FUZZY LOGIC CONTROL FOR THREE PHASE SHUNT ACTIVE POWER FILTER (MODELING AND SIMULATION)

by

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DISSERTATION REPORT

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CERTIFICATION OF ORIGINALITY

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

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(Aida Yanti Oredi)

ABSTRACT

Fuzzy Logic Control (FLC) is a control method based on fuzzy logic, where it involves four stages which consist of fuzzification, knowledge base, interference mechanisms and defuzzifcation. The main purpose of this project is to perform studied on fuzzy logic control for a three-phase Shunt Active Power Filter (SAPF) in order to reduce total harmonic distortion and power factor correction in a distribution system supplying non-linear loads. The project mainly focuses on the design of FLC to optimize the function of SAPF. The FLC involves in maintaining a constant DC voltage across the capacitor connected to the inverter. Besides FLC, this project also deals with the peak detector which is used to generate a reference signal as an input for the PWM controller. This project priority is to implement fuzzy logic controller to the shunt active power filter where the DC capacitor voltage is sensed and then compared with the reference value which in this case 220 V. The error and change of error signal at the n^{th} sampling instant are used as inputs for the fuzzy processing. The output of the FLC will be the magnitude of the reference signal for the filter. Then it will be passed on to the peak detector to multiply with the sine vector of the voltage source in order to generate the reference signal. Furthermore, simulation is carried out using Fuzzy Logic Toolbox as well as SIMULINK in MATLAB. Simulation results are verified to find out the optimization of the active power filter in solving the harmonic distortion problem in non-linear loads.

ACKNOWLEDGEMENT

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LIST OF ABBREVIATIONS

AC	Alternating Current
APF	Active Power Filter
BOA	Bisector of Area
COG	Centre of Gravity or Centroid of area
COGS	Centre of Gravity method for singletons
CSI	Current Source Inverter
DC	Direct Current
FLC	Fuzzy Logic Controller
FIS	Fuzzy Inference System
FYP	Final Year Project
IGBT	Insulated Gate Bipolar Transistor
IRCUTP	Information Resource Centre Universiti Teknologi PETRONAS
LM	Leftmost Maximum
MOM	Mean of Maxima

MOSFET	Metal Oxide Semiconductor Field-Effect Transistor
PWM	Pulse Width Modulation
PI	Proportional Integral
PPF	Passive Power Filter
RM	Right Maximum
SAPF	Shunt Active Power Filter
THD	Total Harmonic Distortion
TS	Takagi Sugeno
UTP	Universiti Teknologi PETRONAS
VSI	Voltage Source Inverter

CHAPTER 1

INTRODUCTION

1.1 Background Of Study

Nowadays, the usage of the non-linear loads had been increasing rapidly in power electronics industries. Non linear devices draw non-sinusoidal current that cause the harmonic distortion and affect the efficiency of the system. Non-linear loads such as adjustable-speed motor drives, battery charger, electronic ballast and power electronic controllers increase the harmonic contamination on power system utilities. Harmonics in power system lines can be defined as a form of electrical noise where it is a superposition of signals on fundamental which are multiples of fundamental frequency [1]. The prime source of harmonic distortion is a non-linear load. Non-linear loads draw harmonic current to the line impedance of the system and produce harmonic voltage that cause disturbance on the system. The effect of harmonic distortion in power system is reduction of the power quality as well the stability of the system [1] [2].

In order to solve the problem of harmonic distortion in power systems, the power filter is used to filter the electrical noise in power utility. In general, there are two types of power filters that have been used which are the passive power filter (PPF) and active power filter (APF). The passive power filter is a simplest solution for harmonic distortion [3]. However, due to the inability of PPF to adapt with the network characteristic variation [3], the active power filter is chosen to reduce as well as solve the harmonic contamination in power system utilities.

The author has been assigned to control as well as reduce the harmonic contamination by using Shunt Active Power Filter (SAPF). In general, the active power filter is an analogue electronic filter, distinguished by the use one or more active components such as voltage amplifier [3]. The main purpose of the power filter is to filter the electrical noise that appear on the system as well as correct the power factor.

Active power filter can be divided into three configurations, shunt, series and hybrid [3][4]. However for this study, author has been assigned to use SAPF to solve the harmonic problem that is caused by non linear loads. SAPF is widely and commonly used with power electronic equipment to eliminate unwanted harmonics and compensate fundamental component of reactive power consumed by non-linear devices through injecting the compensating current into the AC lines. SAPF is used mostly because it can keep the power system in balance [3].

In power filter configuration, one type of implementation is the current controller. In general, the current controller is used to generate appropriate gating signals for the switching transition based on estimated compensating current [4]. There are several control techniques that can be used such as the hysteresis technique or PWM technique [4]. Besides the current controller, the author has been assigned to study Fuzzy Logic Control (FLC) and how to implement on the SAPF. FLC is used to sense as well as to control the DC side capacitor voltage to improve the SAPF dynamics, in order to reduce the source current total harmonics and to produce high power quality [5].

1.2 Problem Statement

Employing non-linear loads in addition to normal loads can cause the harmonic distortion in power systems which affect the system in terms of power quality, poor power factor and inefficiency. One of the ways to solve this problem is by implementing APF to the system. However, in implementing the power filter, it required to have the controller such as Proportional Integral (PI) controller. However, PI controller has some drawback such as the PI controller required precise linear mathematical model which is difficult to obtain and the performance of PI controller unsatisfactory for the variations of parameters and load disturbances. Due to some drawbacks of a PI controller, it is suggested to implement FLC to the APF in order to control the DC voltage from the capacitor. The output of the FLC will be used by the current controller as input in order to generate the gating pulses to the semiconductor switches.

1.2.1 Problem Identification

This main purpose of this project is to design the Fuzzy Logic Controller (FLC) for SAPF to correct the harmonic distortion. The SAPF is used to shape the line current to be in phase with the supply voltage. In order to complete this project, the author required to study and understands the basic concepts of the fuzzy logic and the implementation of fuzzy logic concept in the controller. The author is also required to learn about the current controllers which are the Hysteresis Current Controller or Pulse Width Modulation Controller (PWM) used to produce the gating signals. This project is also required the author to design the model on the MATLAB/SIMULINK and analyse as well as compare the results of the total harmonic distortion.

1.3 Objectives

The main objective of this study is to implement the FLC for a three phase SAPF to replace the conventional controller which is Proportional Integral (PI) controller .The function of FLC is to sense and to control the DC side capacitor of the SAPF in order to correct the power factor. Fuzzy logic has been chosen because it is used the linguistic variables (human thinking) to control the output of the controller. From the previous research and journals, FLC is said to be the best choice of controller because it has better response to perturbations, perform very good DC bus regulation during the changes of load than a PI controller [6]

1.4 Scope Of Study

The author is required to read research papers from other researches regarding the FLC, SAPF, and current controllers. Besides the author has to study the basic concepts of the fuzzy logic itself as well as learn on how to design the FLC. Also it is necessary to understand on how FLC works in producing the magnitude of reference current. Besides FLC, the author is required to design the SAPF and current controller to complete the modeling. In addition, the author is required to learn on how to use the MATLAB /SIMULINK in order to model as well as to simulate this project. The specific tool that is used in MATLAB for design the FLC is the Fuzzy Logic Toolbox. In order to complete this project, the author is required to design each model before analysing the final result.

CHAPTER 2

LITERATURE REVIEW

2.1 Fuzzy Logic Theory

Fuzzy set theory provides a means for representing uncertainties [8]. Historically, probability theory has been used as a tool for representing uncertainty in mathematical models. Fuzzy set tools can be called as an amazing tool because of its ability to model the kind of uncertainty associated with vagueness with impression or with a lack of information regarding particular element of the problem [8].

Fuzzy logic is classified as a successful theory when dealing with the complex models where it can handle the process when human thought are involved. The beauty of fuzzy logic lies on the ability to handle the linguistic variables such as a ‘small’, ‘almost’, “positive’ and etc [8]. The fuzziness is actually taken care by fuzzy logic using the membership function technique which is then translated into crisp value as output to be used by computer.

FLC is a control method that used the concept of fuzzy logic in order to solve a problem due to the complexity of the situation [9]. FLC can be configured as shown in the block diagram of a Figure 1. Basically FLC can be divided into four stages which are the fuzzification, inference, knowledge base, and defuzzification.

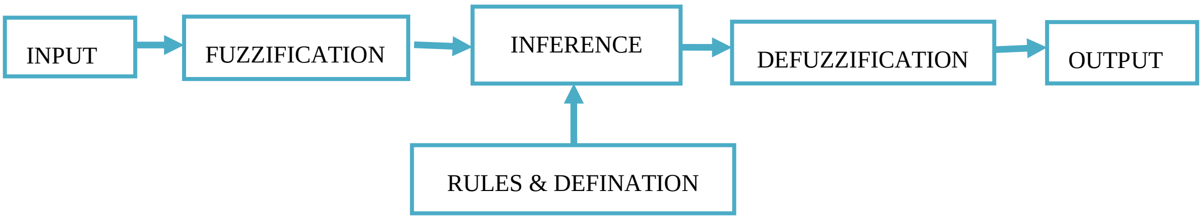


Figure 1: Stages of Fuzzy Logic Control

The fuzzy logic is described by controlling the system by the sentences rather than by numbers. The FLC system usually takes the readings of the error and the rate change of error as the inputs and change in the control input signal as the output of the system [6][9].

2.1.1 Fuzzification

Fuzzification is the first stage of the FLC system. In this stage the input data will be converted by fuzzifier. Fuzzifier performs the function to convert the crisp values of input signal to the fuzzy represented value [6]. Fuzzification play an important rule in designing the controller based on fuzzy logic set. As one of example of fuzzification, if the designer would like to design a motor controller, where it is used to control the speed of motor by changing the input voltage. Usually using an integer as an input such as if voltage is the range of 20 V to 50 V the motor slows down and so on. However, using Fuzzy Logic Controller, it can be designed by the linguistic values. The input is converted into degree of membership functions as shown in Table 1.

Table 1: Fuzzification

Inputs:	Outputs
TS: Too Slow	LV: Less Voltage
JN: Just Nice	NC: No Change
TF: Too Fast	MV: More Voltage

From the value in Table 1, it is shown on how the designer fuzzifier the input from mathematical or binary number to the human thought which is more easily to operate in complex situation.

2.1.2 Knowledge Base

Knowledge base on FLC consists of data base and rule base [6]. The basic function of the data base is to provide the necessary information for the proper function of the fuzzification module, rule base and defuzzification. The information may consist of the meaning of the linguistic values of the membership functions of the process state and the control output variables. The data base also gives the information regarding physical domain and their normalized counterparts together with the normalization, denormalization and scaling factors [8]. The type of membership function of fuzzy set also can be known by using the data base of the FLC. In knowledge base of FLC there are two components taken parts which are the quantization and rule base.

Quantization discretizes a universe into a certain number of segments. This segment is a form of discrete universe [9]. A fuzzy set will be defined by assigning grade of membership values to each generic element of the new discrete universe. In general, the quantization involves by breaking up the fuzzy input and output variable into several subsets [9]. As an example, in quantizing the input of the temperature the designer will break the temperature term into by subsets which the temperature may consist 'very hot'. 'hot', 'less hot', 'cold' and 'very cold' [9]. For each of this subset, a membership function must be assigned as needed in fuzzy sets.

