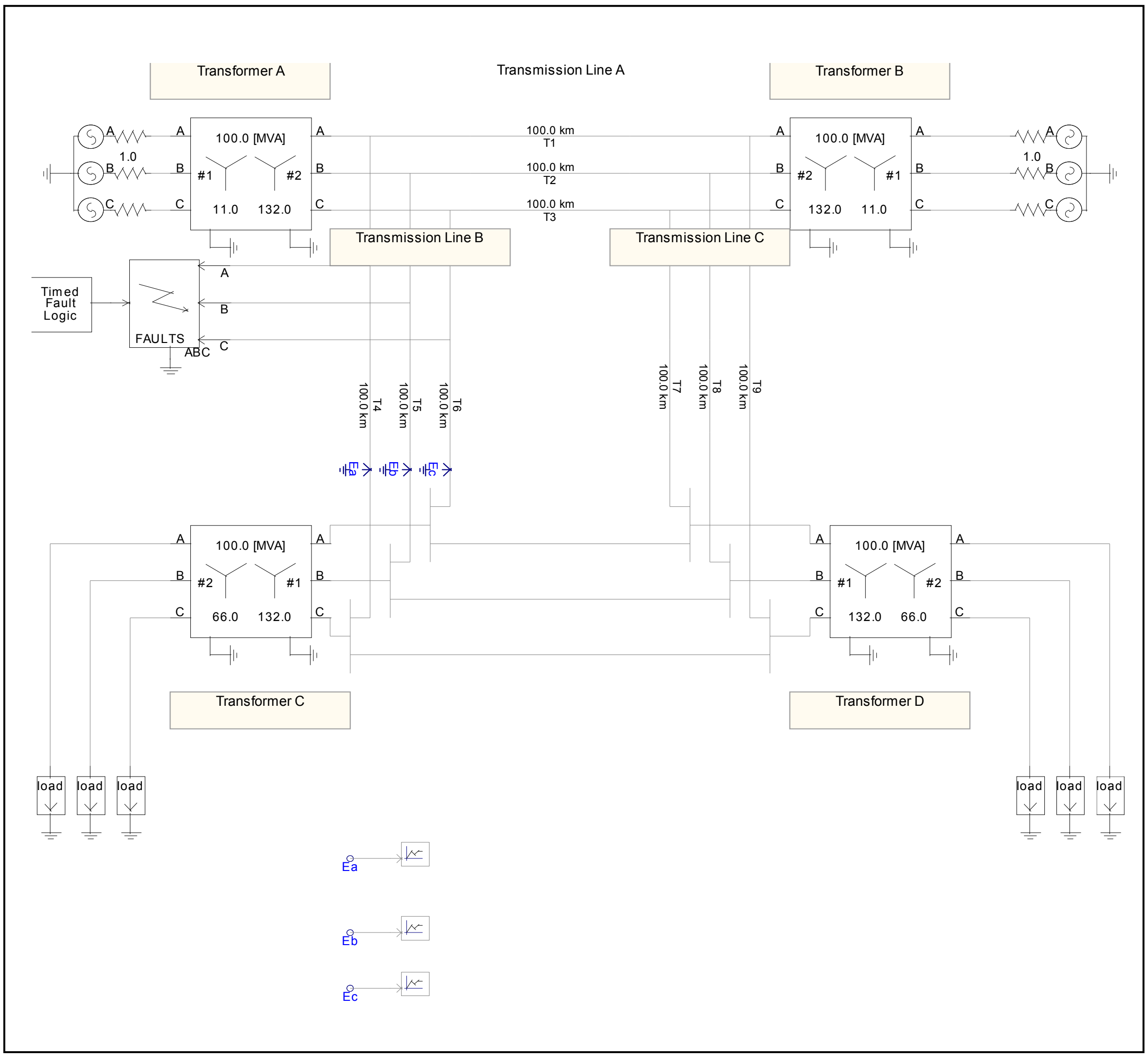

Figure 4.28 Voltage Sag Circuit

The circuit in Figure 4.28 was built inside the PSCAD and it is able to produce the voltage sag disturbance at the measured voltage. The timed fault logic was used to apply fault at the transmission line for duration of 0.05 seconds. The data generated by PSCAD will be used to perform the wavelet decomposition and then wavelet extraction. Figure 4.29 shows the wavelet extraction for voltage sag at 100 km while Figure 4.30 shows the wavelet extraction from the deviation of calculated energy at each level of coefficients.

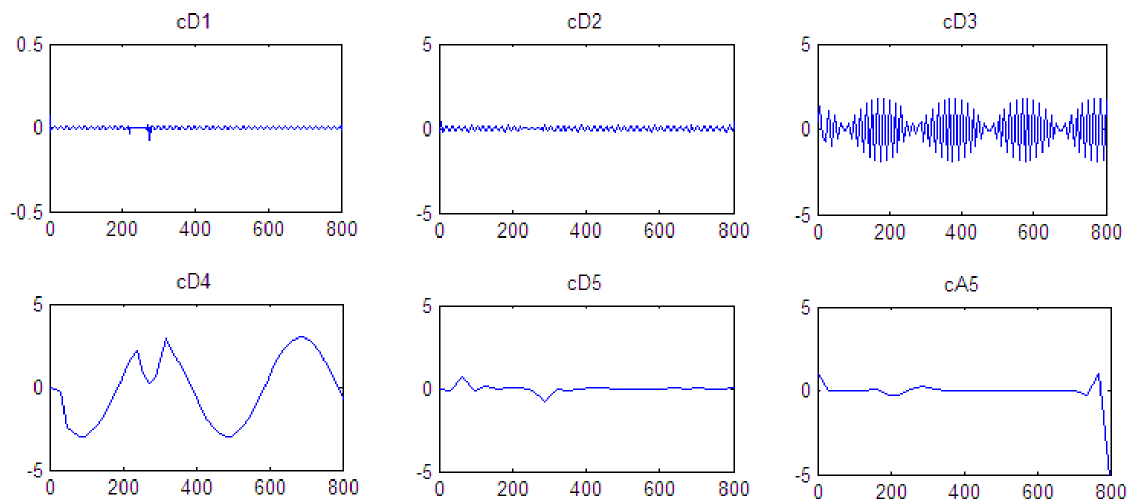

Figure 4.29 Wavelet Decomposition for Voltage Sag at 100 km

Two spikes happened at detailed coefficients level 1 at t=0.2 s and 0.25 s. It shows that sag has occurred for durations of 0.05 seconds. The other wavelet level has also experienced variations at this same instant. At detailed coefficients level 4, it shows that the highest amplitude occur which means that the signal concentrates most at this level. This implies that level 4 carries the frequency that nearly same with the fundamental frequency (50 Hz)

Level of Decomposition	% of Energy Deviation
0	
1	0.003827
2	-0.10668
3	0.52019
4	-13.1876
5	0.27217

Table 4.1 Percentage of Energy Deviation for 5 Levels of Wavelet Decomposition for Voltage Sag at 100 km

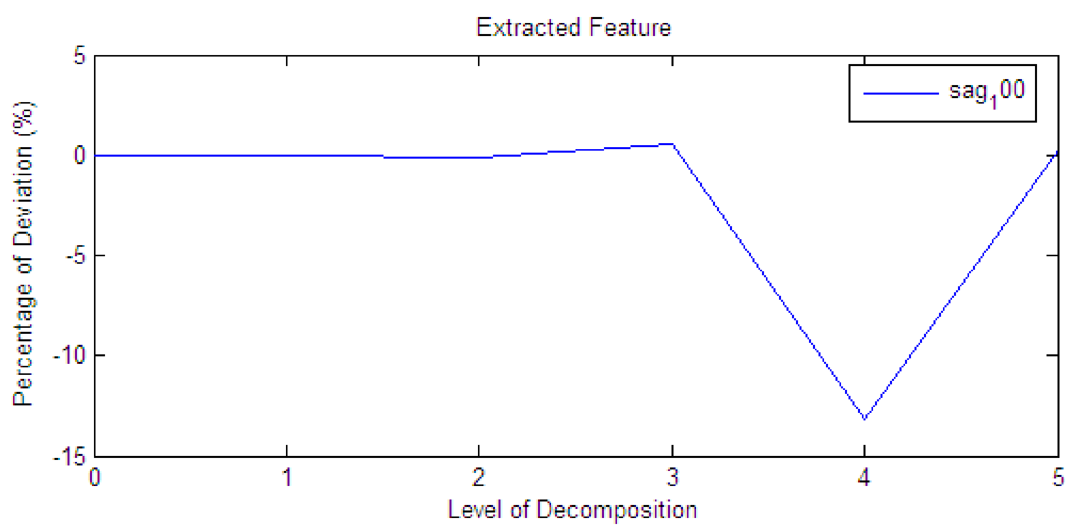

Figure 4.30 Wavelet Extraction for Voltage Sag at 100 km

Based on the extracted feature showed in Figure 4.30, it shows that level 4 has the most percentage of deviation which means that both signals energy have a high concentration of energy at that level. However, the energy of voltage sag at level 4 is slightly lower that the energy of reference signal at that level. Therefore, negative peak deviation was produced at that level. The voltage drop during the sag duration causes low amplitude in detailed coefficient level 4 (cD4).

4.3.2 Voltage Swell

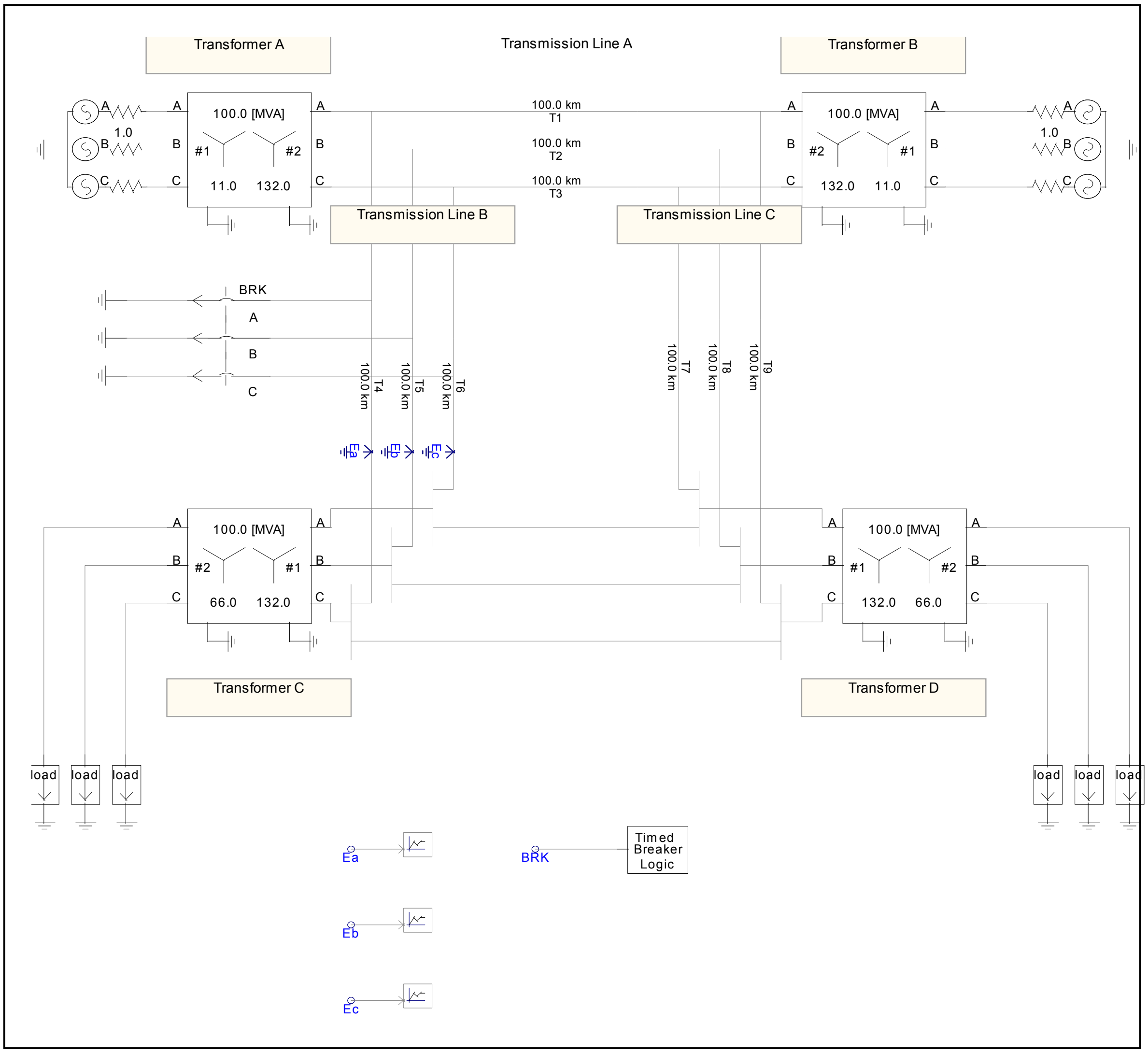

Figure 4.31 Voltage Swell Circuit

Figure 4.31 shows the created circuit for voltage swell within PSCAD environment. The breaker was applied at the transmission line to produce voltage swell, which means increased in voltage for 0.05 seconds. Based on data generated by PSCAD, it will be used to do wavelet decomposition and then based the Parseval's energy theorem, wavelet extraction will be executed. Figure 4.32 shows the wavelet decomposition for five levels of Deubechies wavelet for voltage swell at 100 km while Figure 4.33 shows the wavelet extraction of it.

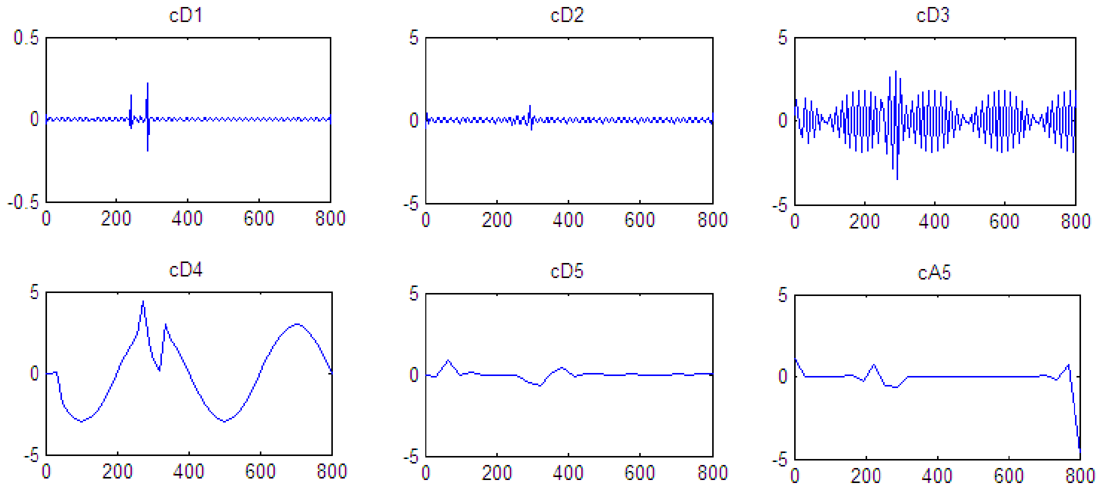

Figure 4.32 Wavelet Decomposition for Voltage Swell at 100 km.

The level 1 of the detailed coefficients showed that spikes occurred at two different times which also means that swell has occurred for duration of 0.05 seconds. The increased voltage during the swell duration causes high amplitude in detailed coefficients level 4 (cD4), therefore a peak was produced in the extracted feature as the deviation of energy was at its highest by that level. The two signals have a high concentration of energy at level 4 but the energy of voltage swell is higher than sinusoidal because of the swell effects.

Level of Decomposition	% of Energy Deviation
0	-
1	0.04982
2	0.6596
3	20.3558
4	-2.4116
5	0.4931

Table 4.2: Percentage of Energy Deviation for 5 Levels of Wavelet Decomposition for Voltage Swell at 100 km

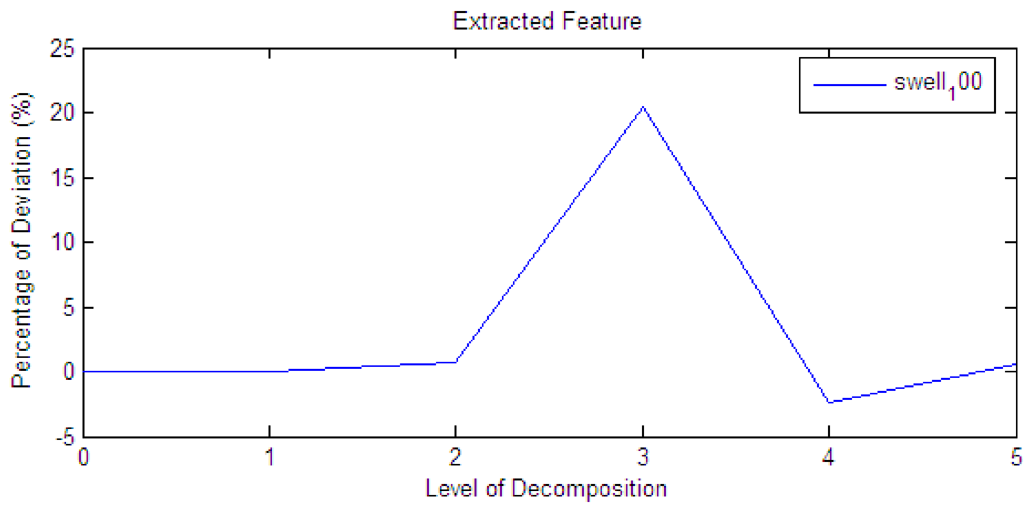

Figure 4.33 Wavelet Extraction for Voltage Swell at 100 km.

The pattern for wavelet extraction for voltage swell shows that the percentage of deviation has its highest magnitude at level 3. The wavelet extraction pattern showed that it has met the desired pattern for voltage swell which has a positive peak based on the reference that is used to determine the types of disturbance The data from this feature will be implemented into the neural network to recognize type of disturbance occur and the location.