In designing the FLC, the designer may choose any kind of shape of the membership function to get the optimum result. Figure 2 show several types of membership functions in FLC toolbox in MATLAB/SIMULINK.

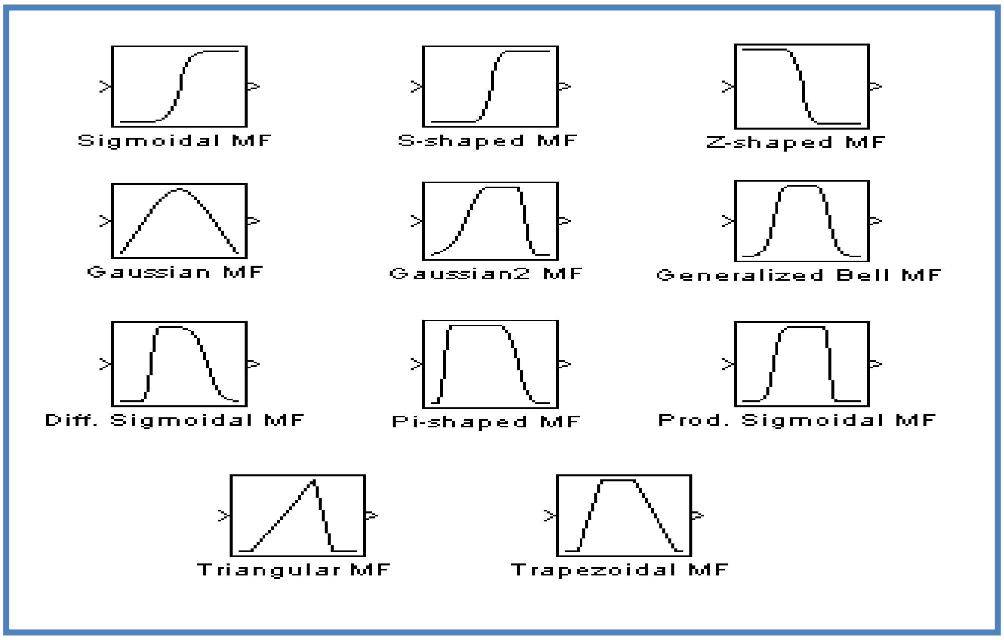
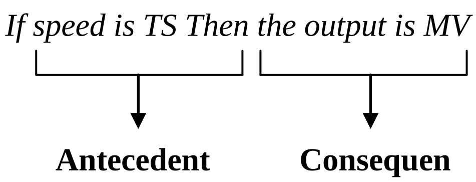


Figure 2: Shape of membership functions

In solving problems regarding the FLC, the most common shaped membership function that has been used for simplicity design is a triangular-shaped function. Basically, the shape will overlap around 25 % each membership function [9], the transition from one fuzzy subset to another provides a smooth transition from one control action to another. In general, for simplicity in design the designer can choose same triangular shape for all input and output variables.

The other component of the knowledge base is rule base. Rule base is essential in the control strategy of the system. It is usually expressed in ***"If-Then"*** format [8][9]. The rule is based on the fuzzy inference concept, the antecedent and the consequences of the rules are associated by the linguistic variables. The examples of rule base in a fuzzy logic. FLC are as follows:



Rather than "If-Then" format, there are other typeof format which are the 'relational" format and the "Tabular Linguistic" format. The Tabula Linguistic can be shown in Table 2:

Table 2: Tabular Linguistic Format

Change in Error

Erro

	Neg	Zero	Pos
Neg	NB	NM	Zero
Zero	NM	Zero	PM
Pos	Zero	PM	PB

From the Table 2, N is represented Negative, B is representative Big, M is representative Medium, and Positive representative Positive. Table 2 is the example on how the designer defined the membership functions to get the desired output.

In general there are several methods in defining the control rules for the FLC. These methods are not mutually exclusive but rather like a combination of them will be necessary to construct an effective method in designing the FLC. These methods are the defining rules based on expert experience and control engineering knowledge, based on operator’s control actions, based on fuzzy model process and based on learning and study on fuzzy logic concept [8].

2.1.3 Fuzzy Inference

Fuzzy inference is sometimes called a fuzzy reasoning or approximate reasoning [6]. It is used in a fuzzy rule to determine the rule outcome from the given rule input information. Fuzzy rules represent control strategy or modeling knowledge or experience. When specific information is assigned to input variable in the rule antecedent, fuzzy inference is needed to calculate the outcome for input variables in the rule consequent.

There are two basic approaches employed in design of the inference engine in FLC which are compositional rule based inference and individual rules inference. Most of the applications use the individual inference rule base. For this case, the input will be fuzzified to the fuzzy variables which are called as rule antecedents, then clipping the fuzzy set by describing the meaning of rule consequents to the degree to which rule’s antecedents has been matched to the input. Finally, the output will be aggregated thus performing the value of the overall control output for the FLC. Using individual inference rule base is better since it is computationally efficient and save lots of memory [9].

For the general Fuzzy Inference rule such as:

'When the error is Negative and the change of the error is Negative then the output will be Negative Big.'

For the above statement, the error and change of the error are rule antecedents and the output is the rule's consequent of the FLC. Figure 3 show the example for one type of inference method which is the Mamdani's Max-min implication method [6].

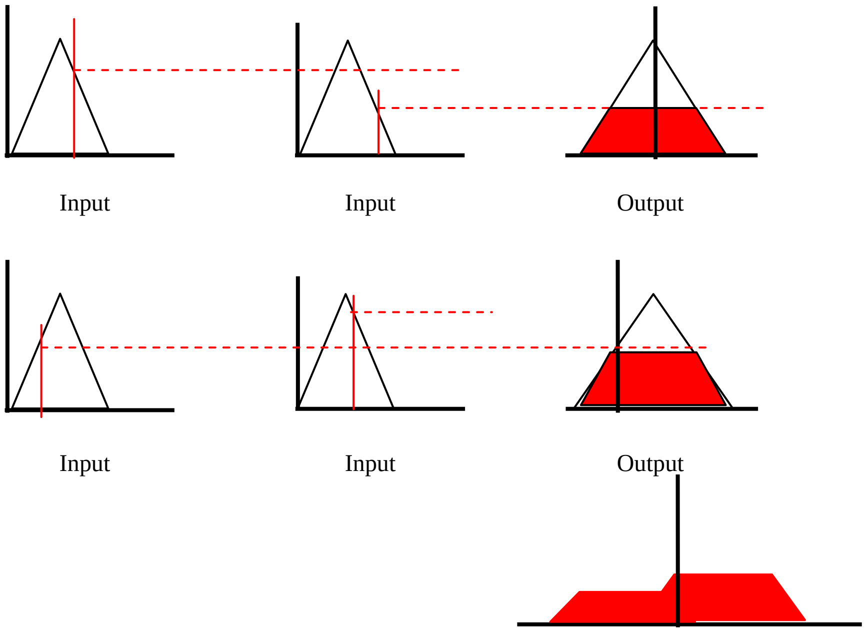


Figure 3: Max-Min Inference Technique [6]

2.1.4 Defuzzification

In defuzzification stage a mathematical process is used in order to convert fuzzy set to a real number. After all, actuators for a control system can accept only one value as their input signal, where as measurement data from physical system being modeled are always crisp. The conversion is important in order to send the real number to the process as a control signal [6]. There are several methods in defuzzification which are as follows [6]:

a. Centre of Gravity or Centroid of area (COG)

b. Centre of Gravity method for singletons (COGS)

c. Bisector of Area (BOA)

d. Mean of Maxima (MOM)

e. Leftmost Maximum (LM) and Right Maximum (RM)

The widely used in defuzzification is center of gravity of centroid area. A fuzzy logic controller model uses a defuzzifier. In a fuzzy logic controller where there are more than one output variable, defuzzification is carried out to each of them separately but in a very similar fashion. In most cases, only one defuzzifier is employed for all output variables, although it is theoretically possible to use different defuzzifiers for different output variables.

2.2 Fuzzy Logic Controller (FLC)

Generally fuzzy controllers have been used in various control schemes since 1996. The most obvious one is direct control, where the fuzzy controller is in the forward path in feedback control system. The process output is compared with the reference and if there is any deviation the controller will take action according to the control strategy, in this case based on the defining rules. Fuzzy Logic Control can be divided into two types generally which are the Mamdani's and Takagi Sugeno (TS) types [8].

Basically, Mamdani's type is usually used in feedback controller and quite close in nature to manual control. Where as the TS type is usually been used in control that is close to the gain scheduling approaches [10]. In this project, the author has been choosing Takagi Sugeno type in defining the membership functions. Takagi Sugeno types is chosen because the number of fuzzy set used for the input fuzzification is lesser than Mamdani types, thus reducing the number of the rules to be used. Since the rules are less, it decreases the computational time for the controller to run in getting the output is lesser [10]. Typically, both types of FLC have their own advantages based on the application that is used.

Figure 4 shows the Fuzzy Logic Toolbox in the MATLAB. From the figure the author has been used two inputs and one output in designing the FLC.

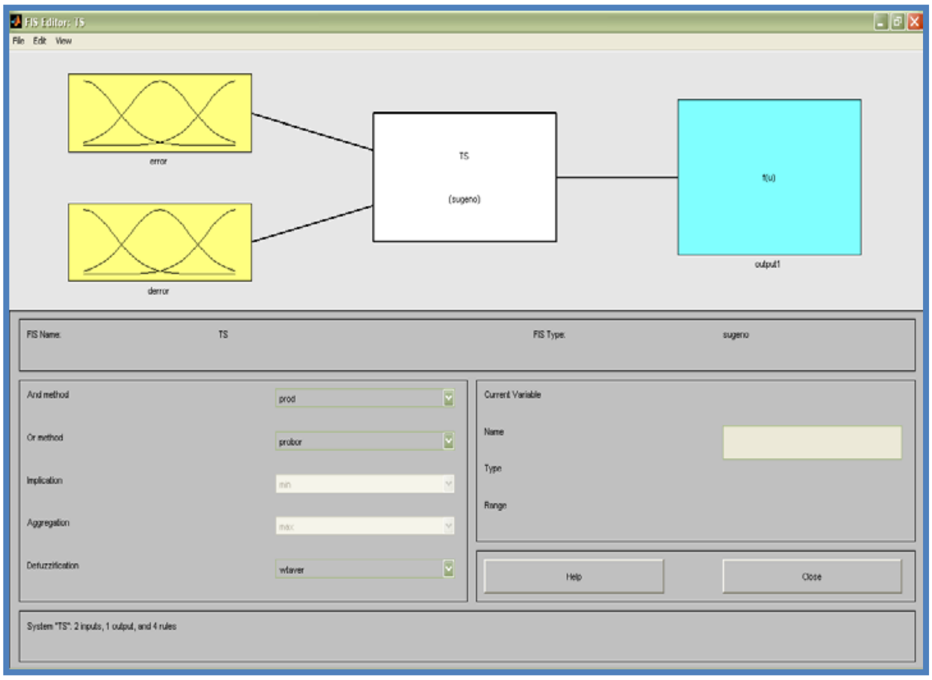


Figure 4: Fuzzy Logic Toolbox [11]

In this project, the Fuzzy Logic Controller (FLC) is used in order to maintain the DC side capacitor voltage of the filter as constant. There are energy losses due to the conduction and also switching losses associated with the electronic switches such as the IGBT, MOSFET or Diodes. These losses will reduce the voltage across the capacitor. The FLC it used to bring back the DC voltage back to its reference value in order to cover the losses caused by the system.

2.3 Shunt Active Power Filter (SAPF)

In the world of power electronics, there are two types of power filters which are Passive Power Filter (PPF) and Active Power Filter (APF) [12]. A PPF is the simplest filter and the cheapest one. However PPF is not applicable on all types of network particularly when non linear load are connected to the network of the power system.

APF in general is used utilizing power electronics technologies to produce specific current to cancel the harmonic current components that are caused by non-linear loads [12]. There are several types of APF which consist of series, shunt and hybrid configurations. However, in this study, only a SAPF is considered.

SAPF is commonly and widely used as a power electronic controller. SAPF can be categorized into two types which are based on current source inverter (CSI) or voltage source inverter (VSI) [12]. In general, SAPF is used to eliminate the harmonic currents by injecting the compensate current into the system since the compensate current is equal to the harmonic currents but different in phase. This injected compensating current cancel out the unwanted harmonic distortion. Besides that, SAPF is also used to increase the power factor (PF) up to unity.

In designing the SAPF three aspects need to be considered which are [12]:

a. Design of power inverter
b. Types of current controller used
c. Method to obtain the reference current for the reference to use in current controller

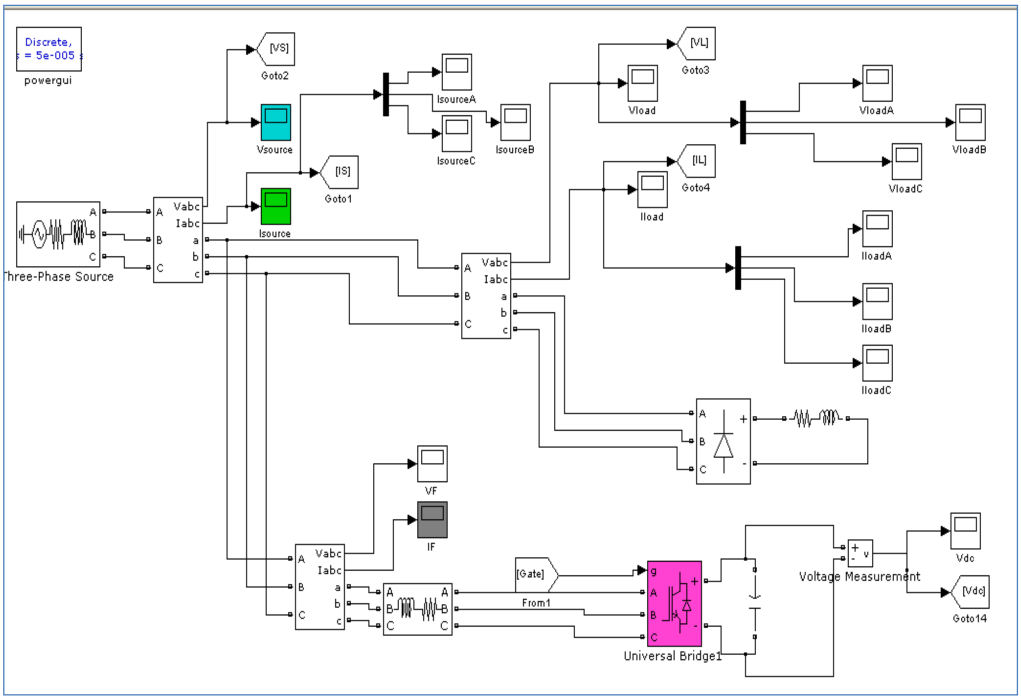


Figure 5: Shunt Active Power Filter

Basically, the SAPF is composed of three-phase voltage source inverter with an AC inductor and DC capacitor to provide a constant DC voltage and the real power to cover the losses on the system. The whole model has been supplied by three phase AC supply voltage. In general, the SAPF performance depends on power semiconductor devices design, switches modulation control technique and coupling elements design [13]. In this project, the author has studied on how to compensate harmonics of the power lines.

The basic operation of SAPF is used to inject the compensating current to the power system to cancel the unwanted noise that can cause harmonic distortion in power lines. The compensating currents need to be equal to the distorted currents in order to eliminate them. The compensating current is produced by the VSI or CSI switches [13].

From the Figure 5, it can be seen how the SAPF actually eliminates the distorted current. The SAPF will inject compensating current, I_F to the power lines, meanwhile AC supply or AC source will supply the source current, I_S to the load. From the Figure 5 the non-linear load current can be expressed as:

$$I_L = I_S + I_F \tag{1}$$

$$I_L = I_{L,f} + I_{L,h} \tag{2}$$

The non-linear load current consists of $I_{L,f}$ and $I_{L,h}$. The $I_{L,f}$ is the fundamental current component or can be assumed as the source current. For $I_{L.h}$ is the harmonics current that cause by the non-linear load.

Thus the source current that is supplied to the load is:

$$I_S = I_L - I_F \tag{3}$$

$$I_S = I_{L,f} - I_{L,H} - I_F \tag{4}$$

Equation (4) shows that the harmonic current can be eliminated by injecting the compensate current, I_F to the power lines. The I_F will have same magnitude as the $I_{L,h}$ but different in phase.

2.3 Pulse Width Modulation (PWM)

Basically the PWM is a commonly used technique for controlling power to an electrical device and made practical by modern electronics power switches [14]. The basic principle of PWM in controlling the electronic switches is that it uses a rectangular pulse wave as a gating signal to trigger the switches as shown on Figure 6. The basic operation of PWM controller is to compare two signals, which in this case are the switching frequency and the reference signal that is generated by the peak detector. The intercept between these signals will generate the rectangular waveform which is called as gate signal.

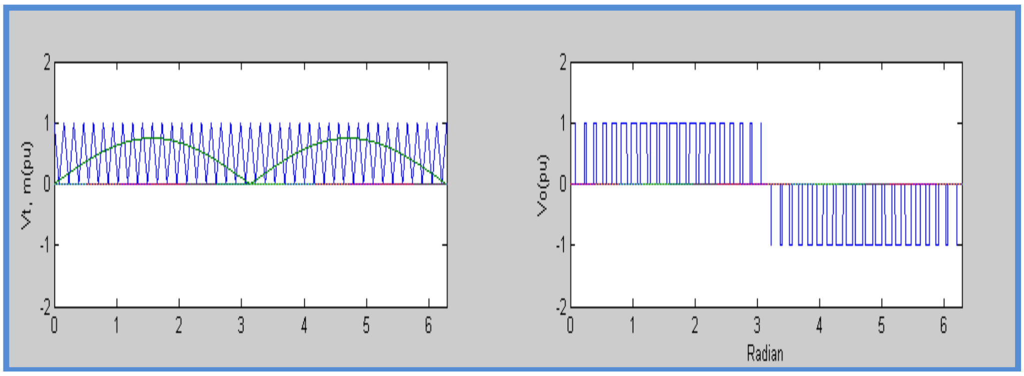


Figure 6: Example for PWM operation.

PWM has been used in various applications such as in telecommunication, power delivery, voltage regulation and audio effects and amplification. For this project, the author only study about the PWM current controller, where on this case PWM is used to generate gate signal to the switches of the SAPF. Using PWM as a current controller is called as linear technique. In the linear technique, the switching frequency will be fixed and maintained constant. The block diagram of PWM generator in MATLAB/SIMULINK to produce the gate signal is as shown on Figure 7.

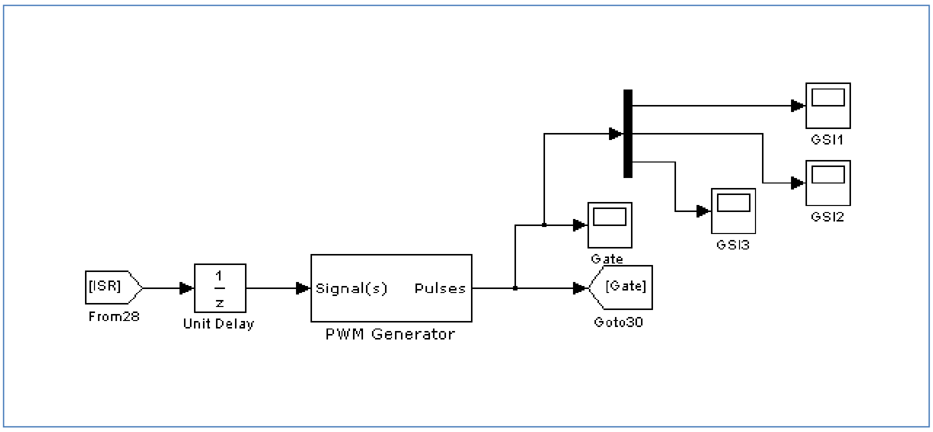


Figure 7: Block Diagram of PWM generator at SIMULINK

In general a PWM controller is required to generate signal from the switching frequency and the reference signal. The switching frequency may be established from the repetitive frequency of the sawtooth. Reference signal is the signal that can control the way the gate signal is used for the SAPF. The reference signal is designed by the designer in order to optimize the on and off times of the switches in the SAPF. The intercept between the control and reference signals will produce the rectangular waveform which is the gating signal. Basically, when the value of reference signal is more than the switching frequency or PWM modulation, the gate signal is in the high state; otherwise it is in the low state as shown on Figure 6.

PWM modulation can be divided into six categories which are the intersective method, delta modulation, delta sigma, space vector modulation, direct control torque and time proportioning [14]. Each of the modulation techniques has their own principle in generating the gating pulse. From the six categories of the PWM modulation, three types of the PWM signal or gate signal are produced which are leading edge modulation (top), trailing edge modulation (middle) and centered pulses (both edges are modulated, bottom) [14].

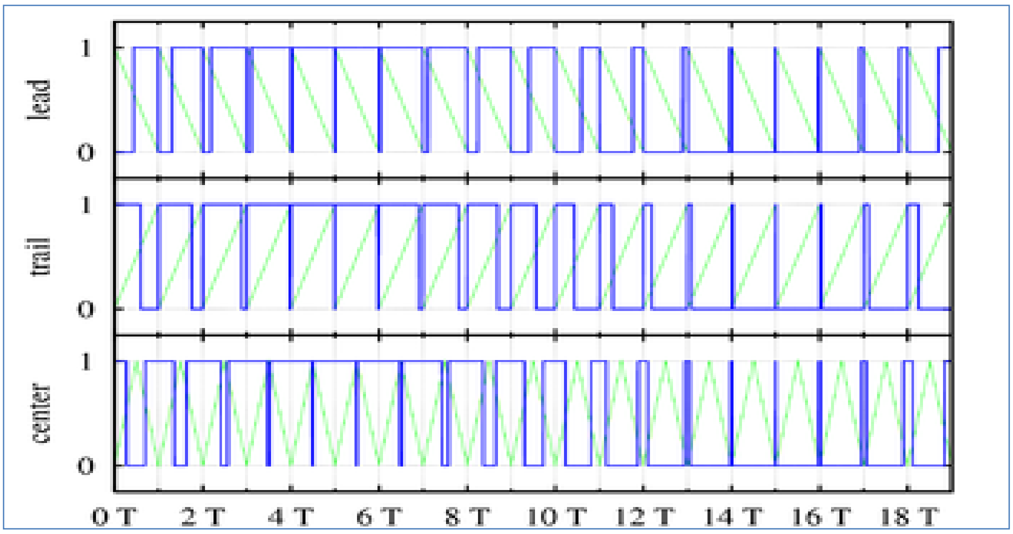


Figure 8: Types of gating signal [14]

Same as in the other techniques, PWM modulation has several advantages and disadvantages in using PWM as a controller to generate the gating pulses. One of the advantages in using PWM is the power loss during switch ON and OFF timers is very low [14]. It is because that when a switch in OFF mode there is practically no current that flows to the system, and when the switch in ON mode there is almost no voltage drop across the switch. This allowed the PWM to response faster for any changes in the switch. Besides the PWM controller is simple to implementation. However, there are several drawbacks in using PWM as a controller to generate gate signals. Since in this project the author deals with the analogue PWM controller, due to inherent problems of analogue circuitry [14][12], the linear technique has an unsatisfactory harmonic compensation performance. It may be caused by the limitation of the achievable bandwidth of the compensated error amplifier.