4.3.3 Outage

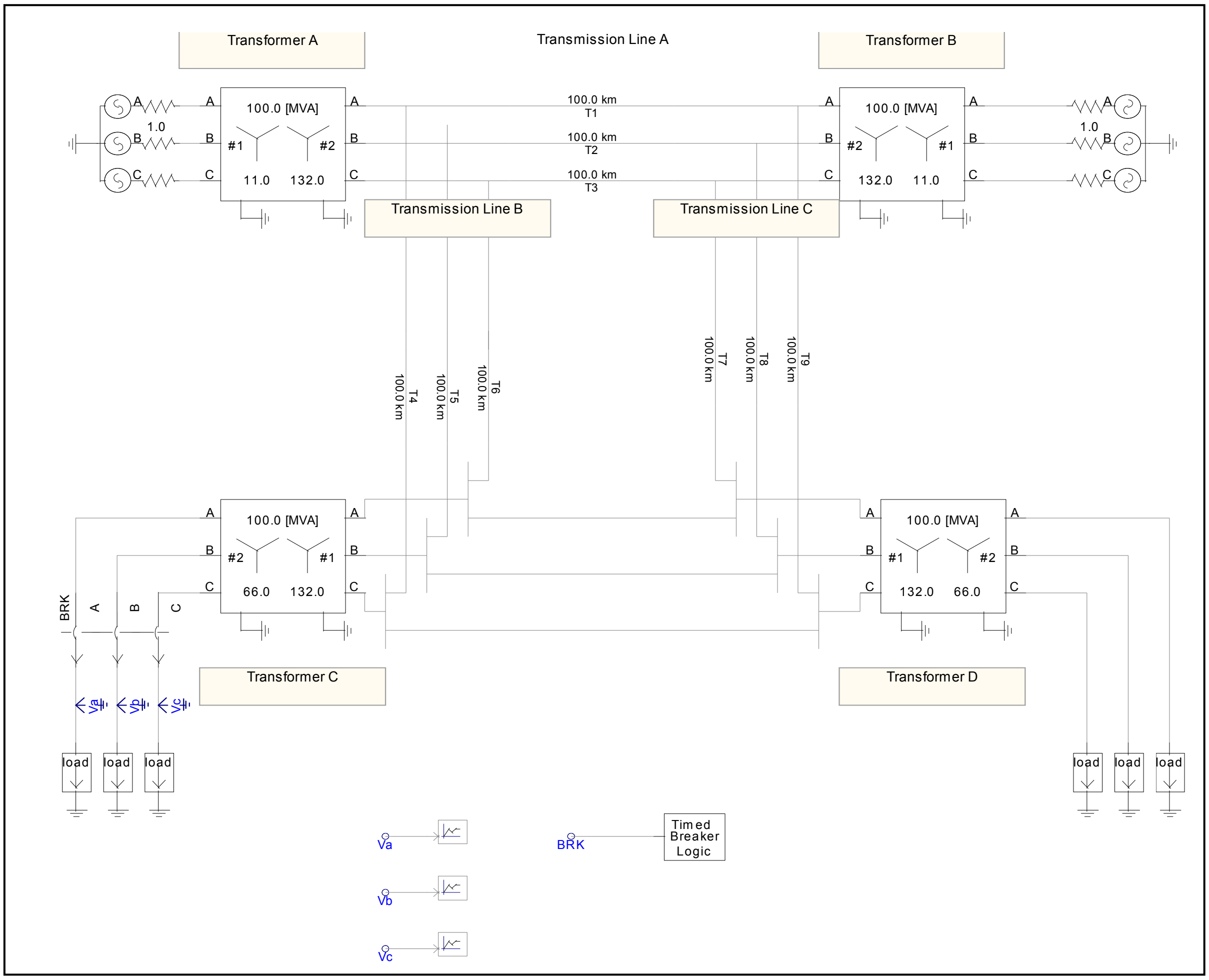

Figure 4.34 Outage Disturbance Circuit

Figure 4.34 shows the outage circuit and the voltage was measured at the load. The breaker was put at the load in order to produce momentarily zero voltage. The data from PSCAD is used to perform wavelet decomposition. The energy at each level will be calculated and the deviation from each level of decomposition of disturbance signal and reference signal then will be used to perform the wavelet extraction. Figure 4.35 shows the wavelet coefficients for 5 levels and Figure 4.36 shows the extracted feature of outage at 100 km.

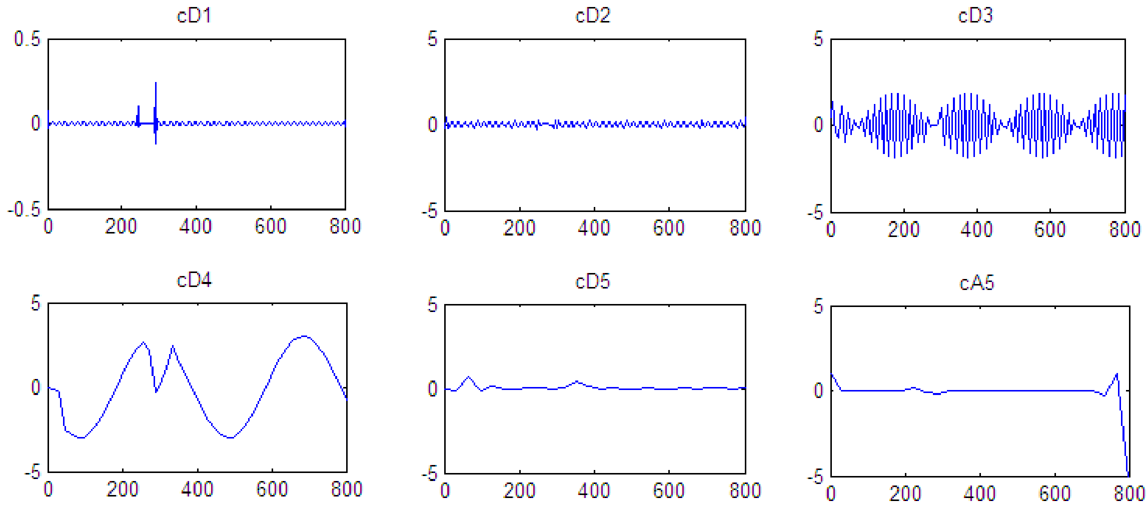

Figure 4.35 Wavelet Decomposition for Outage at 100 km

Based on Figure 4.35, the detailed coefficients level 1 has two spikes at two different time which equals to 0.05 seconds. The energy concentrated at level 4 of detailed coefficients as the amplitude is it highest at that level compared to other level. Therefore, the deviation of energy for disturbance signal and reference signal produce the highest percentage at that level as shown in Figure 4.36.

Level of Decomposition	% of Energy Deviation
0	-
1	0.040518
2	0.0103
3	0.89134
4	-11.9152
5	0.045697

Table 4.3 Percentage of Energy Deviation for 5 Levels of Wavelet Decomposition for Voltage Outage at 100 km

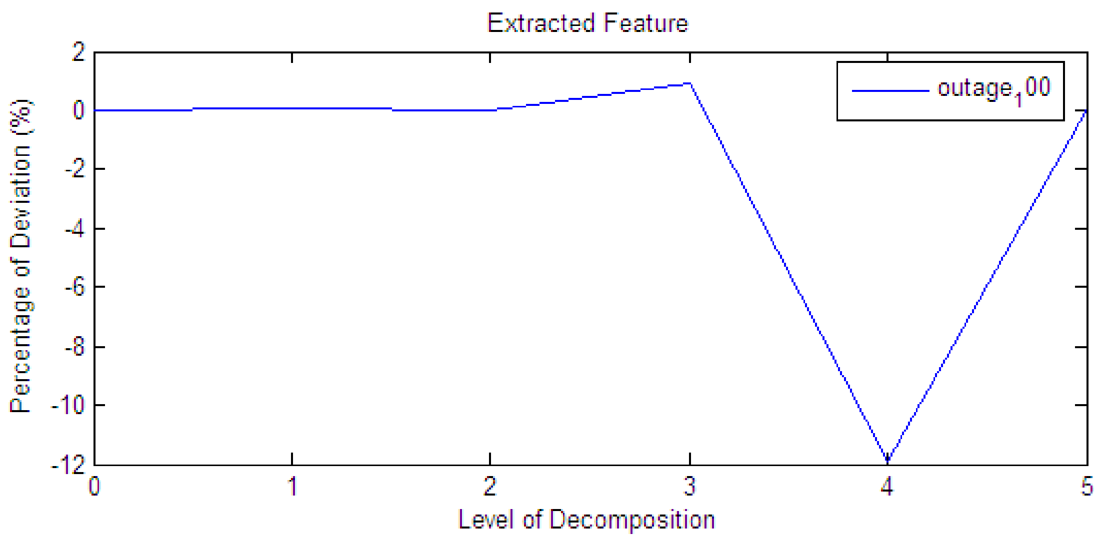

Figure 4.36 Wavelet Extraction for Outage at 100 km

Negative peak was occurred then at level 4 as the energy of outage is slightly lower than reference signal. From the extracted feature, it also shows that level 4 has the most percentage of deviation which means that both signals energy have a high concentration of energy at that level. The decomposition of outage appears almost as the same of voltage sag. Therefore, neural network will be implemented to classify wisely types of disturbance that occurred by choosing the data correctly.

4.3.4 Harmonic

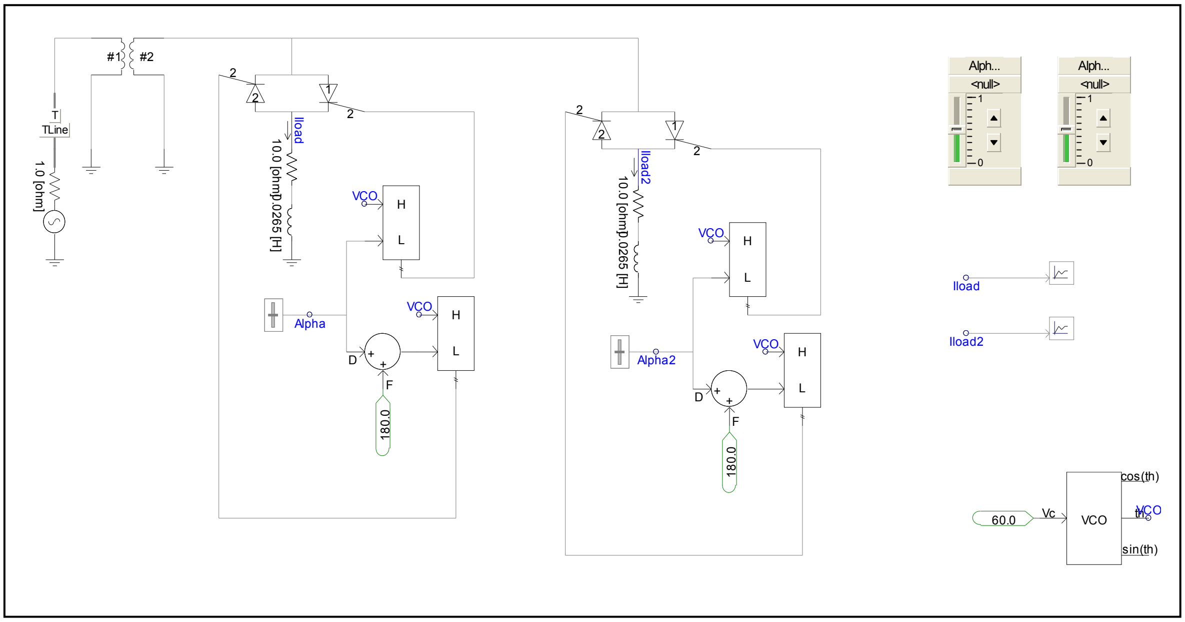

Figure 4.37 Harmonic Disturbance Circuit

The switching on and off of SCR produced the harmonic and the current across the load was measured as THDI is more significant in showing the effect of harmonic compared to THDV. Figure 4.38 shows the wavelet decomposition for five levels of Deubechies wavelet for voltage swell at 100 km while Figure 4.39 shows the wavelet extraction of it.

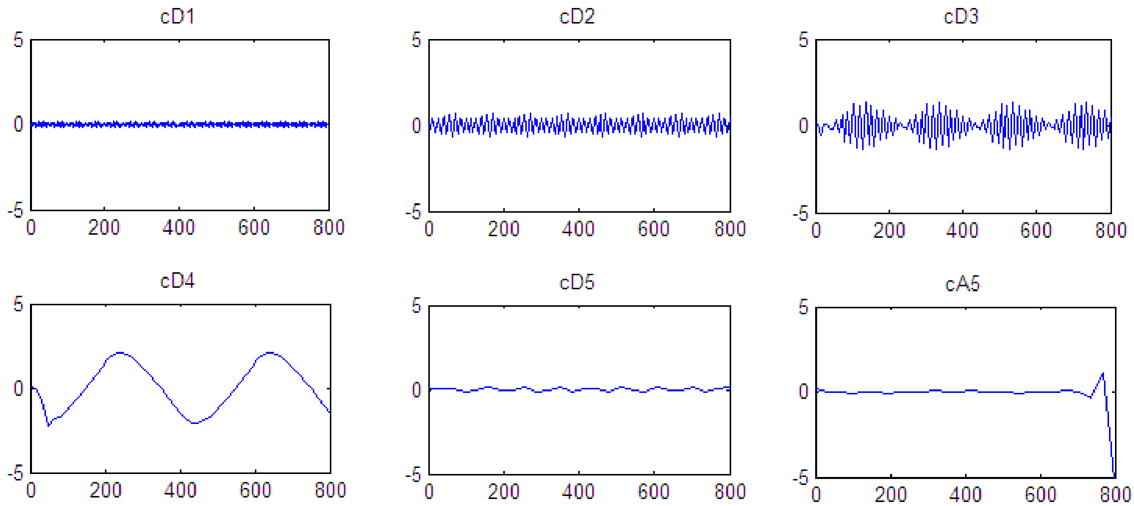

Figure 4.38 Wavelet Decomposition for Harmonic at 100 km

Based on Figure 4.38 the energy concentrated at level 4 of detailed coefficients as the amplitude is it highest at that level compared to other level. This implies that level 4 carries the frequency that nearly same with the fundamental frequency (50 Hz).

Level of Decomposition	% of Energy Deviation
0	-
1	2.1491
2	13.1125
3	39.273
4	-58.4899
5	-0.18371

Table 4.3 Percentage of Energy Deviation for 5 Levels of Wavelet Decomposition for Harmonic at 100 km

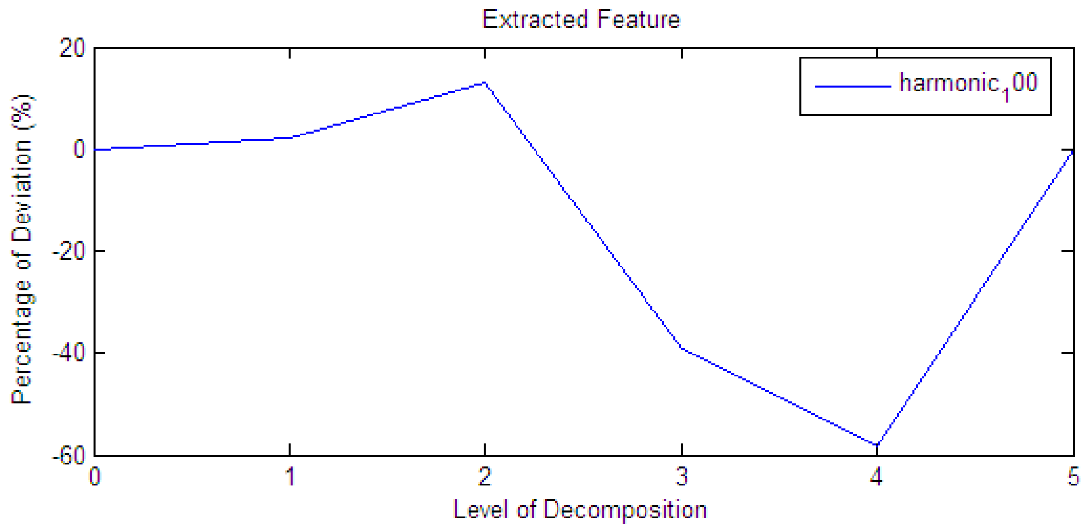

Figure 4.39 Wavelet Extraction for Harmonic at 100 km

From the extracted feature, two peaks occurred which is at level 2 and level 4 of decomposition. This implies that percentage of deviation is significant at this level. However, at level 2, positive peak was produced which means that the disturbance signal holds higher energy than reference signal while at level 4, negative peak occurred which means that the energy of disturbance signal is lower than the reference signal at this level.

The simulation on PSCAD was done for three distance of transmission line which is at 50km, 100km, and 200km by varying the length of transmission line A. The wavelet feature produced on four types of disturbance which are voltage sag, voltage swell, outage, and harmonic on three different locations which are at 50 km, 100 km, and 200 km were shown in appendices ant its clearly showed that the energy deviation produced were different for all three locations but however, the form are still the same. These three locations can represent short transmission line, middle transmission line, and long transmission line. The data from each wavelet extraction feature then will be implemented for further use in to determine neural network structure.

In this project, probabilistic neural network was chose to classify the types of disturbance and location. It is simpler and easier to use compared to backpropagation neural network. Figure 4.40 shows the input for the input layer of PNN while T_c refers to the target that will produce by the input matrices. Then, a network was created and simulated by using the input P to make sure that it does produce the correct classifications

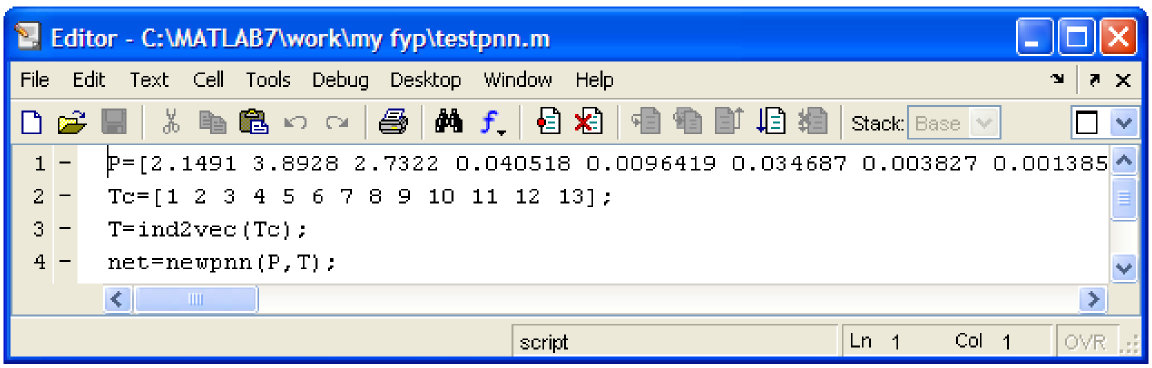

Figure 4.40 M-File for Probabilistic Neural Network

Then, another M-File is created which contains testing command for the designated probabilistic neural network and it is used to test either the output produced follows the desired or not. In order to determine either it is favorable or not, the target for each input must be achieved so that the type of disturbance and location that will be display is able to show the ability of neural network to classify the given input wisely.