2.4 Instantaneous PQ Theorem

PQ-Theorem is called as “Theory of Instantaneous Real Power and Imaginary Power” or sometimes also can be referred ad Theory of Instantaneous Active Power Filter and Reactive Power Filter. There are two techniques in finding the references voltage or current which by time domain or frequency domain. PQ-theorem is one of the time domain techniques which implement a transformation from a stationary reference system in a-b-c coordinates to a system with α-β-0 coordinates.

The calculation of the transformation of PQ-theorem for this project can be shown below:

$$\begin{bmatrix} Vo \\ V\alpha \\ V\beta \end{bmatrix} = \text{T}. \begin{bmatrix} Va \\ Vb \\ Vc \end{bmatrix} \quad (5)$$

$$\begin{bmatrix} io \\ i\alpha \\ i\beta \end{bmatrix} = \text{T}. \begin{bmatrix} ia \\ ib \\ ic \end{bmatrix} \quad (6)$$

Where T is:

$$\text{T} = \sqrt{\frac{2}{3}} \cdot \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \quad (7)$$

From the basic equation the transformation from a-b-c coordinates to α-β-0 coordinates is completed. The next calculation is to get the Instantaneous Zero-Sequence Power (p0), Instantaneous Real Power (p) and the Instantaneous Imaginary Power (q).

The Instantaneous Zero-Sequence Power

$$p0 = v0.i0 = \overline{p}0 + \widetilde{p}0 \quad (8)$$

The Instantaneous Real Power (p)

$$p = v\alpha . i\alpha + v\beta . i\beta = \bar{p} + \tilde{p} \quad (9)$$

The Instantaneous Imaginary Power (q)

$$q = v\alpha . i\beta - v\beta . i\alpha = \bar{q} + \tilde{q} \quad (10)$$

$\bar{p}$: Mean value corresponds to the energy per time unity that is transferred from the source to the loads of voltage and current.

$\tilde{p}$: Alternating value corresponds to the energy per time unity that is exchange between source and the loads in terms of voltage and current.

$\bar{q}$: Mean Value of instantaneous imaginary power

$\tilde{q}$: Alternating Value of instantaneous imaginary power

From the equations, the AC components are $\tilde{p}$ and $\tilde{q}$ are extracted using high-pass filter. The extracted AC components are then used for compensation reference current.

CHAPTER 3

METHODOLOGY

3.1 Procedure Identification

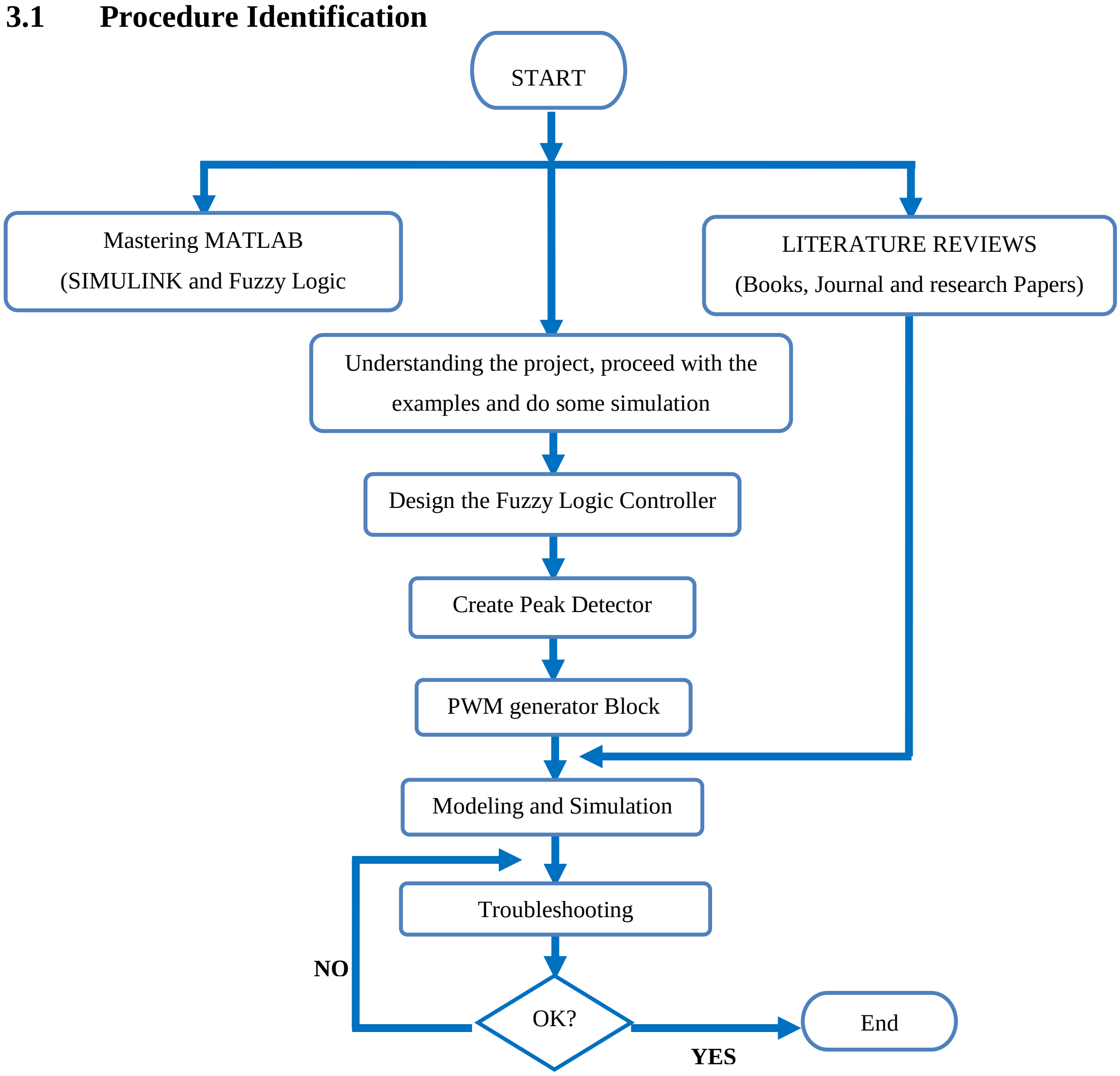


Figure 9: Project work flow chart

Figure 9 shows the steps that have been taken by the author to complete the project. The project begins with the study on the basic concepts of the SAPF, Fuzzy Logic theory as well as on how to use the MATLAB/SIMULINK. Then after understanding the requirements of the project as well as the MATLAB, the author started to model the system and design the FLC using Fuzzy Logic Toolbox. In designing the FLC the author has been tried both the methods which are the Mamdani's type and Takagi Sugeno Type. The author decided to use Takagi Sugeno method since the computational time taken by Takagi Sugeno is smaller than Mamdanis and the rules used also lesser.

After designing the FLC, the author continued the project by designing the peak detector in order to generate the reference signal, since the output of the FLC is only the magnitude of the reference signal. Then, the reference signal will go through PWM Generator, where on this part the author only used the PWM generator block diagram that is available with the SIMULINK. PWM generator is used to generate the gating signals. The gate pulses will be injected to the SAPF to analyse the results. After designing all the component blocks, the author has developed the system by changing the parameters of each model. Then the simulation is started.

The results will be collected and recorded, on this case the Total Harmonics Distortion (THD) before and after injecting the compensated current will be recorded and analyse to check whether the FLC is working or not in reducing the THD on the system.

3.2 Model Construction

3.2.1 Designing the Fuzzy Logic Controller (FLC)

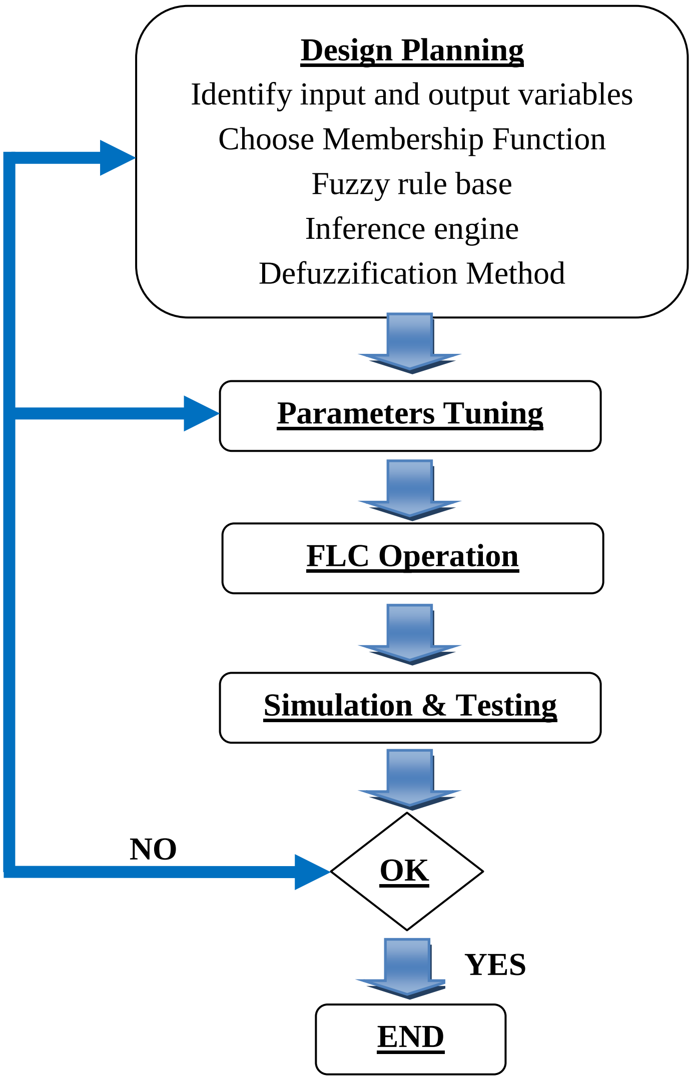


Figure 10: Design procedure of the FLC system

Figure 10 shows the stage in designing the FLC for this project. The first stage in designing on FLC is by planning the parameters that used on the FLC. On this first stage, the first step is identifying the input and the output of the FLC system. In this case, the inputs of the FLC are the error between DC voltage and reference DC voltage and the other input is change of error. The output of the system is the peak magnitude of the compensate current. After identify both inputs and output, the next step will be assigned the shape of the membership functions. For this project, the author has use trapezoidal shape for simplicity and easy to implement. The third step of the first stage in designing FLC is assigned the rules of the system. For this case the author four rules in defined the output of the system. The last step in planning the FLC system is by identify the types of defuzzification method, for this project the method that been used in Centroid of Area (COA).