Figure 4.41 shows the network architecture for probabilistic neural network that designed before. It clearly shows that two layer was used which are iput weights layer and second layer weights that are set to the matrix of target vectors. It was generated by MATLAB during running the file in command window.

```
net =

    Neural Network object:

    architecture:

         numInputs: 1
         numLayers: 2
       biasConnect: [1; 0]
      inputConnect: [1; 0]
      layerConnect: [0 0; 1 0]
     outputConnect: [0 1]
     targetConnect: [0 0]

        numOutputs: 1  (read-only)
        numTargets: 0  (read-only)
    numInputDelays: 0  (read-only)
    numLayerDelays: 0  (read-only)

    subobject structures:

            inputs: {1x1 cell} of inputs
            layers: {2x1 cell} of layers
           outputs: {1x2 cell} containing 1 output
           targets: {1x2 cell} containing no targets
            biases: {2x1 cell} containing 1 bias
      inputWeights: {2x1 cell} containing 1 input weight
      layerWeights: {2x2 cell} containing 1 layer weight

    functions:

          adaptFcn: (none)
           initFcn: (none)
        performFcn: (none)
          trainFcn: (none)

  parameters:

        adaptParam: (none)
         initParam: (none)
      performParam: (none)
        trainParam: (none)

  weight and bias values:

                IW: {2x1 cell} containing 1 input weight matrix
                LW: {2x2 cell} containing 1 layer weight matrix
                 b: {2x1 cell} containing 1 bias vector

  other:

          userdata: (user stuff)
```

Figure 4.41 The Probabilistic Neural Network Architecture

Probabilistic neural network was chose as it is simpler compared to feedforward neural network. Besides that, it can produce accurate output which the output produced will definitely be the same as target, while for feedforward neural network, the output will be only nearly to the target because it depends on the number of epochs and learning rate.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Power quality problems required a new and fresh idea in order to recognize the types of disturbance and location in a faster and simpler way so that the system can be restore back as soon as possible to avoid more severe damage and reduce the cost of it.

Therefore, the goal of this project is to introduce a new way that involved the implementation of neural network to simplify the automated recognition system for the types of disturbance that occurred and it location. The methods used in order to reach the goals are wavelet transform and neural network. Wavelet transform is used to create characteristics for each types of disturbance while neural network then will be applied to classify the types of disturbance and also the location of where it occurred.

Finally, the "Power Quality Disturbance and Location Detector" was successfully developed at the end of this project. It contains the wavelet transform and neural classifier which was created before in MATLAB toolbox by using command line. The GUI builder was used to compiled all the scripts written before and also could help users to easily used this program. Beside that, the manual for the created program was also composed to simply help the users so that they can refer it in order to use the program correctly. However, it still has its weakness as the scope for this project actually focused on five types of disturbances, which are voltage sag, voltage swell, outage, harmonic, and capacitor switching. Nevertheless, due to problems faced during the circuit design within PSCad environment, the output did not match as desired.

This project also involves the usage of PSCAD to create model circuits which are able to produce disturbances at different location. All the simulations imply the same result in the wavelet process, showing that the program can actually be adapted to the real situation case.

5.2 Recommendations

The project still has its weakness and therefore, improvement is very important so that it can meet its best performance. For future works, some recommendations have been listed based on the problems in order to improve it.

a) Develop an algorithm that can show difference on extracted feature for different location at the same time
b) Build up a neural network classification based on the original disturbance data from the electricity service provider
c) Display the energy graph for each wavelet decomposition on the GUI
d) Use other types of neural network such as fuzzy neural network, backpropogation and etc.
e) Add many types of power quality disturbances such as capacitor switching, flicker, surge, notching, and so on.

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APPENDIX A

Characteristic of Voltage Sag, Voltage Swell and Interruptions

Short Duration voltage variation in Electric Power	Spectral Content	Typical Duration	Typical voltage Magnitude
A – Instantaneous			
Sag	-	0.5 - 30 cycles	0.1 - 0.9 pu
Swell	-	0.5 - 30 cycles	1.1 - 1.8 pu
B - Momentary			
1 – Interruption	-	0.5 cycles - 3 s	< 0.1 pu
2 – Sag	-	30 cycles - 3 s	0.1 - 0.9 pu
3 - Swell	-	30 cycles - 3 s	1.1 - 1.2 pu
C - Temporary			
1 – Interruption	-	3 s - 1 min	< 0.1 pu
2 – Sag	-	3 s - 1 min	0.1 - 0.9 pu
3 - Swell	-	3 s - 1 min	1.1 - 1.2 pu
Characterization **Sags and Swells**	RMS vs Time, Magnitude, and Duration		
Typical Causes	Remote System Faults, large loads, and non linear loads for short duration		
Examples of solutions	Ferroresonance Transformers, Energy storage technologies, UPS		
Characterization **Interruptions**	RMS vs Time, Magnitude, and Duration		
Typical Causes	System Protection (Breakers and Fuses), Maintenance		
solutions	Backup Generators, Energy storage technologies, UPS		

APPENDIX B

Characteristics of DC-Offset, Harmonics and Inter Harmonics

Waveform Distortion	Typical Spectral Content	Typical Duration	Typical voltage Magnitude
1 - DC offset		steady state	0 - 0.1 %
2 - Harmonics	$0\text{-}100^{th}$ harmonic	steady state	0 - 20 %
3 - Inter-Harmonics	0.6 kHz	steady state	0 - 2%
Method of Characterization	Harmonic Spectrum, Total Harmonic Distortion, Statistics		
Typical Causes	Non-Linear Loads, System Resonance		
Examples of solutions	Active and Passive Filters, Transformers		

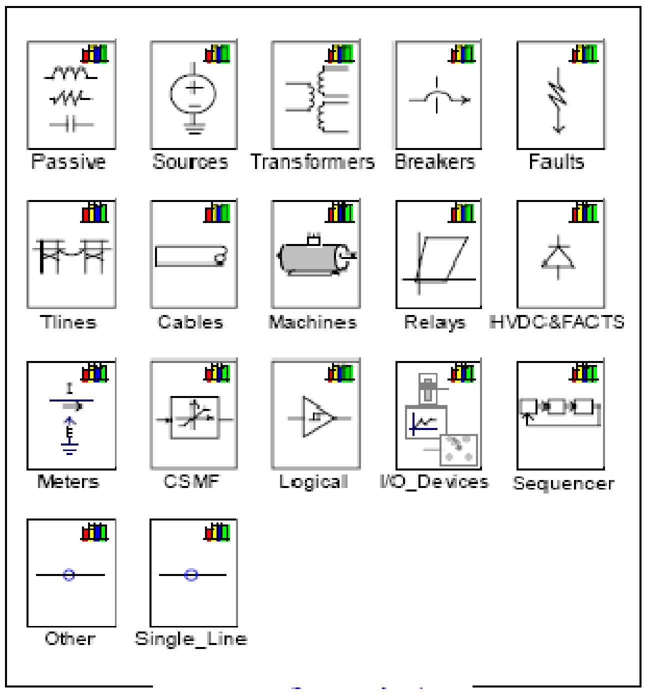
APPENDIX C

Characteristics of Voltage Imbalance, Notching, Noise, Voltage Fluctuations and Power Frequency Variations

PQ type	Typical Spectral Content	Typical Duration	Typical voltage Magnitude
Voltage Imbalance	-	steady state	0.5 - 2.0%
Notching	-	steady state	
Noise	broad-band	steady state	0 - 1 %
Voltage Fluctuations	< 25 Hz	Intermittent (non-stationary)	0.1 - 7%
Power Frequency Variations	-	< 10 s	