The second stage in designing the FLC is parameter tuning. On this stage, the author will used trial and error method in designing the rules as well as the parameters of the inputs and output in order to get satisfied results. The changes will be done at the Fuzzy Logic Toolbox that available in the MATLAB. The third stage will be the operation of the FLC, where the author required inserting the inputs for the FLC on the SIMULINK block. The fourth stage will be the simulation of the FLC system and then analysing the results of the system until it is satisfied for the project.

The steps in designing FLC are presented on the Appendix D.

3.2.2 *Shunt Active Power Filter (SAPF)*

As a whole project, SAPF is designed on the second stage of the project, where the first stage is designing the FLC system. For this project, the author used IGBT switches for the SAPF as shown on Figure 11.

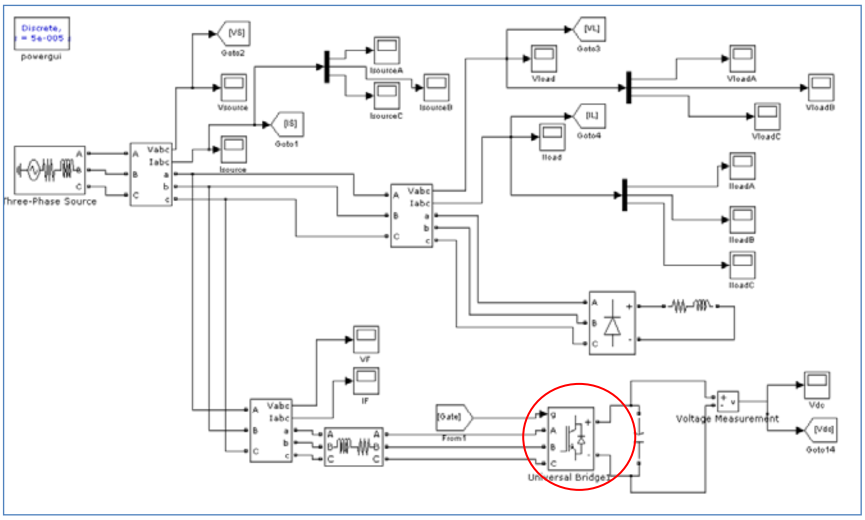


Figure 11: Shunt Active Power Filter

On this stage, the Block Parameters of the SAPF are shown on Figure 3:

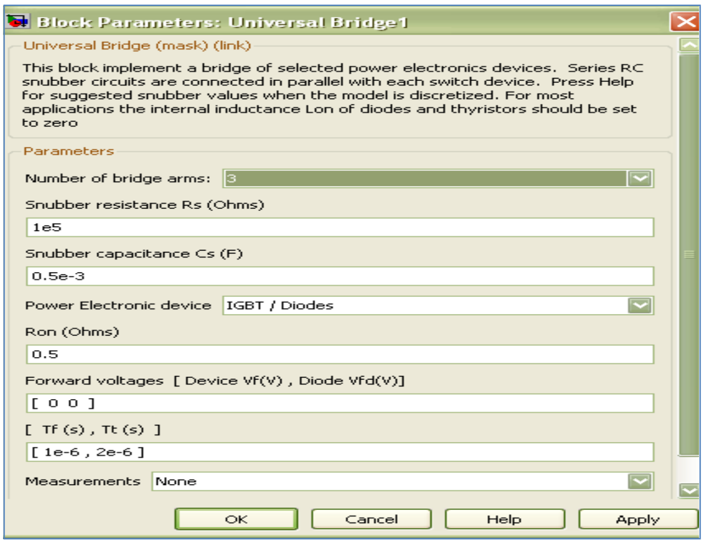


Figure 12: Block Parameters of SAPF

3.2.3 Pulse Width Modulation (PWM)

PWM general operation is by compare between the command signal or reference signal with the Chopping signal. On this case the Chopping signal come from the switching frequency that defined by the author. The interaction between these signals will trigger the ON and OFF state of the output signal. The bigger the command signal, the wider the width of the pulses.

The Function Block Parameters of the PWM for this project is shown on Figure 13.

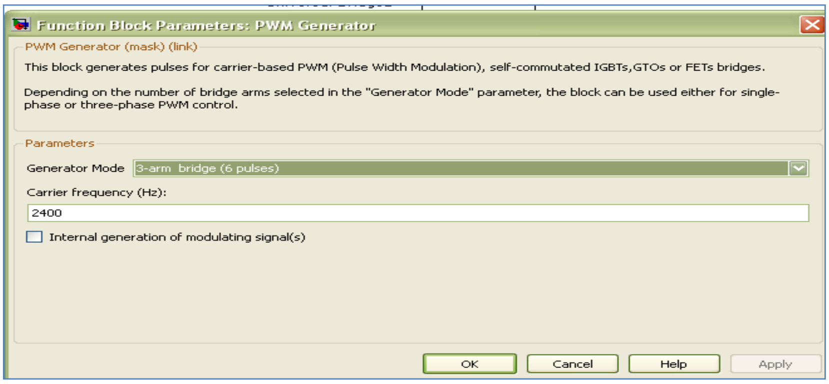


Figure 13: Function Block Parameters of PWM

The gating signals that produce by the PWM is shown in Figure 14:

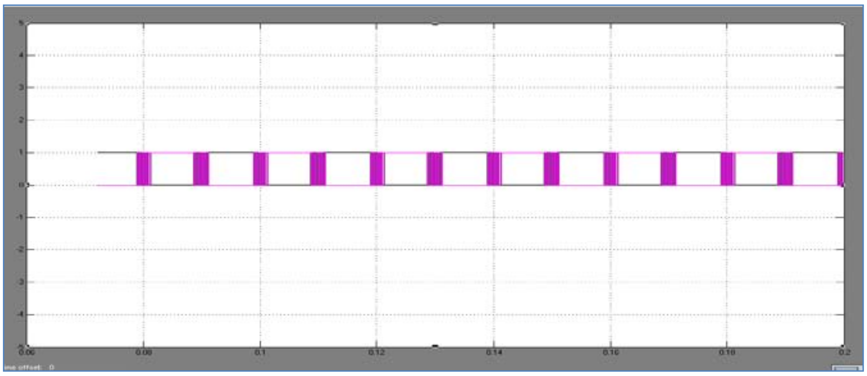


Figure 14: Gating Signal phase A

3.2.4 Peak Detector Method

Peak detector is used as an estimation of reference source current. On this part, the peak magnitude of reference current which the output of FLC will multiply with the unit sine vector in phase with the source voltage to generate the compensated current (reference current). The whole figure of the peak detector is presented on the Appendix C part 3.

3.2.5 Instantaneous PQ Theorem

PQ Theorem is based on αβ0 transformation which transforms three-phase voltages and current into αβ0 stationary reference frame. As a general, the transformed quantities which are the instantaneous active and reactive power of the load is calculated which consists of DC and AC components. The AC component is extracted using high-pass filter and taking inverse transformation to obtain compensation signal.

On this part, Instantaneous PQ Theorem is used to determine the references signal of for the PWM.

3.3 Tools and Equipment

3.3.1 Software

As the project is based on simulation the software tools, namely MATLAB/SIMULINK and FIS Editor are used.

CHAPTER 4

RESULT AND DISCUSSION

4.1 System Configuration

Figure 15 shows the schematic representation of FLC together with the SAPF in a distribution system

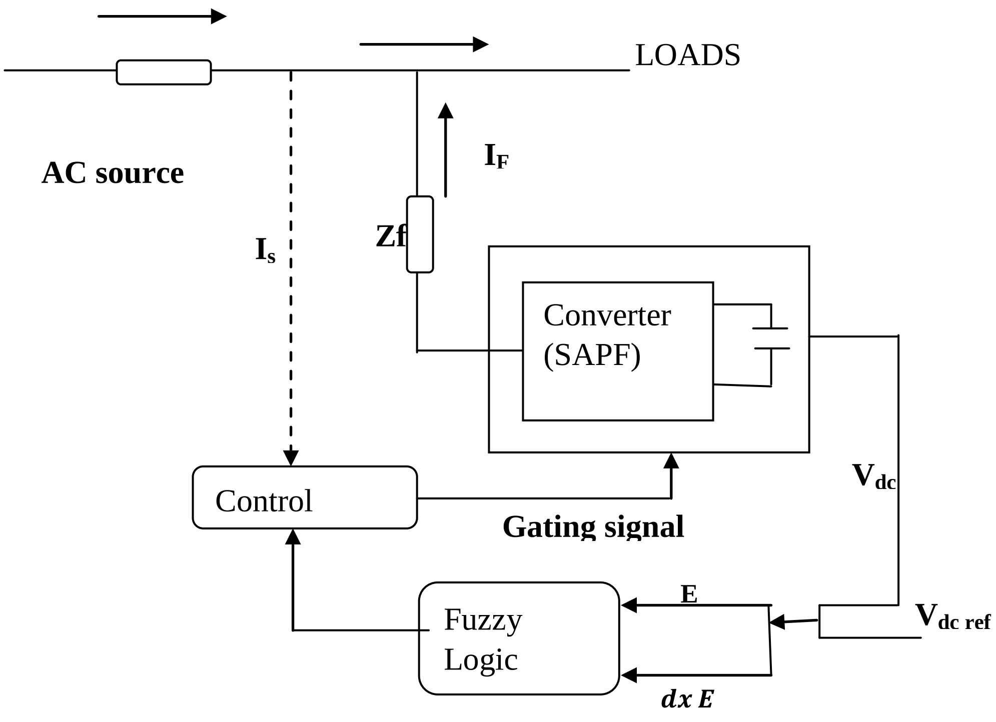


Figure 15: Schematic of Fuzzy Logic Controller and 3-Phase Shunt Active Power Filter

Table 3: Parameter for the Three Phase Shunt Active Power Filter

System Parameter	**Values**
Source Voltage (Vs)	*100V (peak)*
System frequency (f)	*50Hz*
Source Impedance (R_S ; L_S)	*0.1Ω ; 0.15mH*
Filter Impedance (R_C ; L_C)	*0.1Ω ; 0.66mH*
Load Impedance (R_L ; L_L)	*5Ω ; 20mH*
Reference DC Link Voltage	*220v*

The FLC is used to compare the V_{DC} from the DC capacitor with the voltage reference, Vref and then the resultant of voltage error and the calculated integral error as are given inputs for the fuzzy inference system. The voltage error ($E = Vref – Vdc$) and the change of error as inputs to FLC, and the output of the FLC is considered as a magnitude of peak reference current, Imax [14]. The peak detector method is used to determine the reference current. The output of the peak detector will be the input of the current controller which generated the PWM gate signal to the SAPF.

The goal of this project is to reduce the harmonic distortion by sensing the DC voltage of the capacitor and to compare with the DC reference voltage using FLC in order to produce the reference signal to be used in generating the gate signal. The complete model of the project is presented in Appendix C.

4.2 Results

4.2.1 *Fuzzy Logic Controller (FLC)*

The FLC is used to generate the peak magnitude of the desired current. This magnitude will be used to generate the compensating signal. The peak magnitude of the reference current is shown in Figure 16.

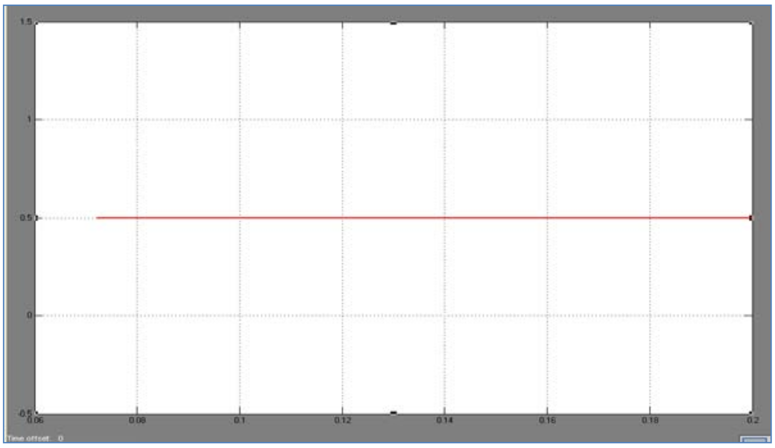


Figure 16: Peak Magnitude of reference current

The membership functions are defined using Takagi Sugeno's method in FLC. The author has defined all the parameters by using the Fuzzy Logic Toolbox that available in MATLAB. The parameters of the membership functions, as well as the rules that are used for generating the magnitude of current can be referred from Appendix D. The rule viewer and the waveforms of error and change of error is presented in Appendix E. The rules set which are defined based on trial and error method to get the desired magnitude of the reference current.

4.2.2 Peak detector Method

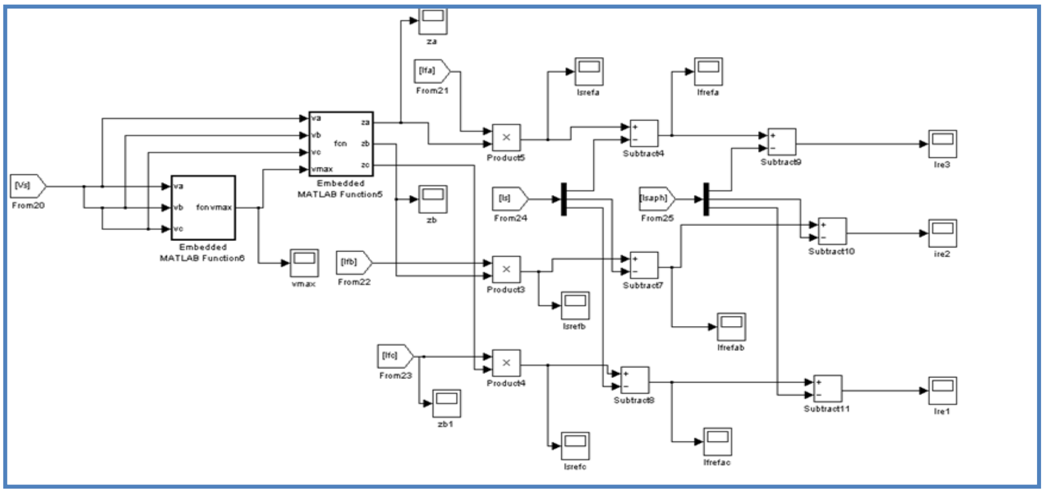


Figure 17: Peak Detector Method

The peak detector method will determine the reference current which is the input to the PWM current controller in order to produce the gating signals. The waveforms of compensated references signal is shown in Figure 18.

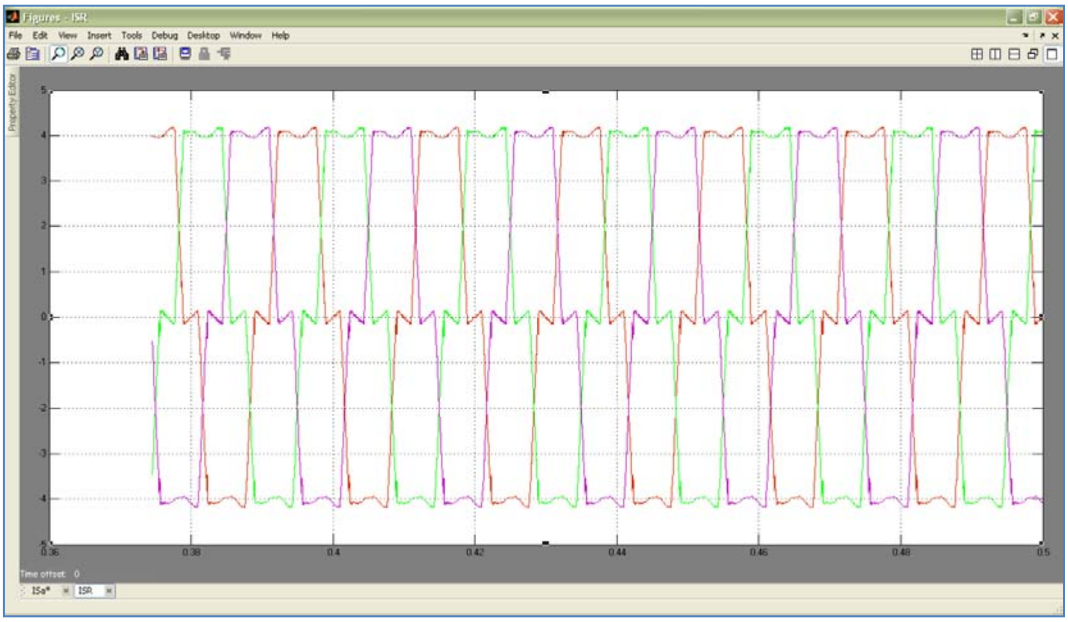


Figure 18: References current

Figure 19 and 20 shows the comparison between the harmonic current and the reference current. Both currents have same magnitude but different in phase. As in general, the function of current controller is to produce the reference current to be used for the switching of the IGBTs of the SAPF. From the Figure 19 and 20, the *blue circle* shows the phases for both current during 0.4 s. It shows that the phases of the waveforms are different.

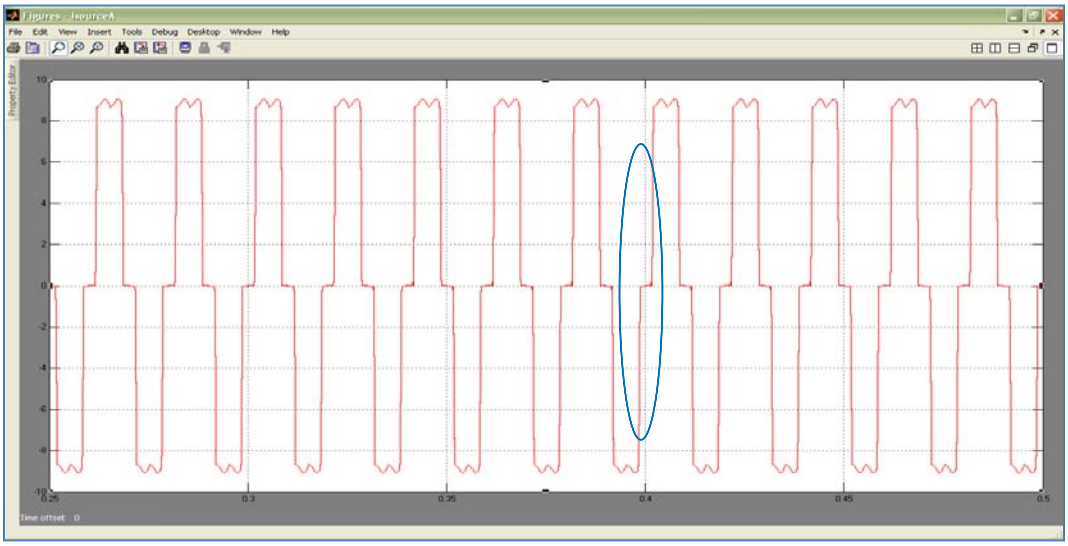


Figure 19: Source Current (Is)

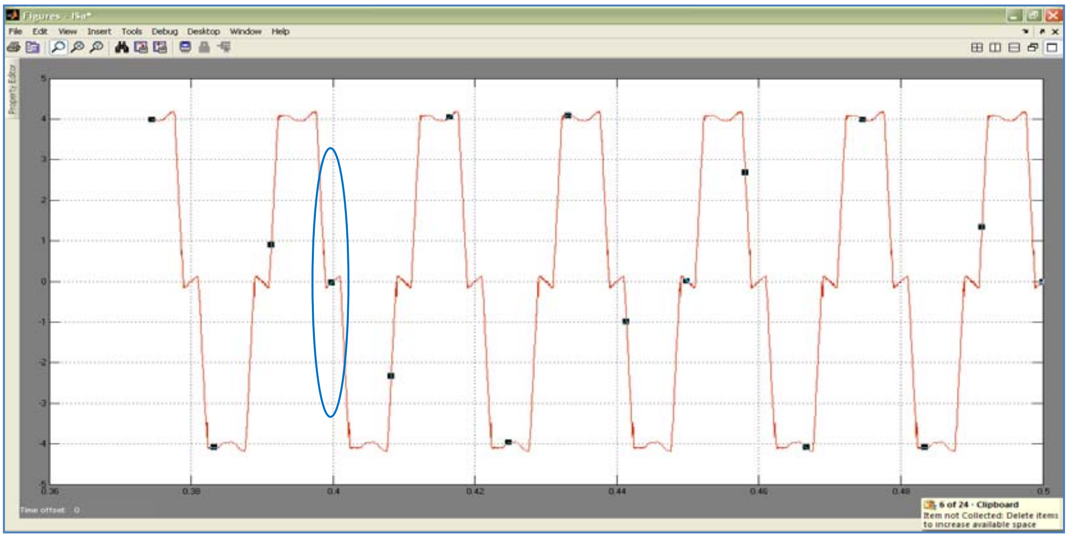


Figure 20: Compensating current

4.2.3 Instantaneous PQ Theorem

Besides that FLC, other method to produce the reference signal is using Instantaneous PQ Theorem. This method is able to reduce harmonics contamination in the distribution system. The simulation shows that Instantaneous PQ Theorem able to reduce 58 % of Total Harmonic Distortion (THD). By using this type of method, the THD of the system is decrease from 27.74 % to 11.63%. Figure 21 shows the waveform of the source current after instantaneous PQ theorem is implemented on the distribution system.