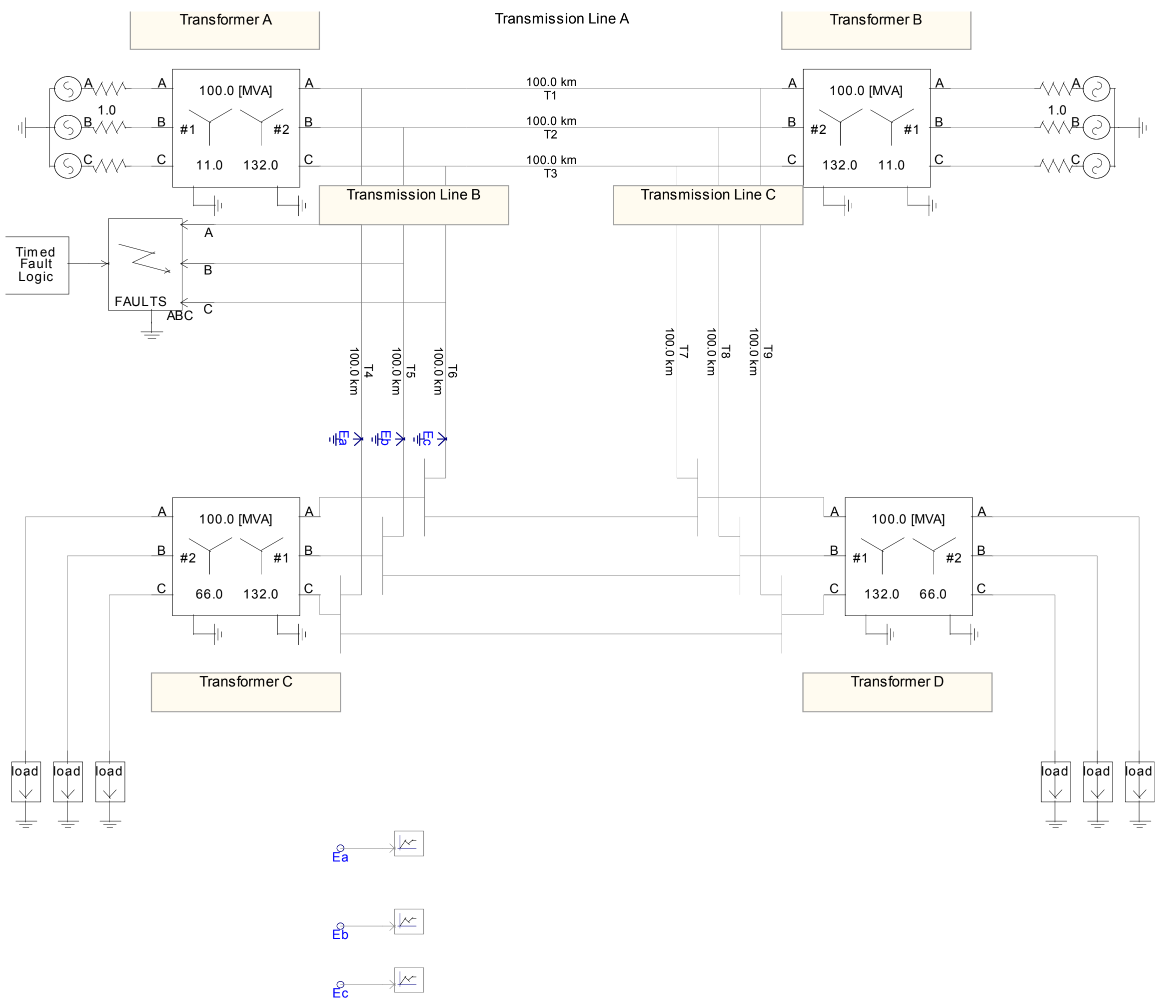
APPENDIX D

Library of PSCAD



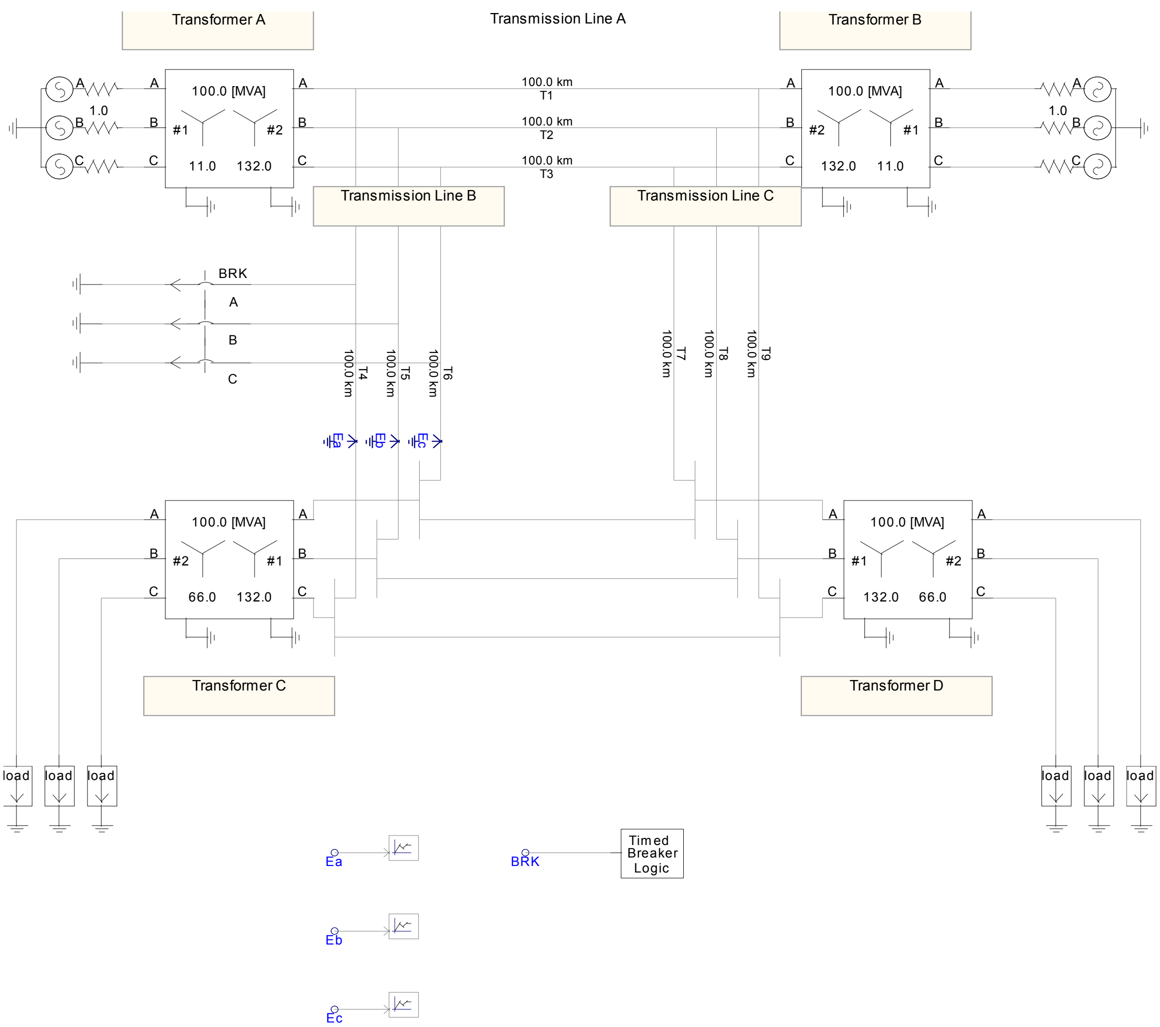
APPENDIX E

Schematic diagram for voltage sag



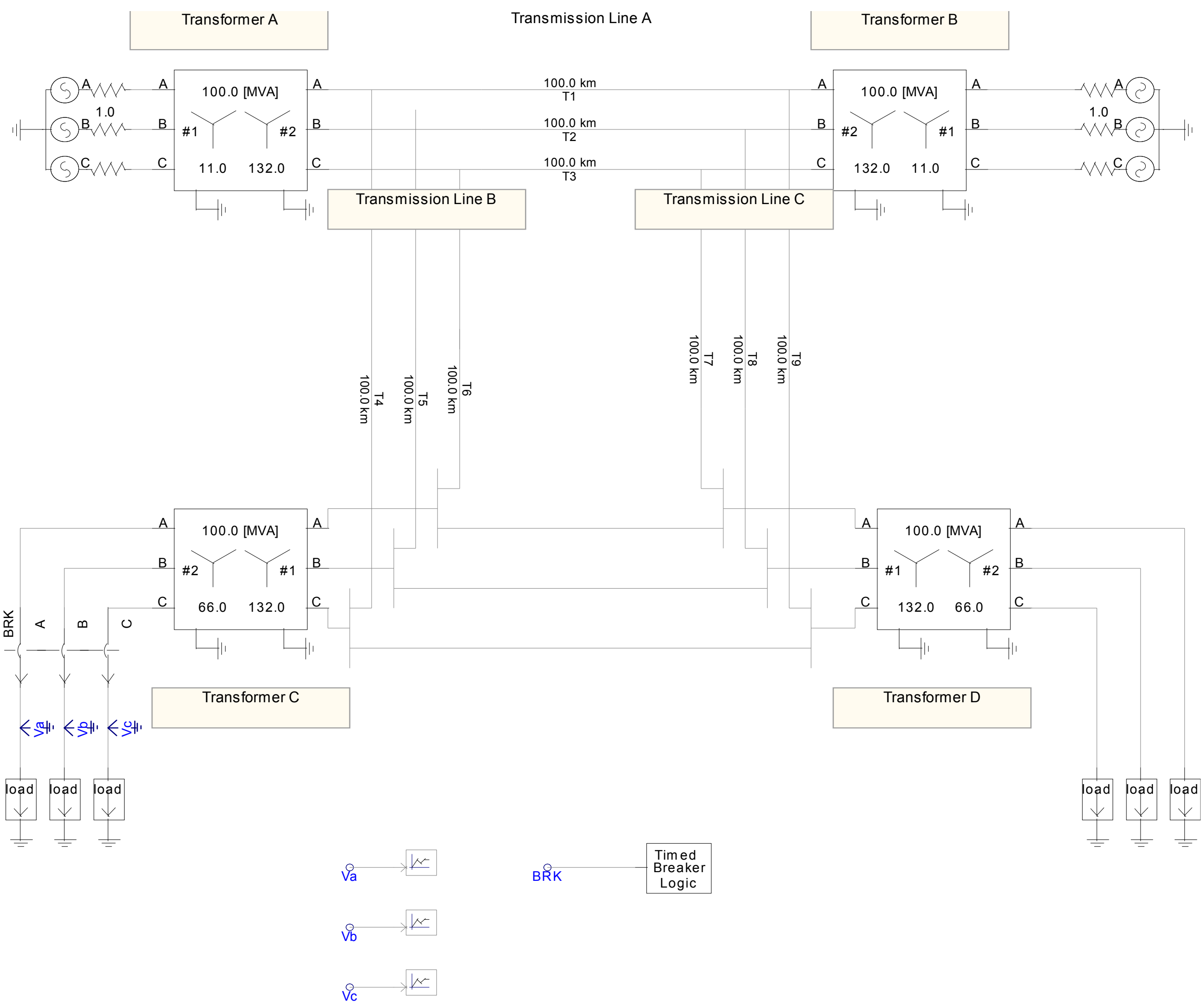
APPENDIX F

Schematic diagram for voltage swell



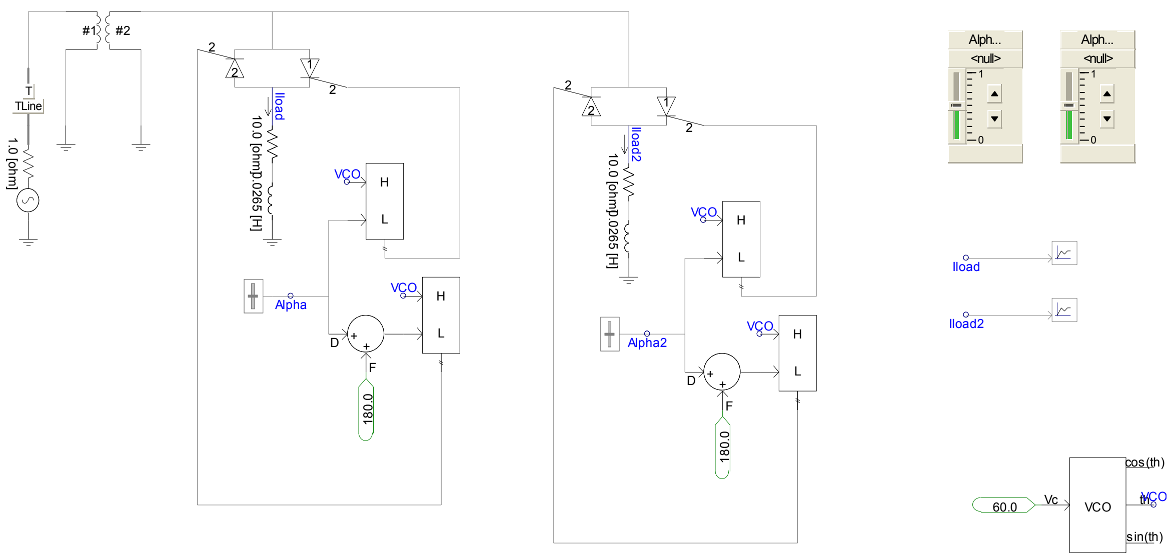
APPENDIX G

Schematic diagram for outage



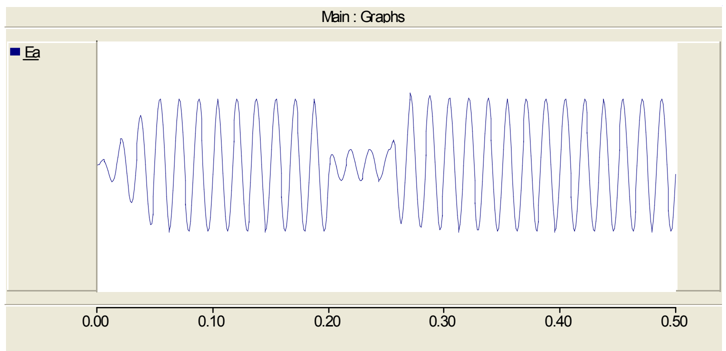
APPENDIX H

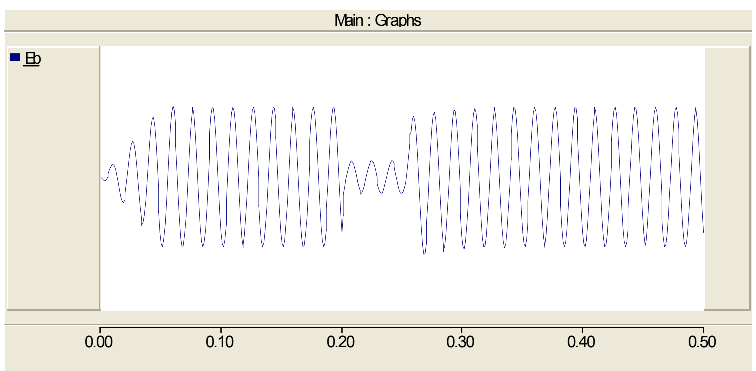
Schematic diagram for harmonic

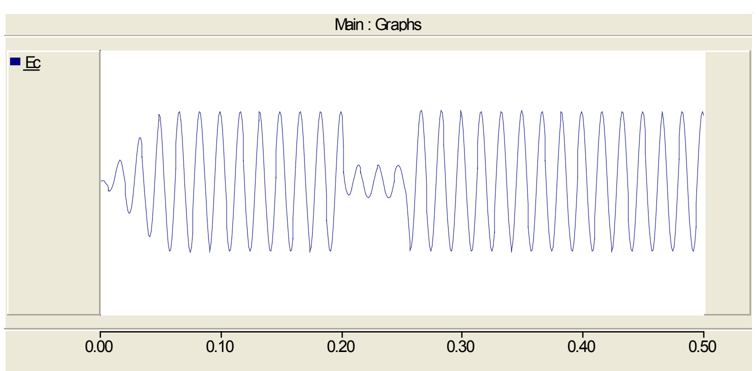


APPENDIX 1

Signal for voltage sag

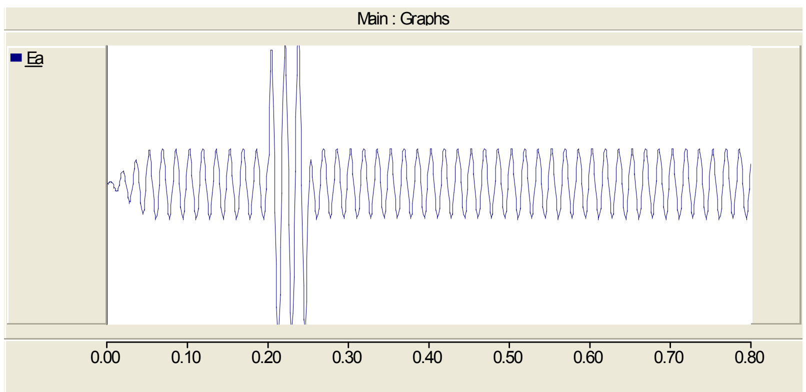


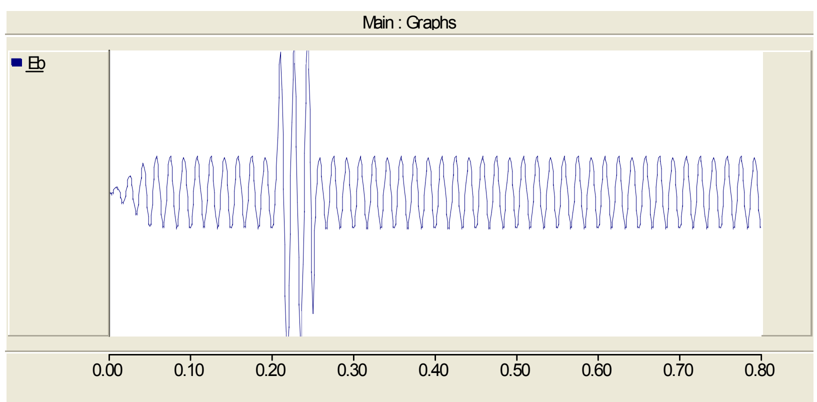


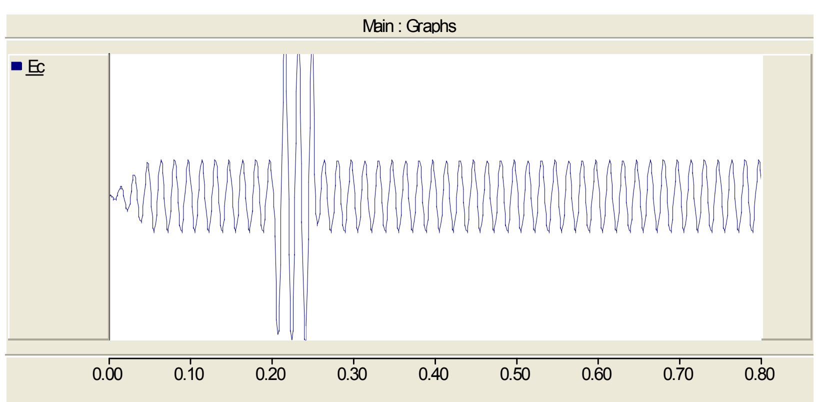


APPENDIX J

Signal for voltage swell

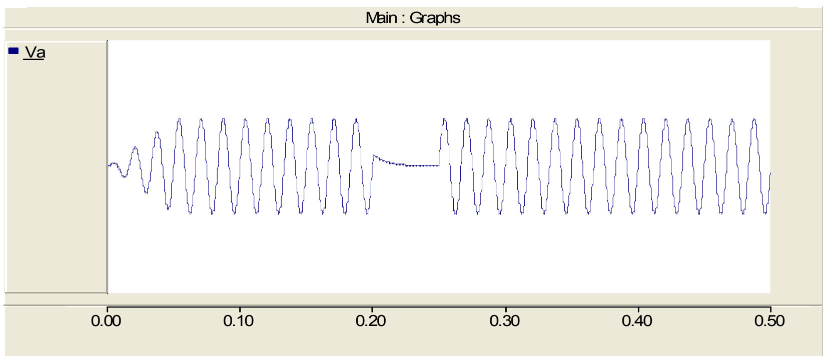


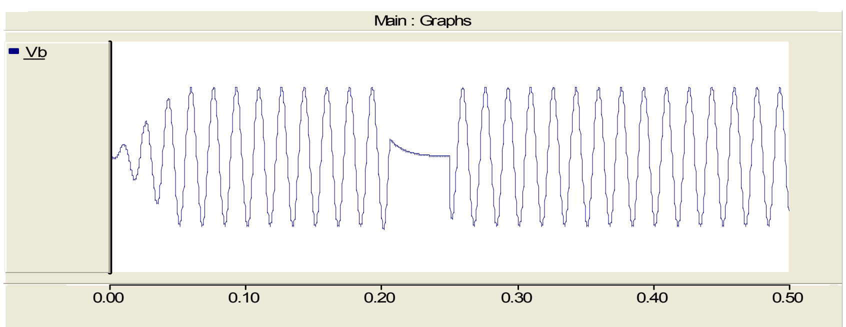


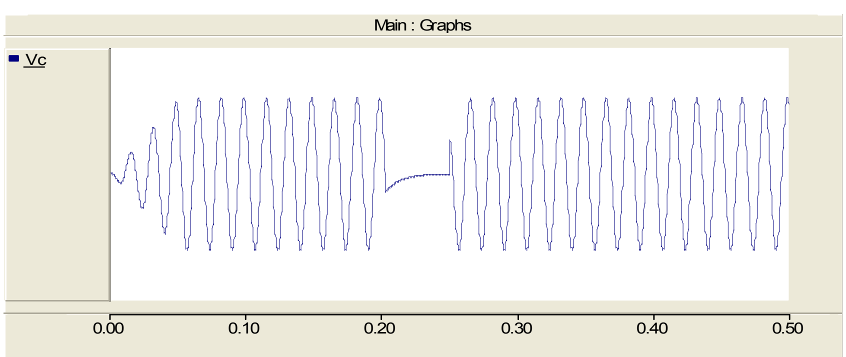


APPENDIX K

Signal for outage

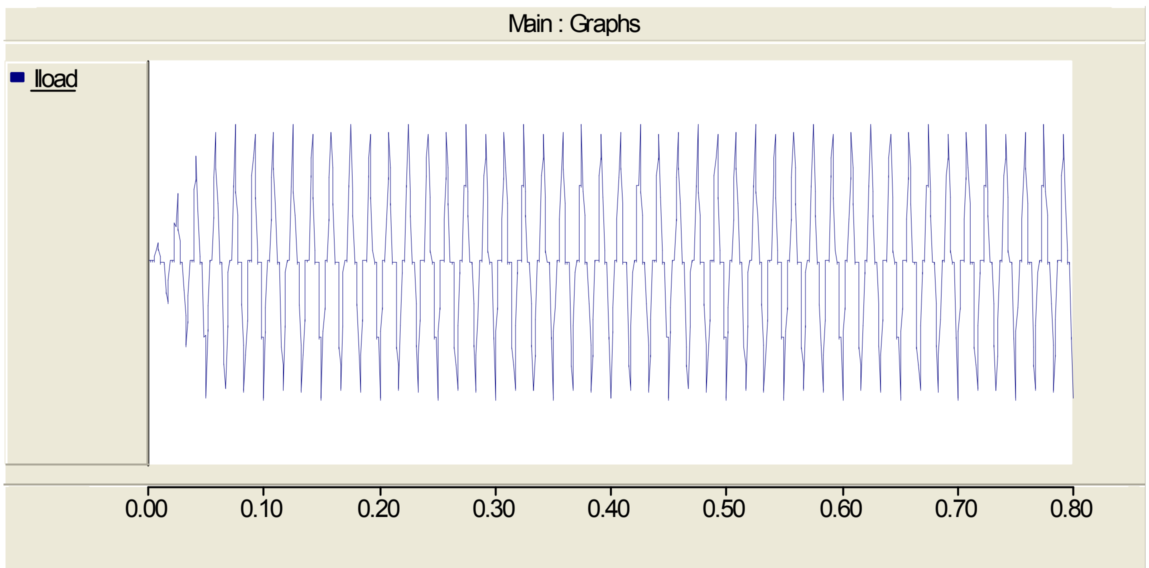






APPENDIX L

Signal for harmonic



APPENDIX M

Sample data of voltage sag

.0000000000000	.0000000000000	.0000000000000	.0000000000000
.10000000000000E-02	.15347236731508	-.58952202309870	.45604985578102
.20000000000000E-02	.86511146167430	-1.4866670194142	.63146566774003
.30000000000000E-02	2.0587621308269	-2.2101549412142	.17359281068754
.40000000000000E-02	3.3409773217166	-2.3242928286196	-1.0166844821981
.50000000000000E-02	4.5301501951161	-1.5684602526250	-2.7636859024911
.60000000000000E-02	4.5777362426250	.10964172908882	-4.6873789727339
.70000000000000E-02	3.7786581154008	2.5182518222591	-6.2551259976599
.80000000000000E-02	1.8244946960098	6.2629976082411	-7.0774922049611
.90000000000000E-02	-1.1329045001190	7.7725130545542	-6.6594064944852
.10000000000000E-01	-4.7019649747681	8.4795647961896	-4.7775899214216
.11000000000000E-01	-8.2942764573764	8.8500812898023	-1.3557848824245
.12000000000000E-01	-11.221209473847	8.5421148800299	2.6780896046170
.13000000000000E-01	-12.818471683751	5.4906544611908	7.5258572025598
.14000000000000E-01	-12.566680143058	.84227249923040	11.623296642827
.15000000000000E-01	-10.218830403481	-4.5443543484419	14.783184749923
.16000000000000E-01	-6.8666001269601	-10.170436704026	16.027096020976
.17000000000000E-01	.35901408068069E-01	-15.011949659848	14.972048459059
.18000000000000E-01	6.7294020362469	-18.160096286200	11.428604149883
.19000000000000E-01	13.210851088715	-18.918830280736	5.7079552120205
.20000000000000E-01	18.419061305216	-16.961870026644	-1.6661812687721
.21000000000000E-01	21.587502452001	-12.021954058775	-9.3858686952258
.22000000000000E-01	21.415561548858	-4.8640986248859	-16.551462044273
.23000000000000E-01	18.207513687219	3.7222087002014	-21.529720427421
.24000000000000E-01	11.864847220176	12.541601989906	-24.486448210083
.25000000000000E-01	3.5457295487702	20.257278050219	-23.603007598990
.26000000000000E-01	-6.6049862127821	25.592642796690	-19.087666682878
.27000000000000E-01	-16.195122948829	27.537528751028	-11.358895802399
.28000000000000E-01	-24.253624823646	25.528170222460	-1.2748356098106
.29000000000000E-01	-29.323986716838	19.544833675721	9.7613550571167
.30000000000000E-01	-30.432417807962	10.263186940928	20.179230967024
.31000000000000E-01	-27.124223088509	-1.2478442021593	28.371867290868
.32000000000000E-01	-19.593006935350	-13.268451401066	32.980469326416
.33000000000000E-01	-8.8774042210008	-24.342851685828	33.020255904628
.34000000000000E-01	4.2147242041626	-32.464470964946	28.249746660784
.35000000000000E-01	17.295805709827	-38.349724718079	19.054119008452
.36000000000000E-01	28.640668820086	-38.166176681246	6.5264898711607
.37000000000000E-01	36.472169086419	-29.789881542890	-7.4825275257288
.38000000000000E-01	39.424674379900	-17.862442446115	-21.572220931864
.39000000000000E-01	36.821285379702	-3.7385251427255	-33.082760230978
.40000000000000E-01	28.712846946859	11.681198149173	-40.395046095031
.41000000000000E-01	16.011418400981	26.204550727818	-42.215769128577
.42000000000000E-01	.22766214681827	37.669786946269	-37.986448092087
.43000000000000E-01	-16.184885957568	44.216320455749	-28.051854478182
.44000000000000E-01	-31.126839789470	44.680352626710	-13.553812828240
.45000000000000E-01	-42.292421791580	38.692868728554	3.5997330850454
.46000000000000E-01	-47.868896129464	26.820446889680	21.022851470774
.47000000000000E-01	-46.780902650021	10.538607702115	36.224294927906
.48000000000000E-01	-38.861124909234	-8.0017056918120	46.962840681146
.49000000000000E-01	-25.010277102532	-26.195712123207	51.205989225739
.50000000000000E-01	-6.9628867318664	-41.390988129041	48.364825060907
.51000000000000E-01	12.704028858986	-50.669808947542	37.985772356578
.52000000000000E-01	30.742850877927	-52.666851618432	21.924001640606
.53000000000000E-01	44.524110525028	-47.184242585415	2.8401518623878
.54000000000000E-01	52.072267962701	-34.986987726136	-17.085260216606
.55000000000000E-01	52.310041850868	-17.859459611459	-34.450802035167
.56000000000000E-01	46.198189831280	1.8101606484749	-47.008240479767
.57000000000000E-01	31.733455218003	21.258223007082	-52.991878223068
.58000000000000E-01	12.808361072408	37.762478700611	-51.169428772919
.59000000000000E-01	-8.0668750619801	48.975071579818	-42.908198517858