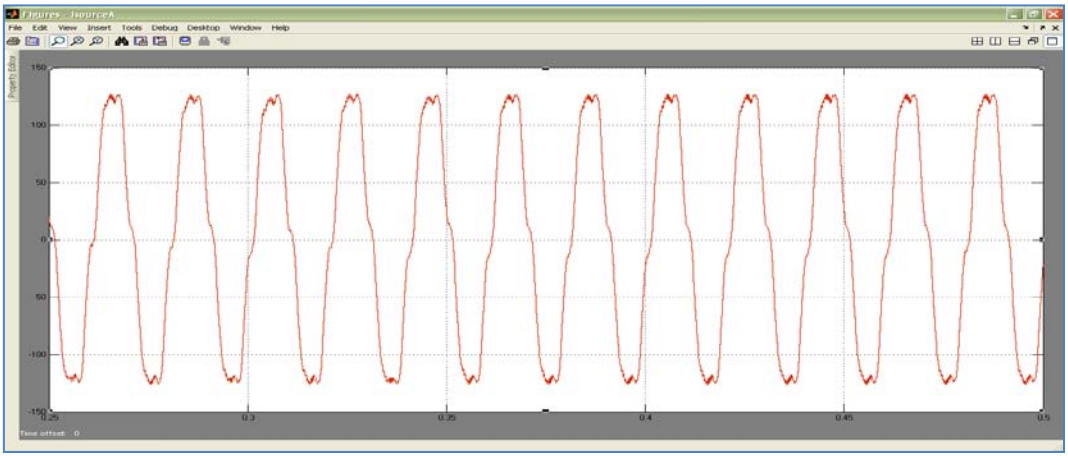


Figure 21: Source Current using PQ Theorem Method.

4.2.4 Total Harmonic Distortion (THD)

The harmonic distortion of the source current can be observed as shown in Figure 22, Figure 23 and 24. The source current waveform before injecting the compensating current will be compared with the waveform after injecting the compensating current. By comparing waveforms of the source current, the author is able to determine the efficiency of the SAPF in reducing the THD. Besides, the author is able to compare between the efficiency in reducing the THD based on two methods which are using Instantaneous PQ Theorem Method and FLC.

The results of simulation SAPF is shown in figures 25, 26 and 27. For Instantaneous PQ Theorem method the THD of the power lines has been decrease up to 58 %. In FLC, the THD of the power lines has been decrease up to 96 %. Without connecting with the SAPF, the THD of the power lines is around 27.74 %. The THD is smaller because on this project the author only uses 6-pulse Diode Bridge with the inductor and resistor in series at the output terminal as a non linear load.

Before Injecting Compensating Current

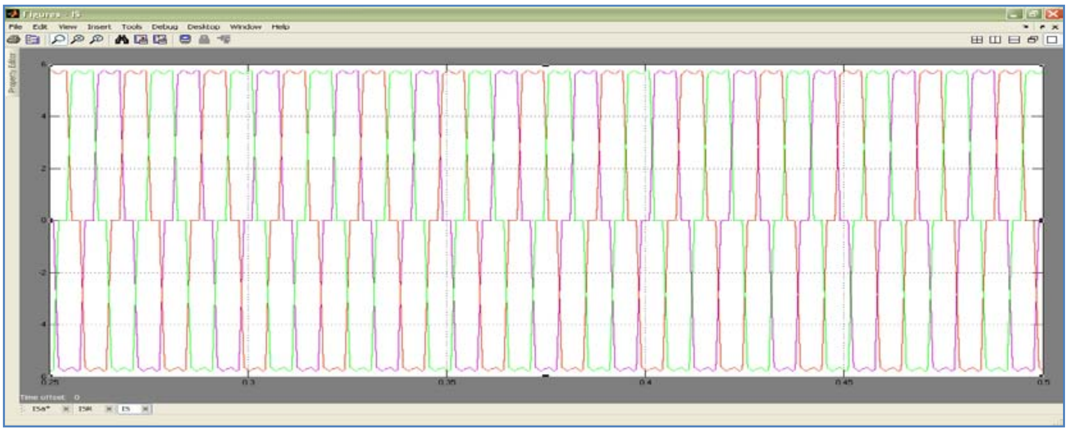


Figure 22: Source Current without filter

After Injecting Compensating

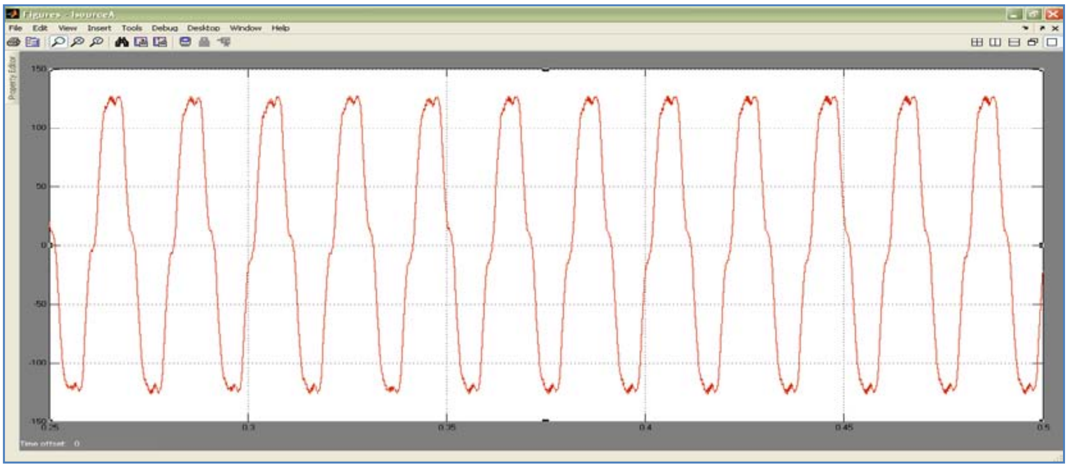


Figure 23: Source Current using PQ Theorem Method

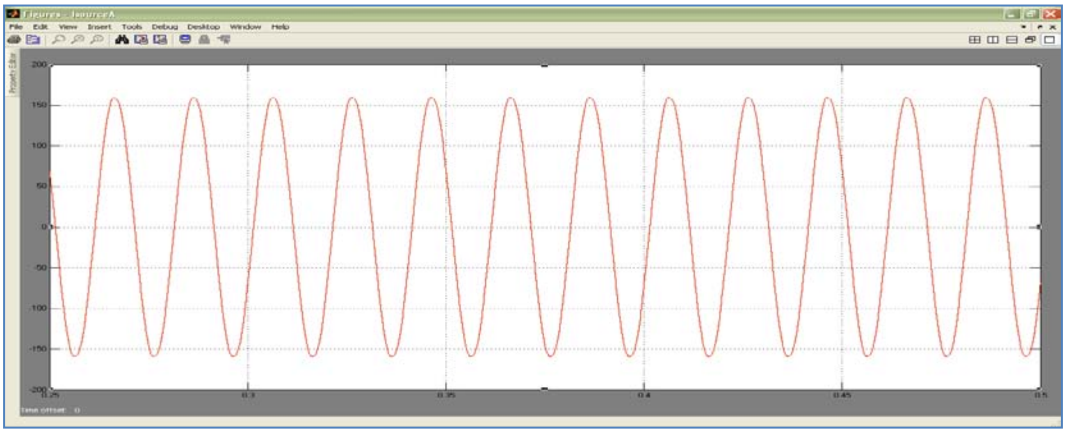


Figure 24: Source Current using FLC

From the figure above, it shows that both methods are able to reduce the harmonics contamination on power system to increase the efficiency of the system. The analysis of the result is been done using FFT analysis that is available in MATLAB/SIMULINK. The THD of the system without filtering the harmonics current is around 27.74 % that shows in Figure 24. The THD of the system using Instantaneous PQ Theorem is 11.63 % which is presented on Figure 25. In Figure 26, the THD of the system using FLC method is 0.98 %, it is prove that FLC method shows the greatest achievement in reducing the THD on distribution system.

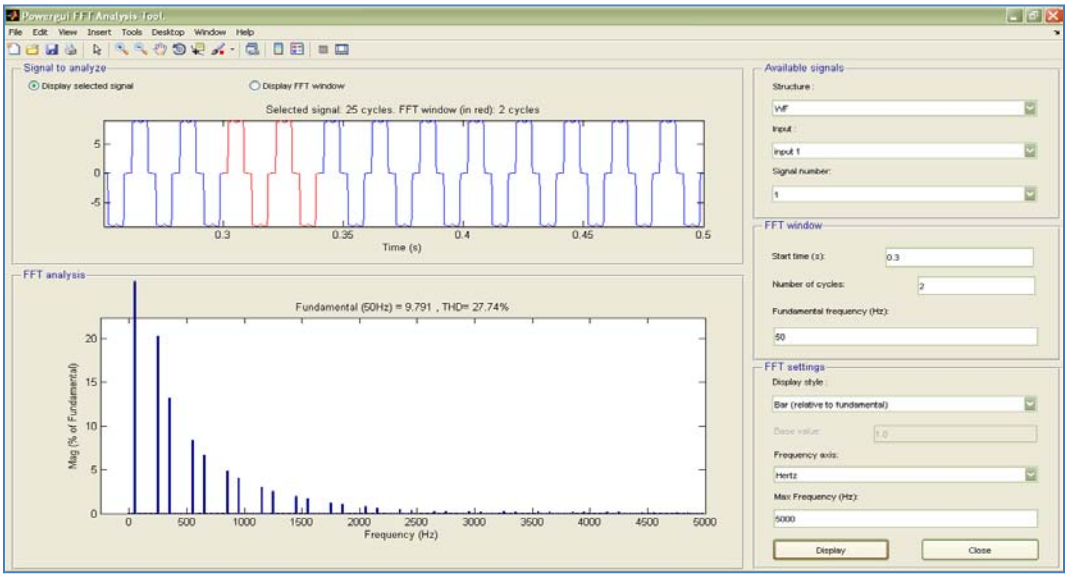


Figure 25: THD of the Source Current without SAPF (27.74 %)

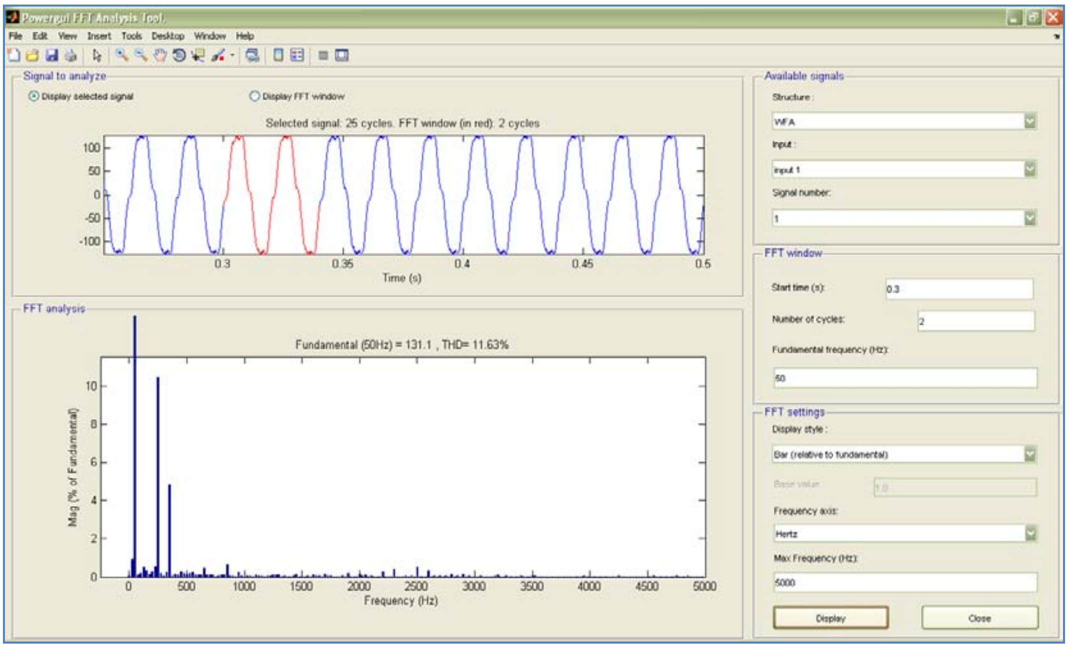


Figure 26: THD of the Source Current with SAPF using PQ Theorem (11.63%)