APPENDIX N

Sample data of voltage swell

.0000000000000	.0000000000000	.0000000000000	.0000000000000
.10000000000000E-02	.12454308203937	-.15949874373249	.34955661693125E-01
.20000000000000E-02	.35908590369092	-.30029000862984	-.58795895061085E-01
.30000000000000E-02	.60402964182625	-.30127264831829	-.30275699350796
.40000000000000E-02	.76606678783700	-.12183925201268	-.64422753582432
.50000000000000E-02	.76342279344596	.23335700502649	-.99677979847245
.60000000000000E-02	.54540980621265	.71280606452012	-1.2582158707328
.70000000000000E-02	.10671414863474	1.2256113776101	-1.3323255262448
.80000000000000E-02	-.50681033857725	1.6575642200116	-1.1507538814343
.90000000000000E-02	-1.2023685198724	1.8931081814751	-.69073966160268
.10000000000000E-01	-1.8541871577257	1.8392770596878	.14910098037883E-01
.11000000000000E-01	-2.3251233158211	1.4471615407361	.87796177508497
.12000000000000E-01	-2.4923292238831	.72670859570019	1.7656206281829
.13000000000000E-01	-2.2724696910075	-.24833871497974	2.5208084059873
.14000000000000E-01	-1.6418318633983	-1.3469447987394	2.9887766621377
.15000000000000E-01	-.64732243236036	-2.3983562481626	3.0456786805230
.16000000000000E-01	.59426901306523	-3.2183958099371	2.6241267968718
.17000000000000E-01	1.9094588207044	-3.6404579596700	1.7309991389656
.18000000000000E-01	3.0923093494440	-3.5461325738950	.45382322445094
.19000000000000E-01	3.9363334190942	-2.8901410470741	-1.0461923720201
.20000000000000E-01	4.2691635612924	-1.7149161297908	-2.5542474315016
.21000000000000E-01	3.9843207205032	-.15162323540831	-3.8326974850949
.22000000000000E-01	3.0645587775321	1.5935006653649	-4.6580594428970
.23000000000000E-01	1.5923278961858	3.2662405246709	-4.8585684208567
.24000000000000E-01	-.25524221275286	4.6013867749718	-4.3461445622189
.25000000000000E-01	-2.2270562986934	5.3642349875932	-3.1371786888998
.26000000000000E-01	-4.0321403567219	5.3901759811395	-1.3580356244176
.27000000000000E-01	-5.3824793620982	4.6158853847748	.76659397732344
.28000000000000E-01	-6.0383126579919	3.0965986700364	2.9417139879556
.29000000000000E-01	-5.8488449935230	1.0058682938990	4.8429766996240
.30000000000000E-01	-4.7816670906035	-1.3832183698496	6.1648854604532
.31000000000000E-01	-2.9355961689834	-3.7335079255336	6.6691040945170
.32000000000000E-01	-.53396888724898	-5.6913604239352	6.2253293111842
.33000000000000E-01	2.1016785332231	-6.9396250889283	4.8379465557051
.34000000000000E-01	4.5945553023414	-7.2481074137177	2.6535521113763
.35000000000000E-01	6.5664656000308	-6.5136076350129	-.52857965017944E-01
.36000000000000E-01	7.6948689811549	-4.7828246870282	-2.9120442941267
.37000000000000E-01	7.7645837696640	-2.2537277040646	-5.5108560655994
.38000000000000E-01	6.7059724947576	.74591132888117	-7.4518838236388
.39000000000000E-01	4.6131278447002	3.8006987405829	-8.4138265852831
.40000000000000E-01	1.7383244366831	6.4651311376520	-8.2034555743351
.41000000000000E-01	-1.5375611452645	8.3284771922247	-6.7909160469603
.42000000000000E-01	-4.7553294183591	9.0775920629790	-4.3222626446199
.43000000000000E-01	-7.4418260144251	8.5481220784222	-1.1062960639971
.44000000000000E-01	-9.1793759248082	6.7558934883816	2.4234824364266
.45000000000000E-01	-9.6701134540291	3.9029103065549	5.7672031474742
.46000000000000E-01	-8.7853767736739	.35596430717843	8.4294124664955
.47000000000000E-01	-6.5921679502826	-3.4001191028553	9.9922870531380
.48000000000000E-01	-3.3517838845369	-6.8287012824458	10.180485166983
.49000000000000E-01	.51031891761896	-9.4179794684145	8.9076605507956
.50000000000000E-01	4.4601151127072	-10.757119715846	6.2970046031384
.51000000000000E-01	7.8042909140516	-10.441085130195	2.6367942161430
.52000000000000E-01	10.035727053861	-8.6103953741390	-1.4253316797222
.53000000000000E-01	10.857578336378	-5.5699909028229	-5.2875874335549
.54000000000000E-01	10.154643593417	-1.7475394210521	-8.4071041723650
.55000000000000E-01	8.0256502847054	2.3200995767215	-10.345749861427
.56000000000000E-01	4.7696085147388	6.0616395331316	-10.831248047870
.57000000000000E-01	.84381895733490	8.9515936449026	-9.7954126022375

APPENDIX O

Sample data of outage

.000000000000000	.000000000000000	.000000000000000	.000000000000000
.100000000000000E-02	.15709774062808	-.89997472512597E-01	.30538216580357E-01
.200000000000000E-02	.28462021860641	-.40689160287442	.20969262814246
.300000000000000E-02	.18720925784024	-.72259172590574	.85421787230695
.400000000000000E-02	-.22367962764410	-.90726421010999	1.4661754240226
.500000000000000E-02	-1.1150107869494	-.81509578641511	2.0010044655758
.600000000000000E-02	-2.0424624666616	-.37467624048414	2.2258498660020
.700000000000000E-02	-2.8804907868905	.40089231266545	1.9735831894875
.800000000000000E-02	-3.3791442272608	1.4160764242226	1.1660703102846
.900000000000000E-02	-3.3280857820500	2.4811580868798	-.15681145792808
.100000000000000E-01	-2.6017260247170	3.4071926688099	-1.8221626241882
.110000000000000E-01	-1.1968595568851	3.9347690801538	-3.5991255127209
.120000000000000E-01	.76296604279891	3.8864224884706	-5.1282710290172
.130000000000000E-01	2.9952680893570	3.1535987868093	-6.0597737620947
.140000000000000E-01	5.1467219182313	1.7467712744477	-6.2108061127234
.150000000000000E-01	6.8425469517502	-.20179598455141	-5.5517884664710
.160000000000000E-01	7.7141221471046	-2.4428422496868	-3.4648821879866
.170000000000000E-01	7.4970250178375	-4.6428245229085	-.75431459897840
.180000000000000E-01	6.0827628218660	-6.4222677416606	2.4221682644280
.190000000000000E-01	3.5524813853579	-7.4683944763046	5.8455986460504
.200000000000000E-01	.18200946041710	-7.4922739287264	8.3718277011113
.210000000000000E-01	-3.5857800811627	-6.3880231861526	10.122559703348
.220000000000000E-01	-7.1398419629810	-4.2041219862240	10.618789080097
.230000000000000E-01	-10.078934500231	-1.1718088571451	9.3824925599345
.240000000000000E-01	-11.702198612620	2.2226926418192	6.6846878614981
.250000000000000E-01	-11.712710125402	5.7842185701274	2.7555855808635
.260000000000000E-01	-9.9629196900624	8.6809066200197	-1.9206214002148
.270000000000000E-01	-6.5735541451176	10.523867244455	-6.7046254577172
.280000000000000E-01	-1.9275347981599	10.948010080969	-10.874587169617
.290000000000000E-01	3.3856893935407	9.7781880990072	-13.752443488536
.300000000000000E-01	8.5686297944464	7.0700891782570	-14.808228752843
.310000000000000E-01	12.881290345986	3.1176157702516	-13.752650495817
.320000000000000E-01	15.600946087167	-1.5760202566190	-10.598619672849
.330000000000000E-01	16.214185152318	-6.3818764411810	-5.8859344300415
.340000000000000E-01	14.492762666726	-10.624769246926	.40856612628667
.350000000000000E-01	10.544717375923	-13.438579354613	6.8122806778328
.360000000000000E-01	4.9182798690210	-14.560709272918	12.609861980444
.370000000000000E-01	-1.9462095775333	-13.855352250787	16.909618812984
.380000000000000E-01	-8.8112284184712	-10.671921082296	18.991742077418
.390000000000000E-01	-14.772506247647	-5.5985221894084	18.424680590586
.400000000000000E-01	-18.904780481022	-.19882727681288	16.147975246621
.410000000000000E-01	-20.505081877775	5.9319082278798	9.4978254577498
.420000000000000E-01	-19.208124647266	11.616290800287	2.1791293492411
.430000000000000E-01	-15.057696245814	15.710733852784	-5.8219218850919
.440000000000000E-01	-8.6196847642604	17.834449609286	-13.370220260166
.450000000000000E-01	-.45329540814998	17.477879852728	-19.345242537189
.460000000000000E-01	8.0968096682919	14.675889206629	-22.796652126966
.470000000000000E-01	15.848459957697	9.4531002817189	-23.122190585217
.480000000000000E-01	21.466813621226	2.6866187686128	-20.103672842421
.490000000000000E-01	24.537858702498	-4.7290210838591	-14.062246819130
.500000000000000E-01	24.112669199890	-11.791844887610	-6.7344414751912
.510000000000000E-01	20.010482258000	-17.370122059409	3.7379570588581
.520000000000000E-01	12.918788234607	-20.442579230610	12.808660632027
.530000000000000E-01	3.7441058968968	-20.858448157807	20.122544008591
.540000000000000E-01	-6.0897476020729	-17.962121671672	24.621200214294
.550000000000000E-01	-14.718609514447	-12.719509327794	25.885986195426
.560000000000000E-01	-21.497427969286	-5.6909920910966	22.102200668216
.570000000000000E-01	-25.271182525455	2.1455984700876	17.297195501718
.580000000000000E-01	-26.508420898466	9.6991219862596	9.0670389421648
.590000000000000E-01	-22.175036578578	15.898974795109	-.45820488032859

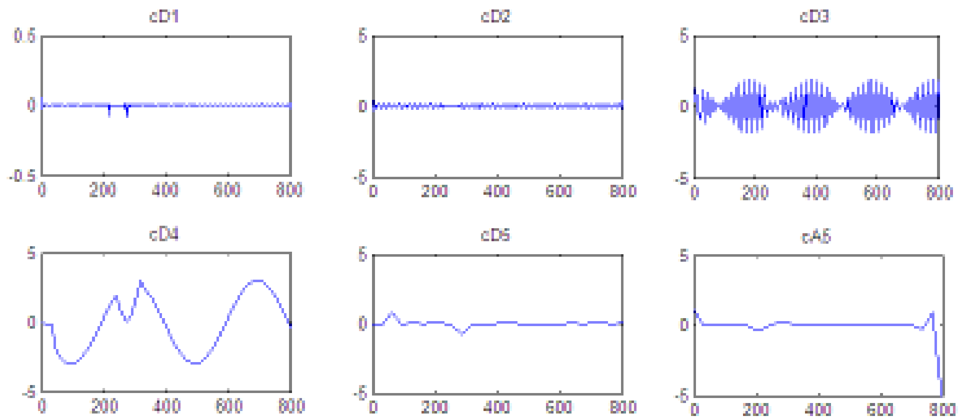
APPENDIX P

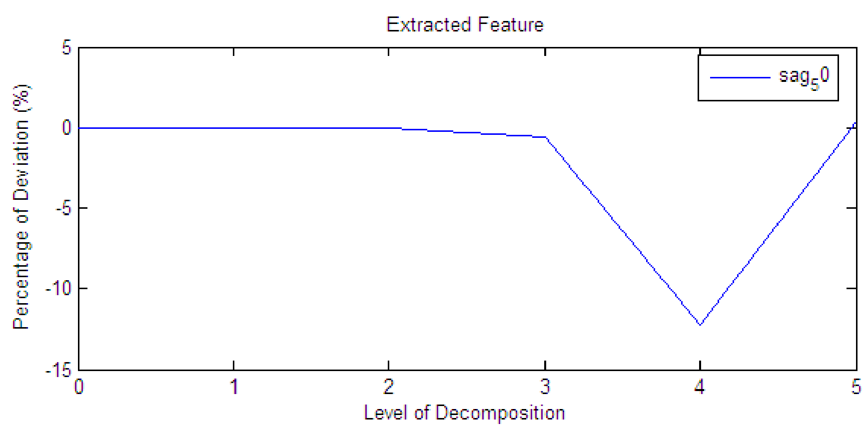
Sample data of harmonic

.0000000000000	.0000000000000	.0000000000000
.10000000000000E-02	.42317054762502E-08	.42317054762502E-08
.20000000000000E-02	.82621980166532E-06	.82621980166532E-06
.30000000000000E-02	.21277430486848E-04	.21277430486848E-04
.40000000000000E-02	.30427271827462E-04	.30427271827462E-04
.50000000000000E-02	.37251269545432E-04	.37251269545432E-04
.60000000000000E-02	.84063116481282E-02	.84063116481282E-02
.70000000000000E-02	.14854962421947E-01	.14854962421947E-01
.80000000000000E-02	.26703606918076E-01	.26703606918076E-01
.90000000000000E-02	.18270872858645E-01	.18270872858645E-01
.10000000000000E-01	.86475902169017E-02	.86475902169017E-02
.11000000000000E-01	-.87245505400880E-04	-.87245505400880E-04
.12000000000000E-01	-.11266629497121E-02	-.11266629497121E-02
.13000000000000E-01	-.87452171791713E-04	-.87452171791713E-04
.14000000000000E-01	-.82194282680598E-04	-.82194282680598E-04
.15000000000000E-01	-.41083007195874E-01	-.41083007195874E-01
.16000000000000E-01	-.46478827076612E-01	-.46478827076612E-01
.17000000000000E-01	-.80882171473459E-01	-.80882171473459E-01
.18000000000000E-01	-.26468712794821E-01	-.26468712794821E-01
.19000000000000E-01	.38952208775205E-04	.38952208775205E-04
.20000000000000E-01	.16767472228006E-02	.16767472228006E-02
.21000000000000E-01	.18410159475188E-05	.18410159475188E-05
.22000000000000E-01	.12287902678079E-02	.12287902678079E-02
.23000000000000E-01	.55885184087034E-01	.55885184087034E-01
.24000000000000E-01	.51607627560122E-01	.51607627560122E-01
.25000000000000E-01	.99573170644129E-01	.99573170644129E-01
.26000000000000E-01	.48241716622206E-01	.48241716622206E-01
.27000000000000E-01	.29413974855480E-01	.29413974855480E-01
.28000000000000E-01	-.19667664648668E-02	-.19667664648668E-02
.29000000000000E-01	-.25770207774459E-05	-.25770207774459E-05
.30000000000000E-01	-.19486751821766E-02	-.19486751821766E-02
.31000000000000E-01	-.41586279582787E-01	-.41586279582787E-01
.32000000000000E-01	-.79084108126632E-01	-.79084108126632E-01
.33000000000000E-01	-.12354227972723	-.12354227972723
.34000000000000E-01	-.89681062869871E-01	-.89681062869871E-01
.35000000000000E-01	-.52531150281386E-01	-.52531150281386E-01
.36000000000000E-01	.19020842120476E-02	.19020842120476E-02
.37000000000000E-01	.33512505125832E-05	.33512505125832E-05
.38000000000000E-01	.27566922108698E-02	.27566922108698E-02
.39000000000000E-01	.23785135480595E-05	.23785135480595E-05
.40000000000000E-01	.10560259847826	.10560259847826
.41000000000000E-01	.12182884552007	.12182884552007
.42000000000000E-01	.16607412865667	.16607412865667
.43000000000000E-01	.73502804958105E-01	.73502804958105E-01
.44000000000000E-01	.71240622824142E-02	.71240622824142E-02
.45000000000000E-01	-.38280850323508E-05	-.38280850323508E-05
.46000000000000E-01	-.37403066646880E-02	-.37403066646880E-02
.47000000000000E-01	-.27809533775551E-05	-.27809533775551E-05
.48000000000000E-01	-.11222011296869	-.11222011296869
.49000000000000E-01	-.10854727498154	-.10854727498154
.50000000000000E-01	-.20143707481961	-.20143707481961
.51000000000000E-01	-.10090520408405	-.10090520408405
.52000000000000E-01	-.66098466003442E-01	-.66098466003442E-01
.53000000000000E-01	.33581568741825E-05	.33581568741825E-05
.54000000000000E-01	.46641672803847E-02	.46641672803847E-02
.55000000000000E-01	.33677251791723E-05	.33677251791723E-05
.56000000000000E-01	.66278008898187E-01	.66278008898187E-01
.57000000000000E-01	.12473384783182	.12473384783182
.58000000000000E-01	.13246211292796	.13246211292796
.59000000000000E-01	.13548038507984	.13548038507984

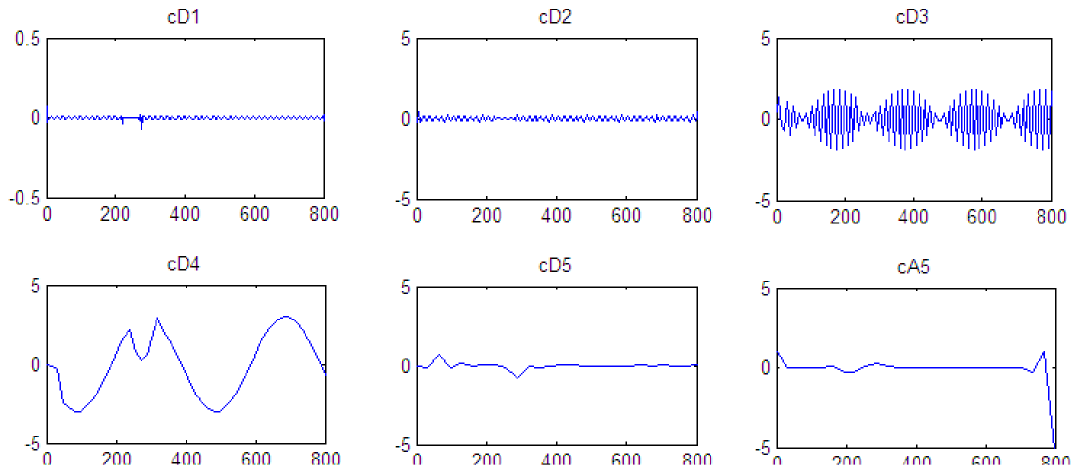
APPENDIX Q

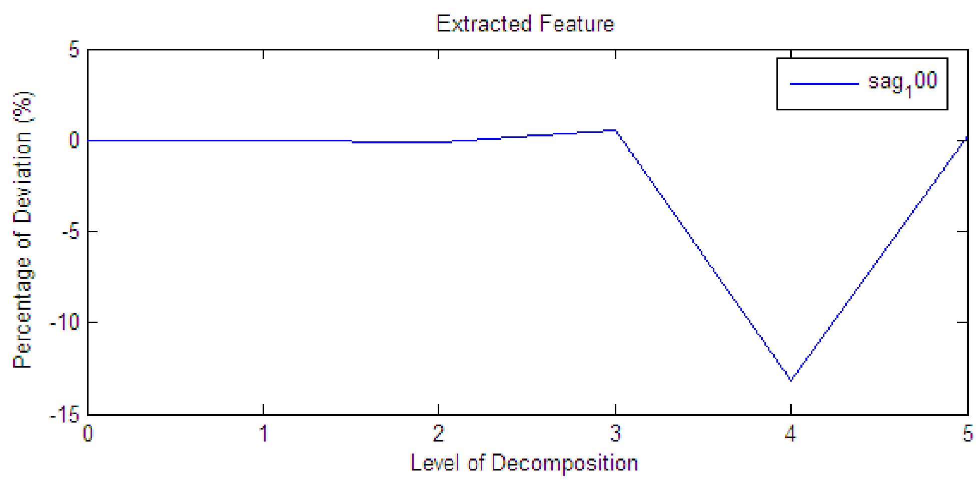
Wavelet Decomposition and Extraction



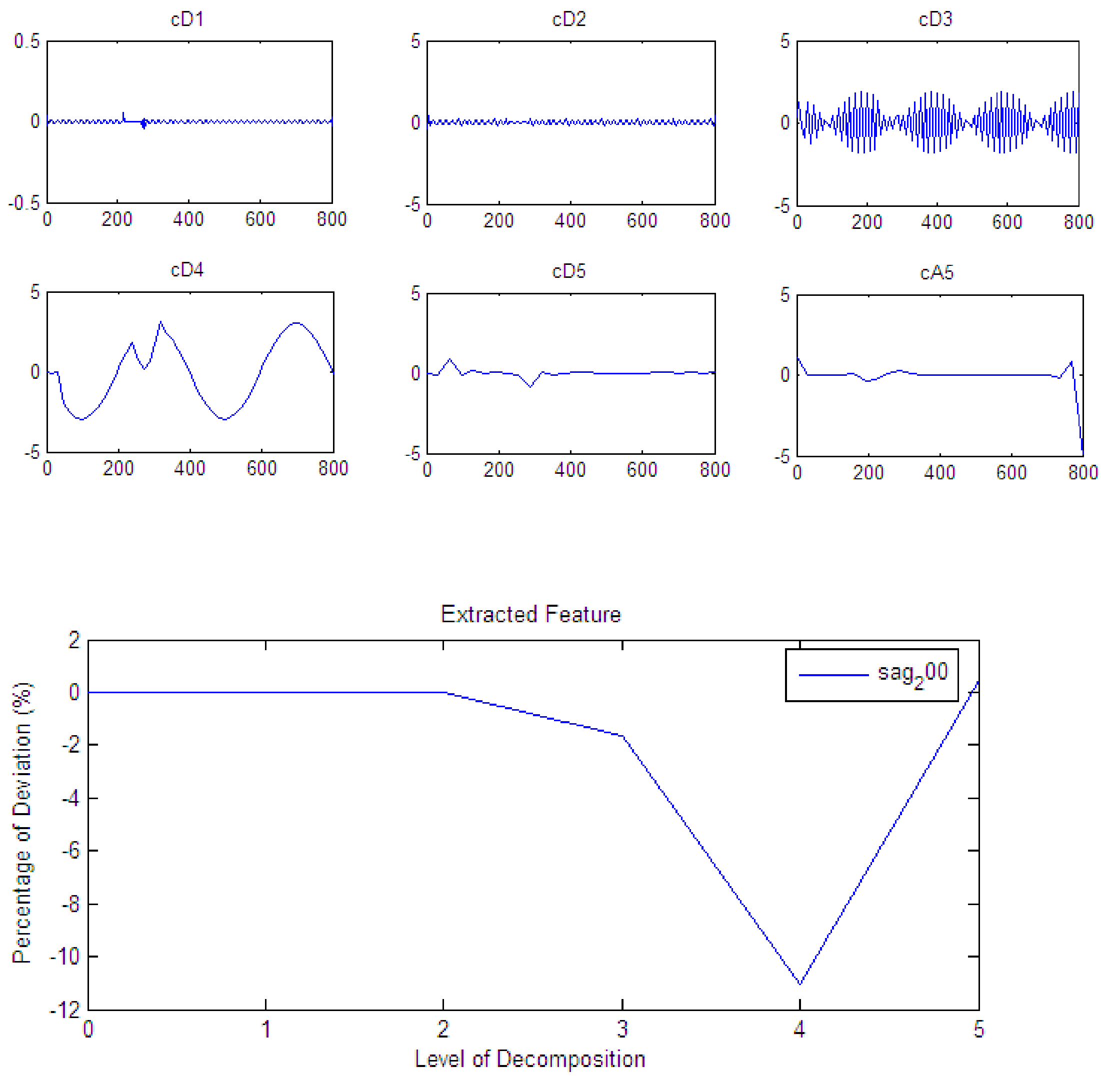


Voltage Sag at 50 km

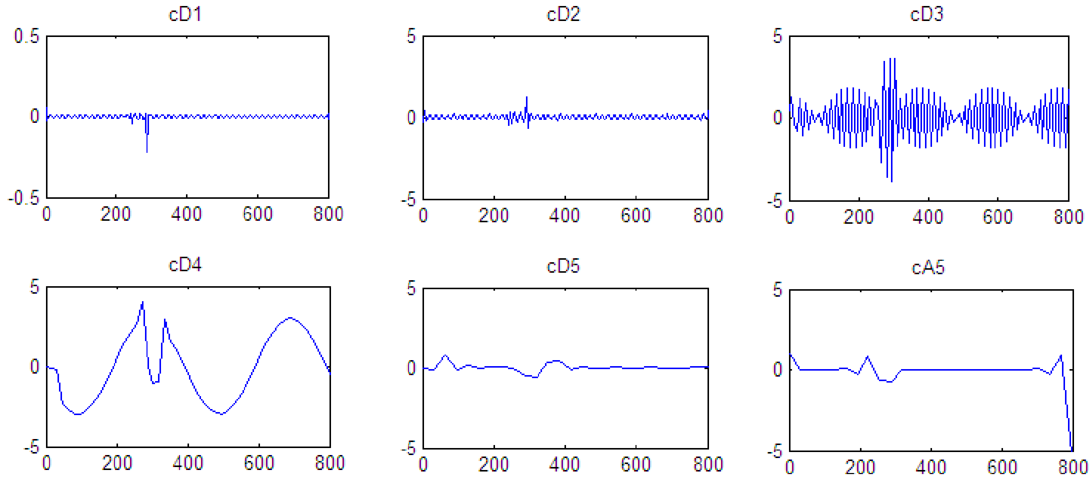


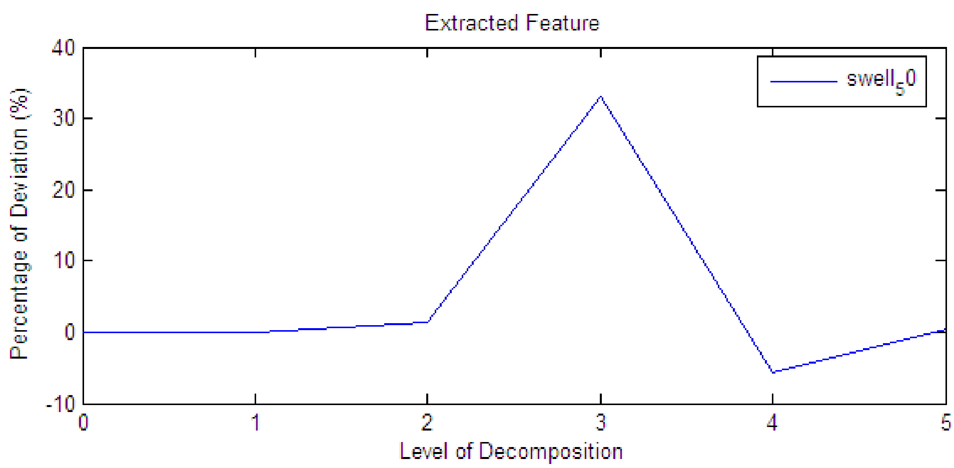


Voltage Sag at 100 km

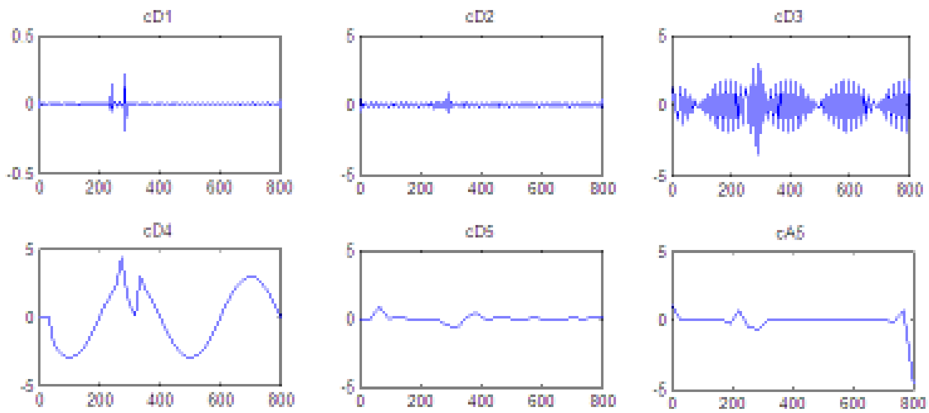


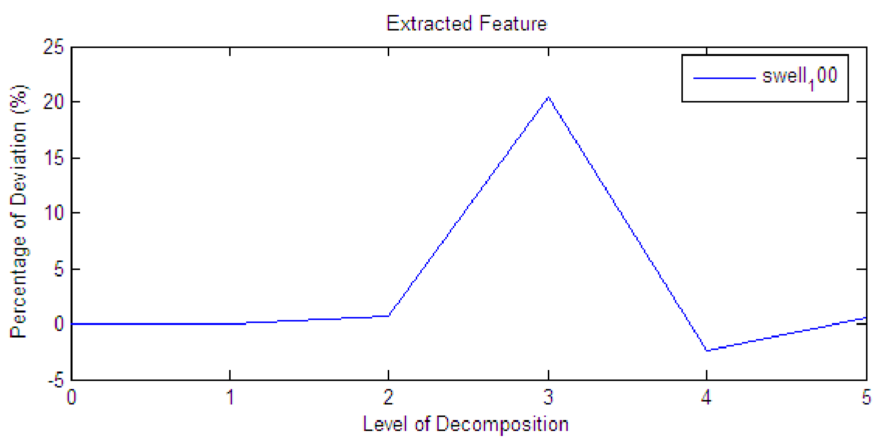
Voltage Sag at 200 km



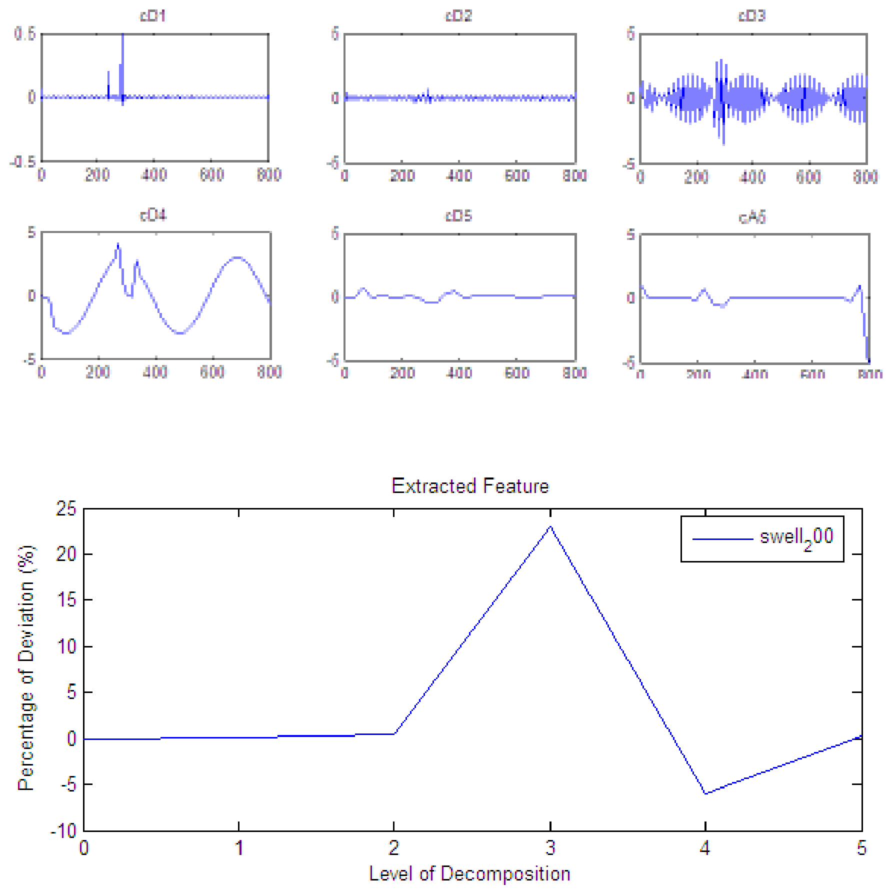


Voltage Swell at 50 km

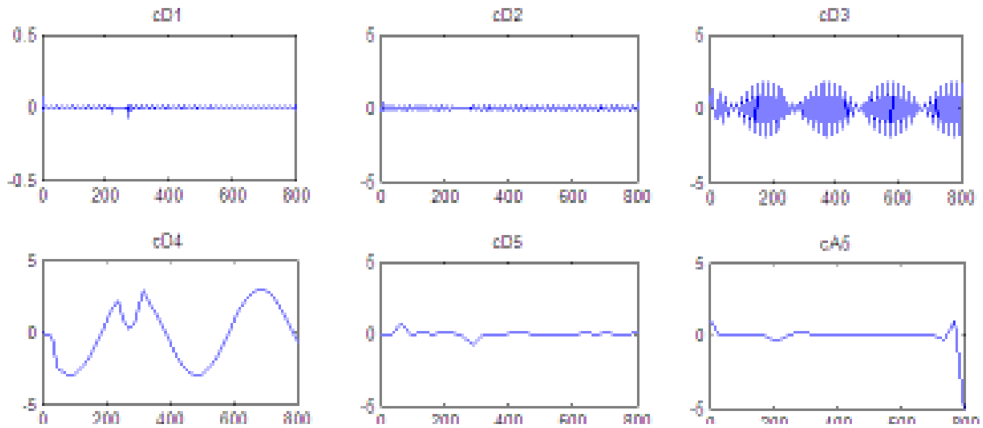


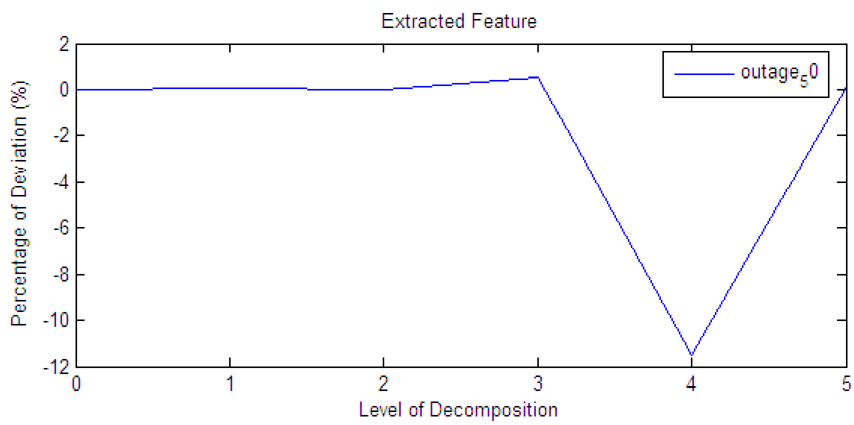


Voltage Swell at 100 km

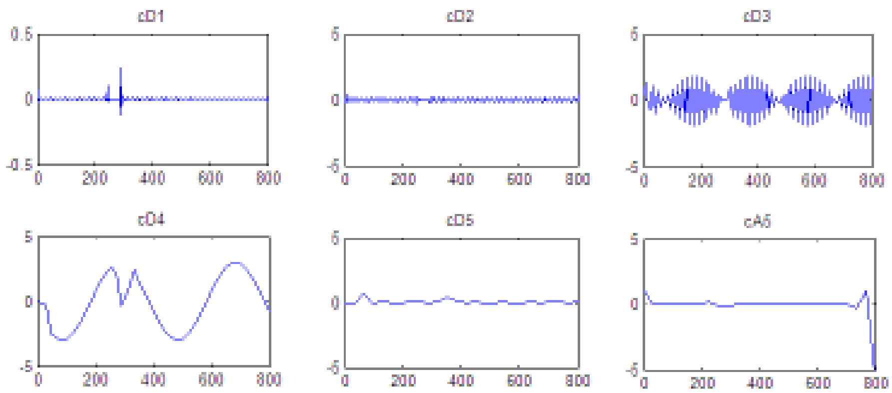


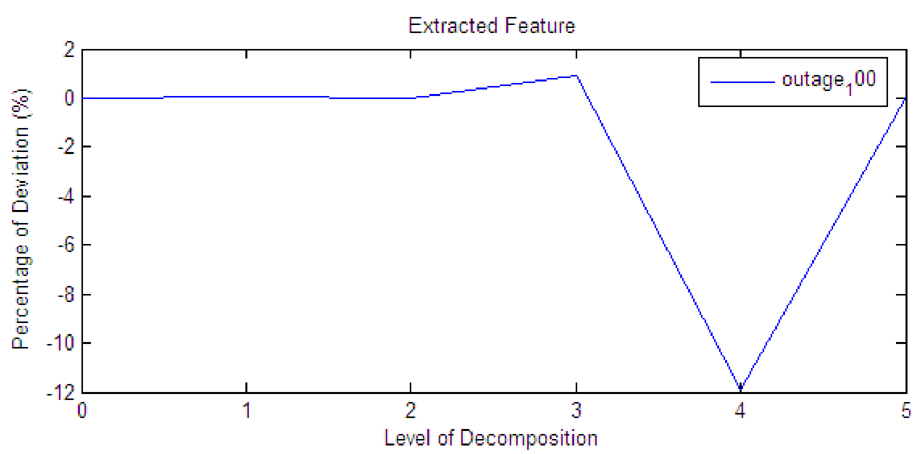
Voltage Swell at 200 km



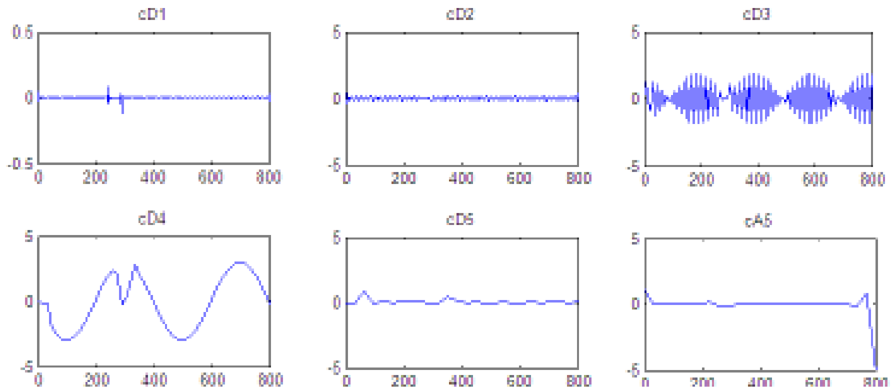


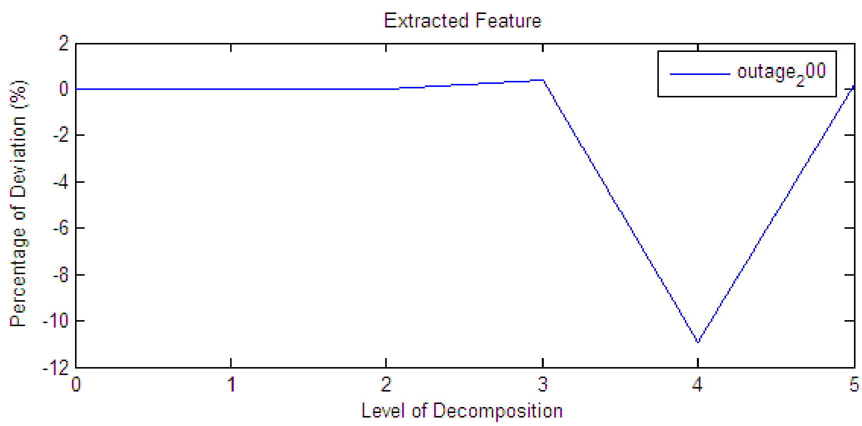
Outage at 50 km



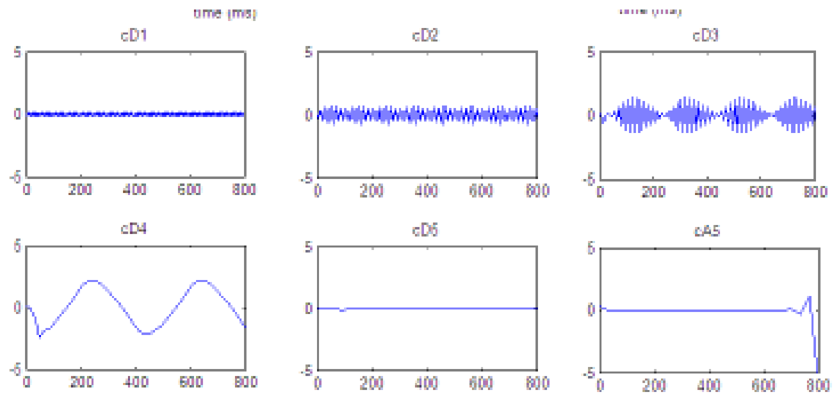


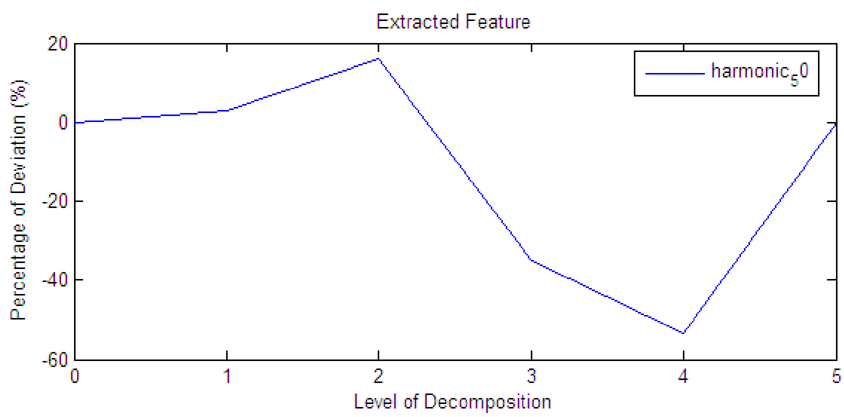
Outage at 100 km



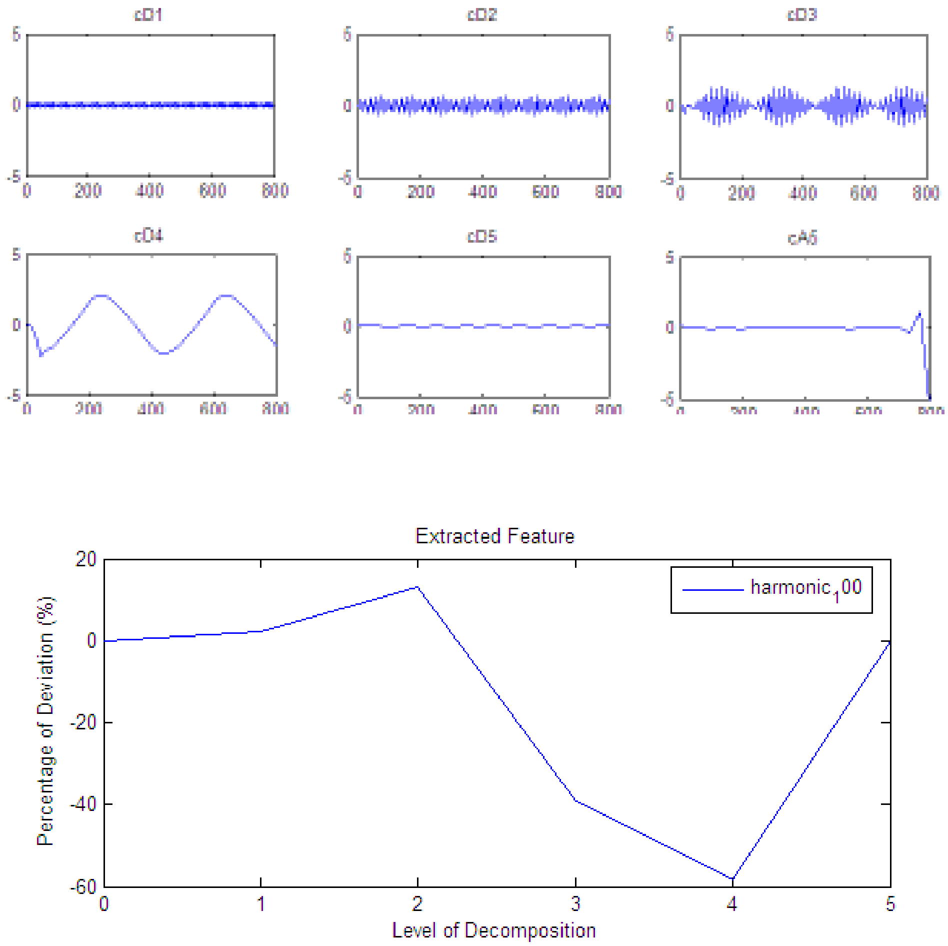


Outage at 200 km

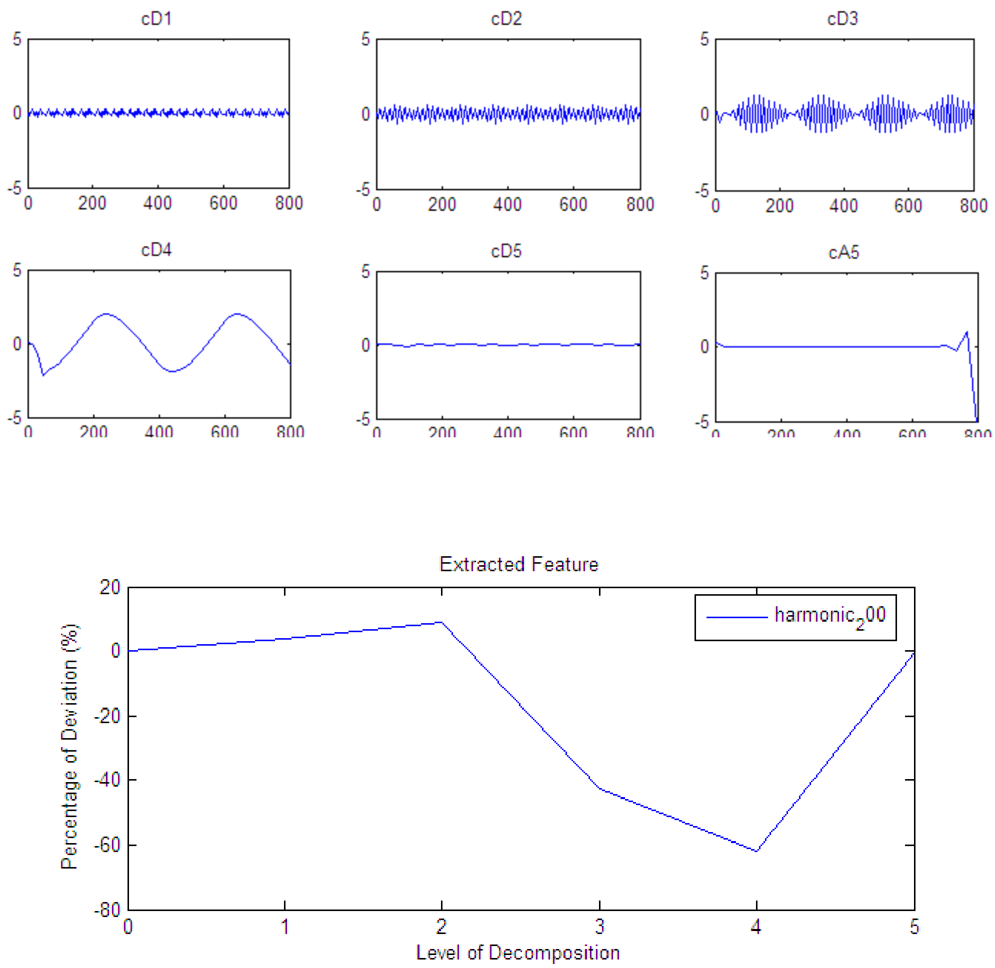




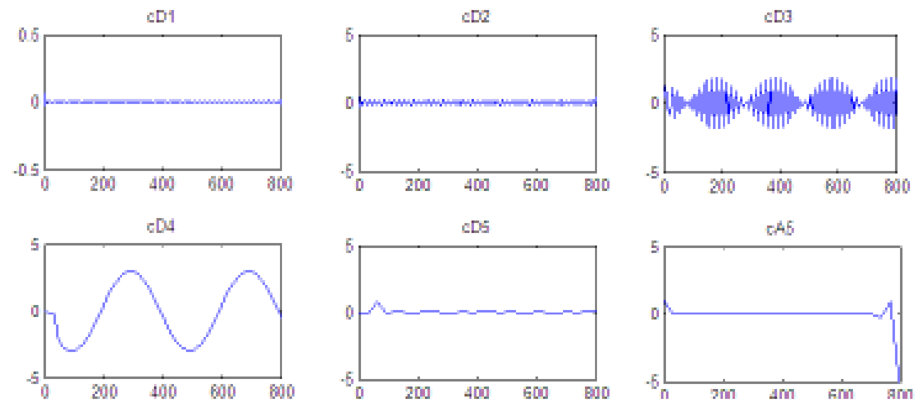
Harmonic at 50 km

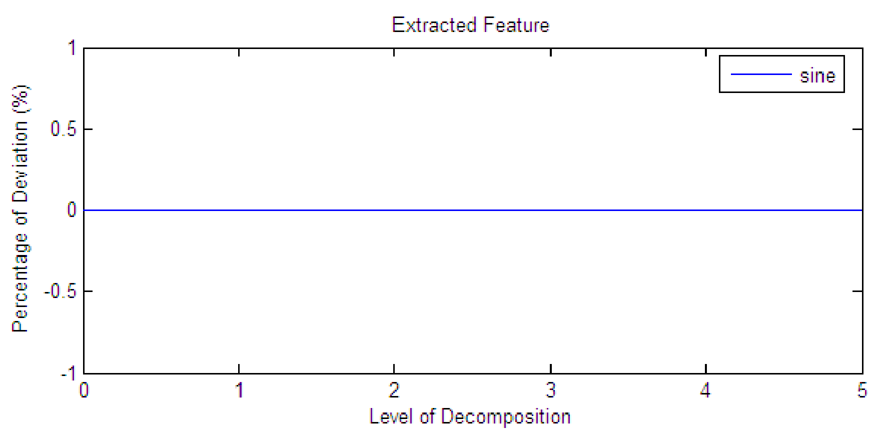


Harmonic at 100 km



Harmonic at 200 km


cD1
cD2
cD3
cD4
cD5
cA5
0.5
0
-0.5
5
-5
0
200
400
600
800


Extracted Feature
sine
Percentage of Deviation (%)
Level of Decomposition
1
0.5
0
-0.5
-1
0
1
2
3
4
5

Sinusoidal

APPENDIX R

USER MANUAL

POWER QUALITY DISTURBANCE AND LOCATION DETECTOR USING ANN

USER MANUAL FOR "POWER QUALITY DISTURBANCE AND LOCATION DETECTOR USING ANN"

CONTENTS

INTRODUCTION

Welcome to Power Quality Disturbance and Location Detector using ANN, the user friendly Neural Network based on Wavelet Analysis program for classification of types of disturbance and location. Using MATLAB operation system and the script files, along with the GUI builder, Quality Disturbance and Location Detector using ANN allows wide analysis of the voltage disturbance data. This program requires correct installation of MATLAB version and all the needed script files for program to function.

This simulation program is developed to perform the classification of selected power quality types. It will also perform the detection for location of disturbance occurred. It is Wavelet Analysis based Neural Network simulation program. Wavelet Transform (Discrete Wavelet Transform) is being used to decompose and extract the signal based on the frequency band that consists in the signal. Neural Network then is applied in order to categorize types of disturbance and location based on the Wavelet Extraction result.

The approach that used to obtain the extracted feature with Wavelet Analysis is based on the Parseval's energy theorem while Deubechies was chosen as type of wavelet. The extracted feature is the deviation of disturbance signal and pure sinusoidal signal which is as reference signal. This data is then fed into Probabilistic Neural Network to identify the disturbance occurred and its location.

The simulation program provides an environment to visualize the extracted feature for power quality disturbance using Wavelet Analysis and also the recognition which shows the detected types of disturbance and the location.

Installation and Setup Information

Recommended Hardware and Software Requirements

The minimum requirement for the program to be able to perform is as same as the Matlab installation minimum requirements. To run the program sufficiently, it is recommended to use the specifications as below:

Category	Required Specifications
Processor	Pentium 4, 1.63 GHz processor (higher speed recommended)
Operating system	Windows 2000, XP
Memory (RAM)	512 MB or higher
Hard disc space	3.0 GB. More space may be required to store data
Software	MATLAB 7.0.0.19920 (R14)
Other Peripheral	A CD-ROM or DVD-ROM drive, a mouse, and keyboard

Software Development Hardware and Software Specifications

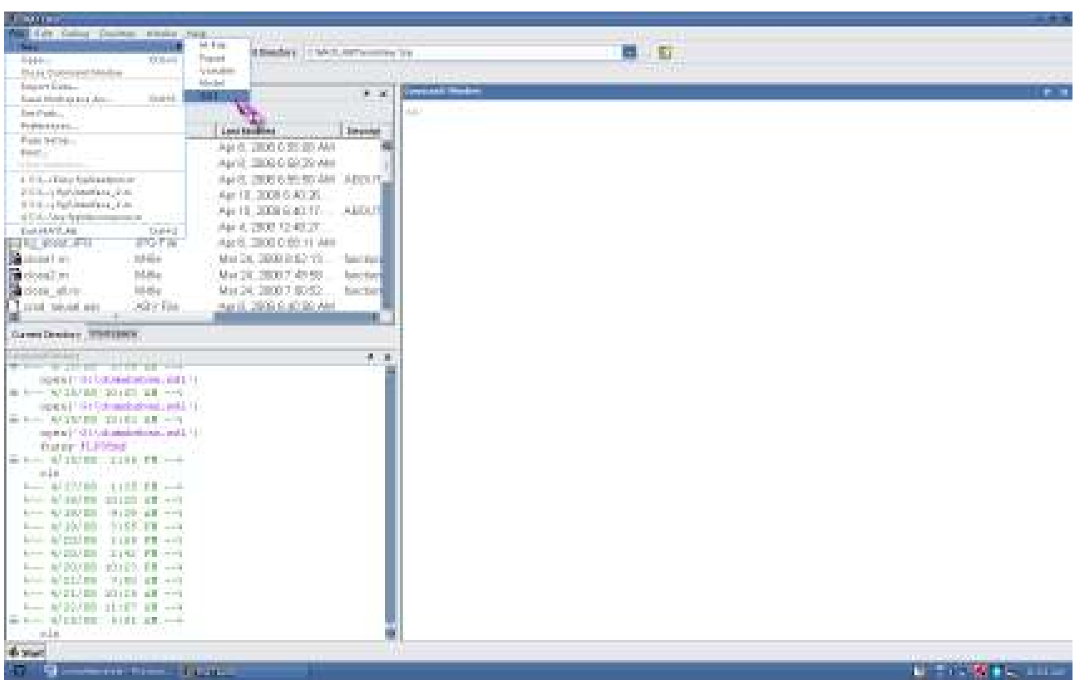
The following is the environment used to develop and testing the software:

Category	**Specifications used**
Processor	Intel Core Duo, 1.83 GHz Processor
Operating system	Windows XP sp2
Memory (RAM)	512 MB (DDR@)
Hard disc space	80 GB
Software	MATLAB 7.0.0.19920 (R14)
Other peripheral	A DVD-RAM drive, a mouse, and keyboard

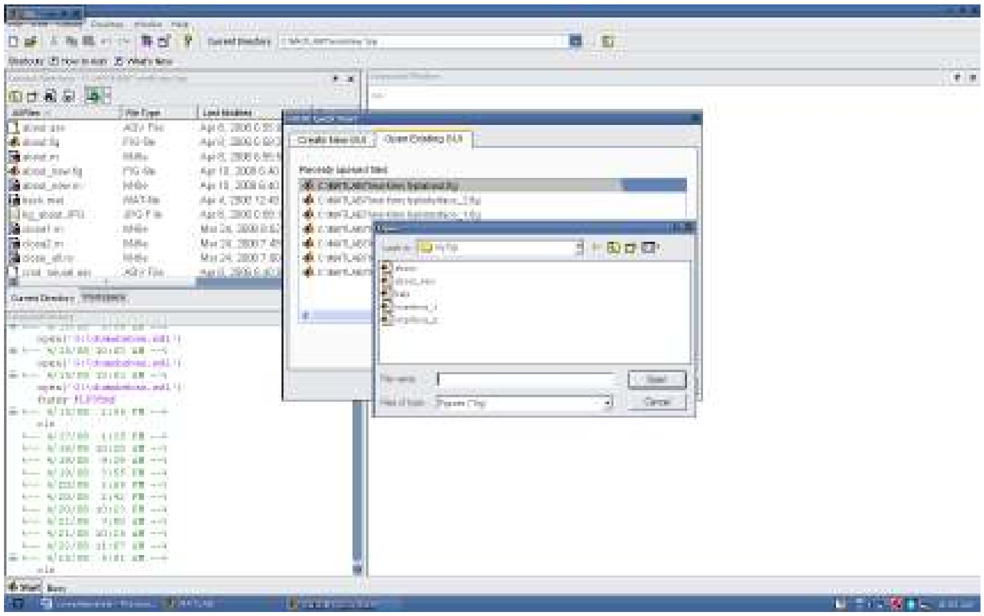
Installation of Program

1. Run MATLAB by clicking on the shortcut. Make sure the MATLAB installed correctly.

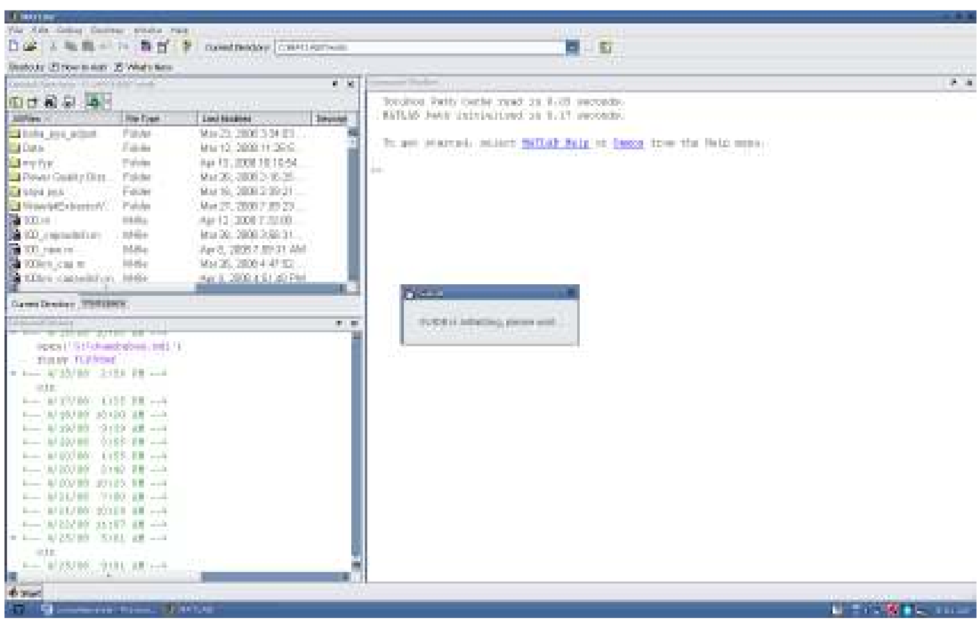
2. After MATLAB is ready, click on the file and select "GUI" under the "New" tab



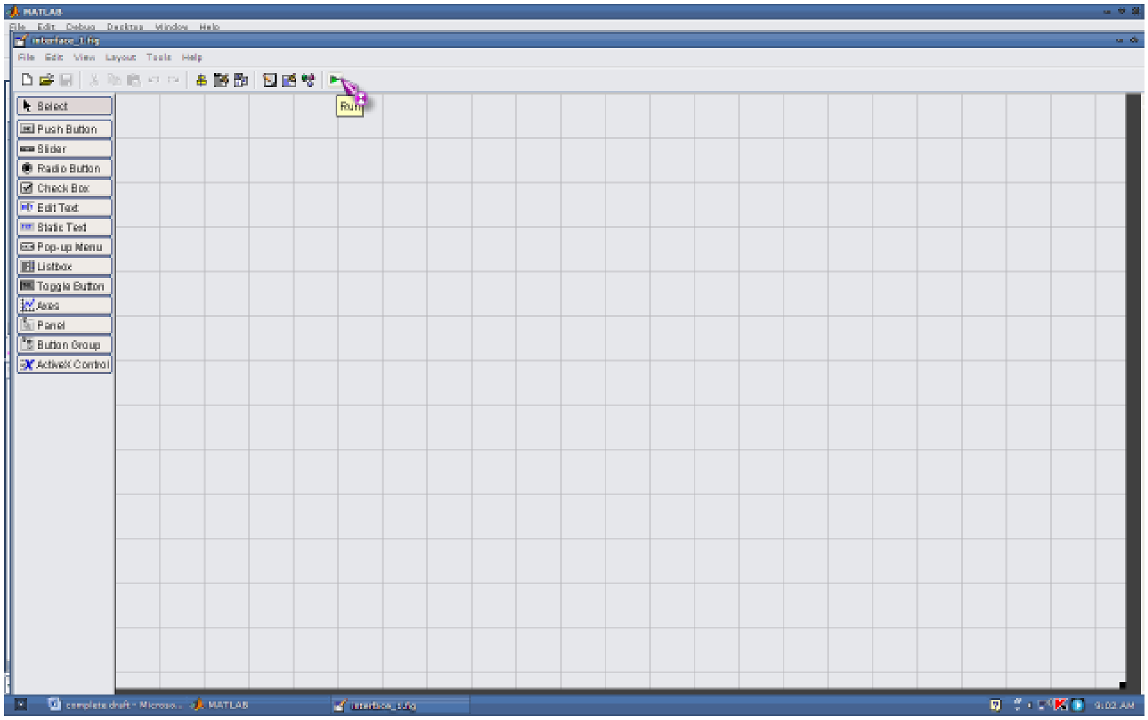
3. Click on “Open Existing GUI” and browse the file with name “interface_1”. Before that, make sure the needed file already placed inside the MATLAV work folder



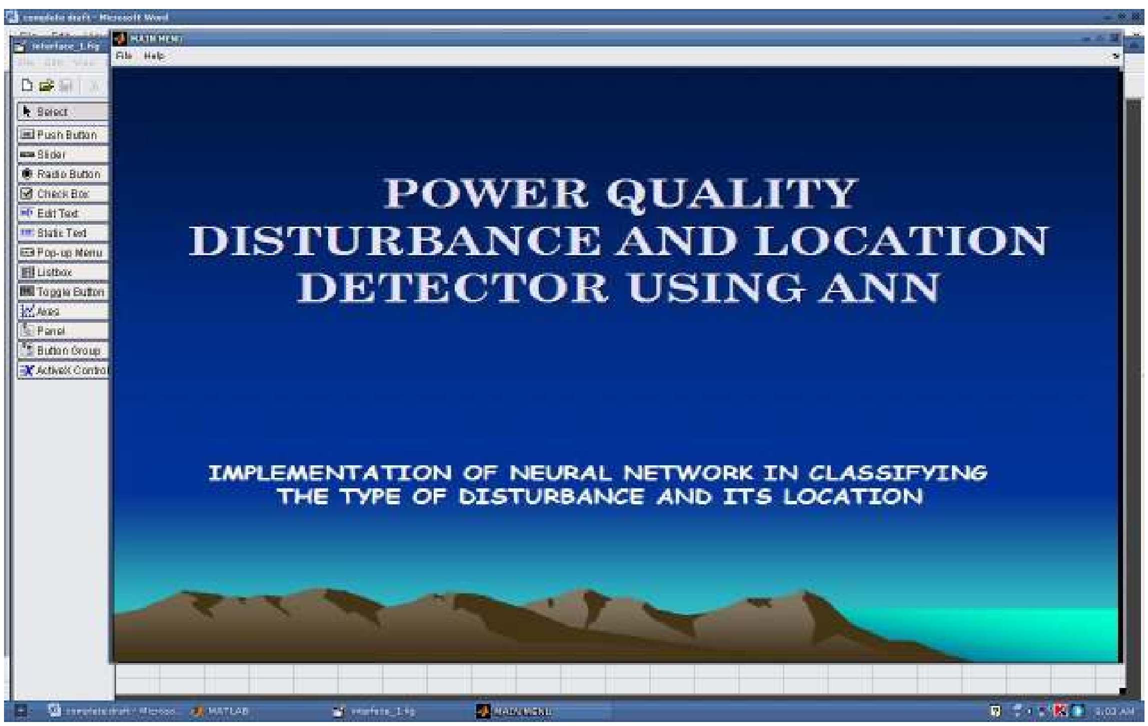
4. After select the file “interface_1”, click on open and wait till GUI finished initialized



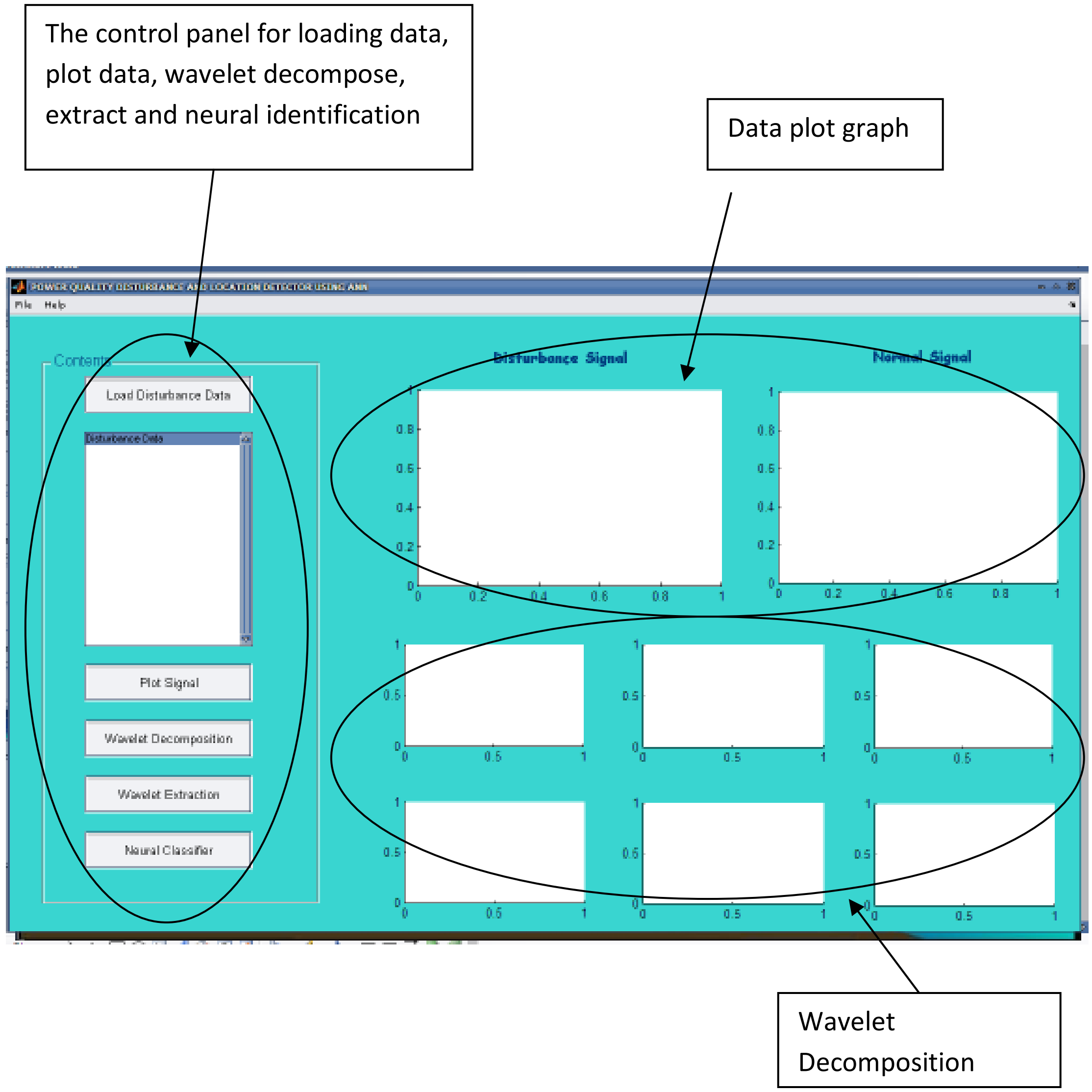
5. After a GUI window appears, click on "Run" button. You can either select the "Run" command by "Tools> Run" or by pressing Ctrl+T



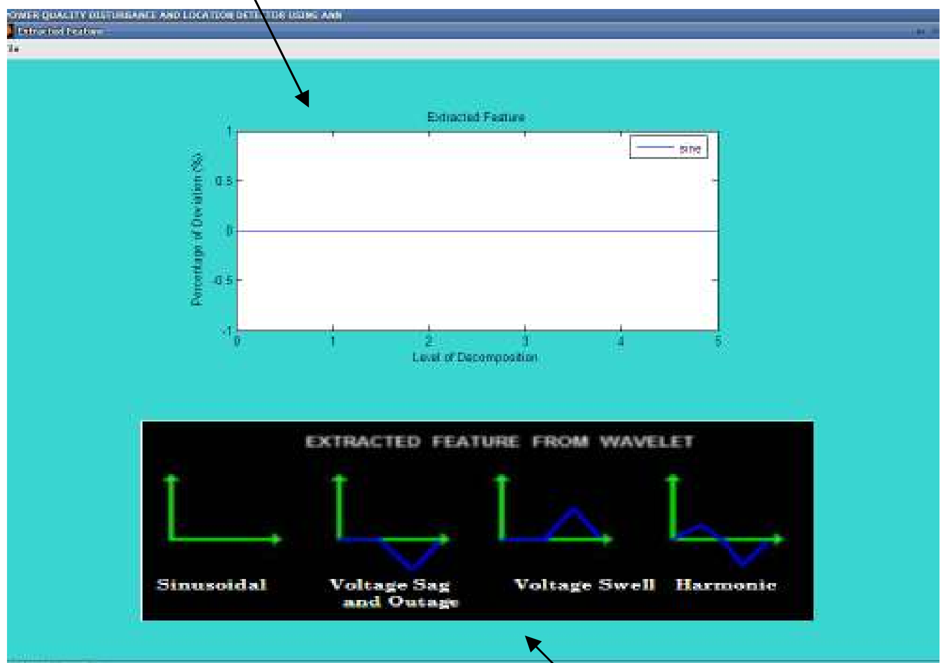
6. Then, the main page will appear.



Program Feature's and Operating Principle

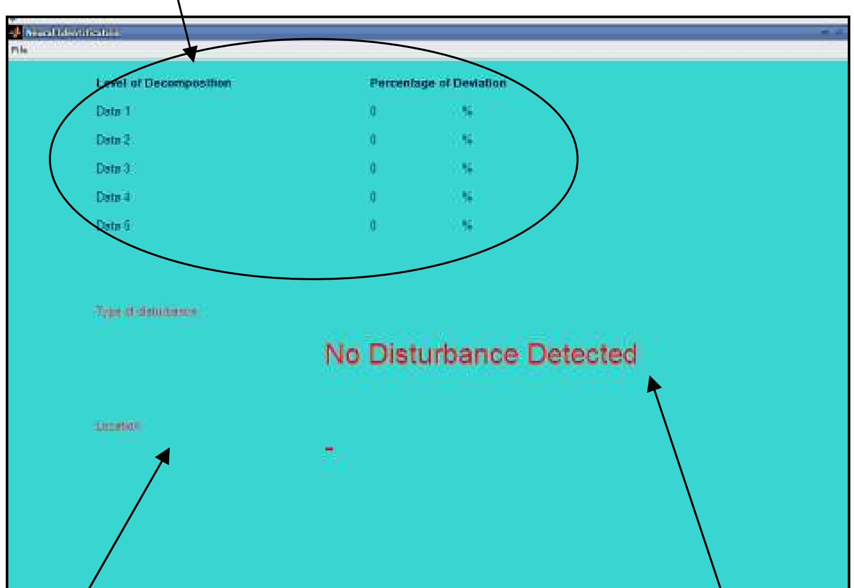


Graph of Wavelet Extraction



References for wavelet extraction

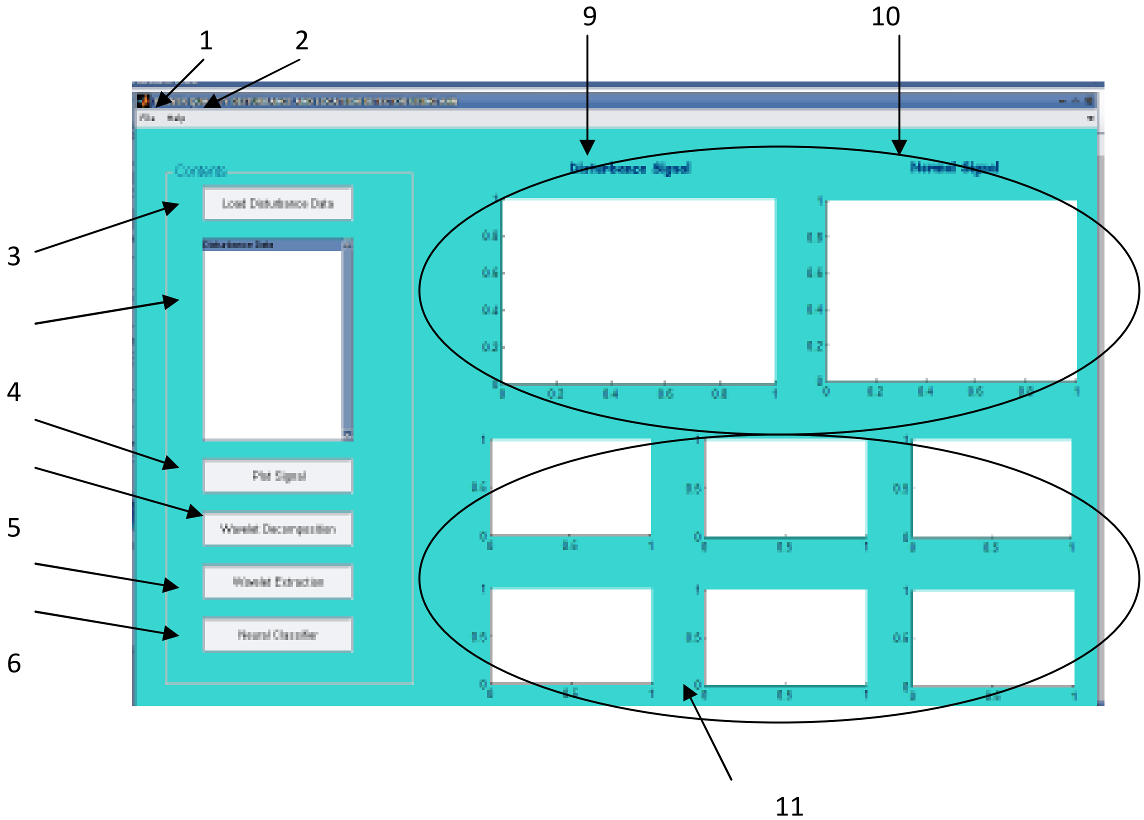
Data value



Location

Type of disturbance

Detail Function List of the Program



The above window appeared as soon as the user select “Start from “File” drop down menu on the main page. From this window, users have to select and click on the appropriate button to go through the wavelet analysis progress and neural network identifier.

List of functions of program main window

1. “File” drop down menu

   Contains command such as “Start”, “Close”, “Reset”

2. “Help” drop down menu

   Contains command such as tutorial using program and info about the creator of the program

3. Load Disturbance Data

   Allow the program to load the list of disturbance data file

4. File list

   The list of data that appear when "Load Disturbance Data" was clicked

5. Plot Signal

   Program will plot the signal and pure sinusoidal

6. Wavelet Decompose

   Program will tart the wavelet decomposition

7. Wavelet Extraction

   It will allow user to view the extracted feature of the wavelet decomposition

8. Neural Classifier

   It will perform neural network to identify types of disturbance and location

9. Disturbance Signal

   The waveform of disturbance signal

10. Normal Signal

    The waveform of pure sinusoidal

11. Wavelet Decomposition Graph

    The graph of wavelet decomposition

Note for Advanced User

The Power Quality Disturbance and Location Detector Using ANN permit users to load their own data (signals) and perform the simulation and analysis. Users are encouraged to compile and store the data in a specific folder. Also, user needs to save their data with extension *.dat file. Before running the program, they need to set the data folder as MATLAB current directory, or place it into the MATLAB current directory. While running the program, once the button "Load Disturbance Data" inside the program is clicked, the user data will automatically be loaded into the list-box. Then, user can perform the simulation and analysis based on his/her own data file.

There are some requirements and limitation on the data format.

1. The number of data must be at least 800 as the program is set to perform the analysis of 800 data only. Otherwise, error will occur.
2. The sampling frequency of the data has to be set as 1 kHz or at the step of 0.001s
3. The data should be in per unit (p.u.) form
4. The data must compile in notepad with extension *.dat

Troubleshooting

The list of troubleshooting for the program is as follows:

a. If error message appeared "Undefined function or variables" or the program cannot be run, please check if all the required files for the program are already installed inside the default MATLAB folder.

b. If the program still cannot run even all the required file is installed, then check the MATLAB version either it is match the MATLAB program version or not. The program is build under MATLAB 7.0.0.19920 (R14).

c. Before analyze on any new data samples, make sure the data is in correct form, which is no text descriptions on the start of data samples files. The data should be in values or error will occur during running.

d. For incorrect number of data, the error message 'Data Dimension Not Match' will be displayed.

e. The extracted feature might slightly different if compared to the reference if the sampling frequency (step unit) of the data is different with the required, or the data is not in per unit (p.u) form.

f. An error dialog 'This action will close all windows and figures! Do you want to quit?' appeared when *the Close All* option from the *File* pull-down menu of the main windows is choose. If the users wish to continue with another analysis, click 'No' and it will return to main windows. Otherwise, click 'Yes' to exit from the program.