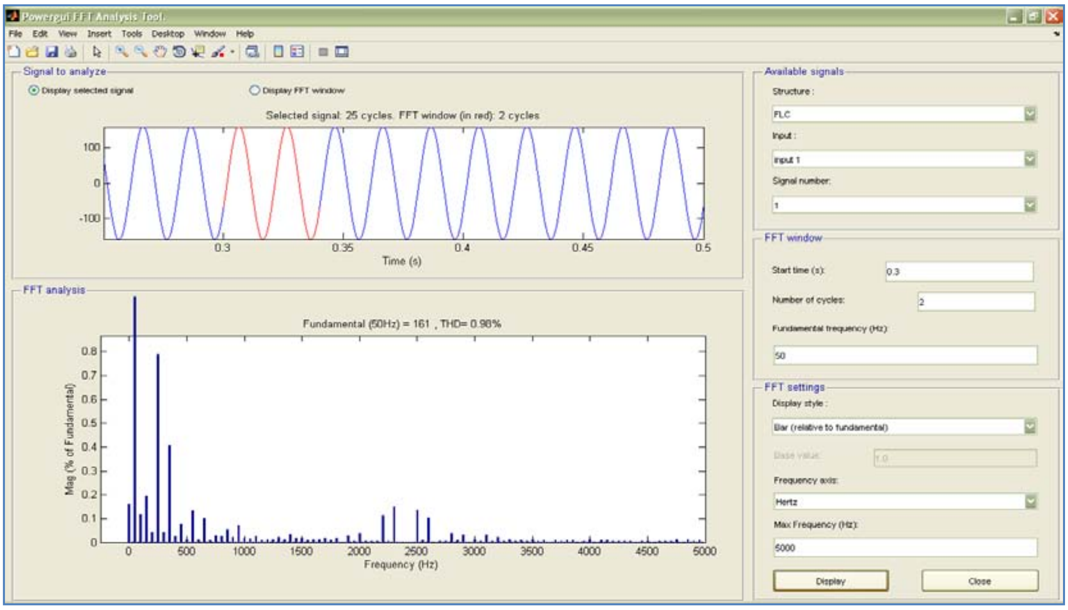


Figure 27: THD in Source Current with SAPF using FLC (0.98 %)

4.3 Discussion

The objective of the project in reducing the harmonic distortion in power lines that is caused by the non-linear loads has been reached and the results show 96 % of reducing in THD.

For this project, the author has been design two types of method in generating the reference current which are the Instantaneous PQ Theorem and Fuzzy Logic Controller. From the simulation, it shows that using Fuzzy Logic Controller has better performance than Instantaneous PQ Theorem in reducing THD. The result shows by using Fuzzy logic Controller the THD is reduce up to 96 % which from 27.74 % of THD drops to 0.98%.

Rather than using PQ Theorem, the THD only reduce up to 58 % which from 27.74% to 11.63%. By compared between these two methodologies, the author has been proved that using FLC is better than Instantaneous PQ Theorem. It is because the FLC is able to maintain the DC side capacitor voltage at the SAPF to its reference values to recover the energy losses due to the conduction and switching power losses associated with the electronic switches such as the IGBT at the filter.

From the simulation of the PQ theorem and FLC, it shows that FLC is able to deal with the complexity and nonlinearity of the system. Besides, FLC also able to deal with imprecise input as well as they are more robust that others conventional method. In general PQ Theorem is used mathematical model to produce the references current, where the current and voltage will undergo αβ0 transformation. These transformation quantities are the instantaneous active power and reactive power which consist of DC and AC components. The AC components are extracted using high pass filter and takes inverse transformation in order to obtain the references signal. Differ from FLC, this method used human though or human intuitive in producing the references signal. FLC are consisting of four stages which are fuzzification, knowledge base, fuzzy inference and defuzzification. Basically, the inputs will be fuzzified from the crisp values to the fuzzy sets. The next stage will be defining the membership functions of the project. For the simplicity of the design, the author has been choosing triangular shaped for both inputs. The output of the fuzzy logic is using trial and error, until get the satisfaction result. After defined the membership functions, the next step will be design the rules of the system. The last step is defuzzification where the fuzzy output will be converted to the numerical values. In this project, the output of the FLC is the magnitude of the references current.

As a general, the objective of the project has been achieved by modeling the distribution system with SAPF which consists of the power system lines with the three-phase source and non linear load. A six-pulse diode bridge is used as a non- linear load for the system. The author has also developed the FLC block to generate the magnitude of the desired source current. The input for the FLC is the DC side voltage of the capacitor of the SAPF and a reference voltage of 220 V is considered. Lastly, the peak detector block is developed which is used to generate the gating signals. The peak detector will multiply the magnitude with the unit of sine vectors in phase with the source voltage.

From the result, the author is able to prove that using FLC as one way to maintain the DC side capacitor which increases the efficiency of the SAPF while reducing the harmonic contamination. This FLC is used to maintain the DC side capacitor voltage to its reference value which is to cover the reduced voltage caused by the energy losses due to the conduction and switching power losses associated with the electronic switches such as the IGBT at the filter.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

As mentioned earlier in this report, the main objective of this project is to use Fuzzy Logic Controller to optimize the function of the Shunt Active Power Filter to reduce the harmonic distortion. The Fuzzy Logic Controller for the three-phase Shunt Active Power Filter is designed to replace the conventional Proportional Integral Derivative controller in order to reduce the harmonic current as well as to increase the power factor to unity.

Simulation is carried out on a distribution system provided with a Shunt Active Power Filter and Fuzzy Logic Controller. The power system model is simulated using MATLAB/SIMULINK

The results simulation of this project shows that, the author is able to reach the objective of this project by reducing the Total Harmonic Distortion by 96 %. The result shows that by using Fuzzy Logic Controller to sense the DC side capacitor voltage a constant DC voltage will be maintain. Fuzzy Logic Controller produce the magnitude reference current and peak detector method is used to produce the reference signal as an input for the current controller.

Pulse Width Modulation as current controller is used to generate gating signals to control the electronics switches in the SAPF. The SAPF will produced the compensating current that necessary has the same magnitude as source current but different in phase. The simulation result have proved to validity of employing Shunt Active Power Filter with Fuzzy Logic Controller in distribution system as the THD is reduce from 27.74% to 0.98%.

5.2 Recommendations

For this project, some improvement can be made in order to improve the results of the future works. Best result for reducing the harmonic distortion can be achieved by using Adaptive Hysteresis Current Controller or Fuzzy Adaptive Hysteresis Current Controller rather than Pulse Width Modulation (PWM) Current Controller to produce the gating signals to control the electronics switches on the filter. Beside than that, the best result may be achieved by defining rules of Fuzzy Logic Controller with knowledge as well as experiences of the designer.

Figure 28 is one of the suggested designs to improve the efficiency of the distribution system in power system.

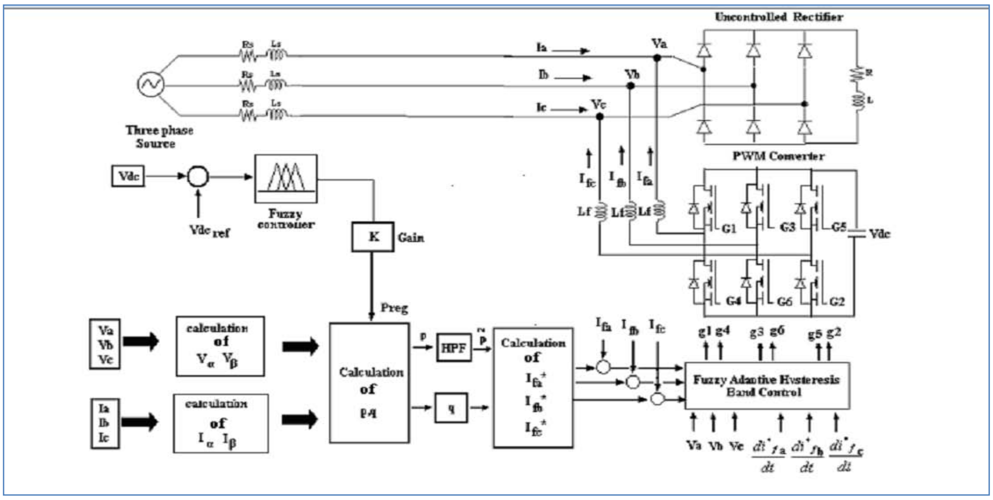


Figure 28: Fuzzy Logic- Adaptive Hysteresis Band and DC Voltage Control in SAPF [14]

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APPENDIX A

GANTT CHART FOR FYP 2

			JUL	AUGUST				SEPTEMBER				OCTOBER				NOV-DEC				
No.	**Task Name**	**Duration**	**1**	**2**	**3**	**4**	**5**	**6**		**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16-18**	**20**
1	Resolve the problems encountered during FYP 1																			
2	Generate the Vdcref and experiment on FLC								M											
3	Preparation for Progress Report 1								I											
4	Submission of Progress Report 1								D										E	
5	Works on FLC to define the rules																		X	
6	Works on Peak Detector Method								S											
7	Preparation for Progress Report 2								E										A	
9	Submission of Progress Report 2								M										W	
10	Complete all the entire model																		E	
11	Pre-EDX Exhibition (Wednesday Week 11)																			
12	Developed System								B										E	
13	Preparation for the Final Report								R										K	
14	Submission Draft of Final Report								E											
15	Submission Final Report (Soft copy) and Technical Report								A											
16	Oral Presentation (week 18)								K											
17	Submission Final Report (Hard Bound)																			

SAF : Shunt Active Power Filter **FLC : Fuzzy Logic Controller**

APPENDIX B

GANTT CHART FOR FYP 1

			JAN	FEB				MAC				APRIL				MEI - JUN				
No.	**Task Name**	**Duration**	**1**	**2**	**3**	**4**	**5**	**6**	**7**		**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16-18**	**19-20**
1	Selection & Confirmation on topic	2 days																		
2	Research Reading on Fuzzy Logic and Active Filter	10 days								**M**										
3	Preparation for Preliminary Report	3 days								**I**										
4	Submission of Preliminary Report	1 day								**D**									**E**	
5	Assemble data & study on Fuzzy logic controller and SAF	30 days																	**X**	
6	Learning the MATLAB - FLC Toolbox	30 days																		
7	Submission Progress Report	1 day								**S**									**A**	
9	Design the FLC	10 days																	**W**	
10	Modelling the design on the MATLAB	7 days								**B**									**E**	
11	Seminar	3 days								**R**									**E**	
12	Designing the PQ theorem transformation	10 days								**E**									**K**	
13	Preparation for Interim Final Report	7 days								**A**										
14	Submission of Interim Final report	1 day								**K**										
15	Oral Presentation	1 day																		

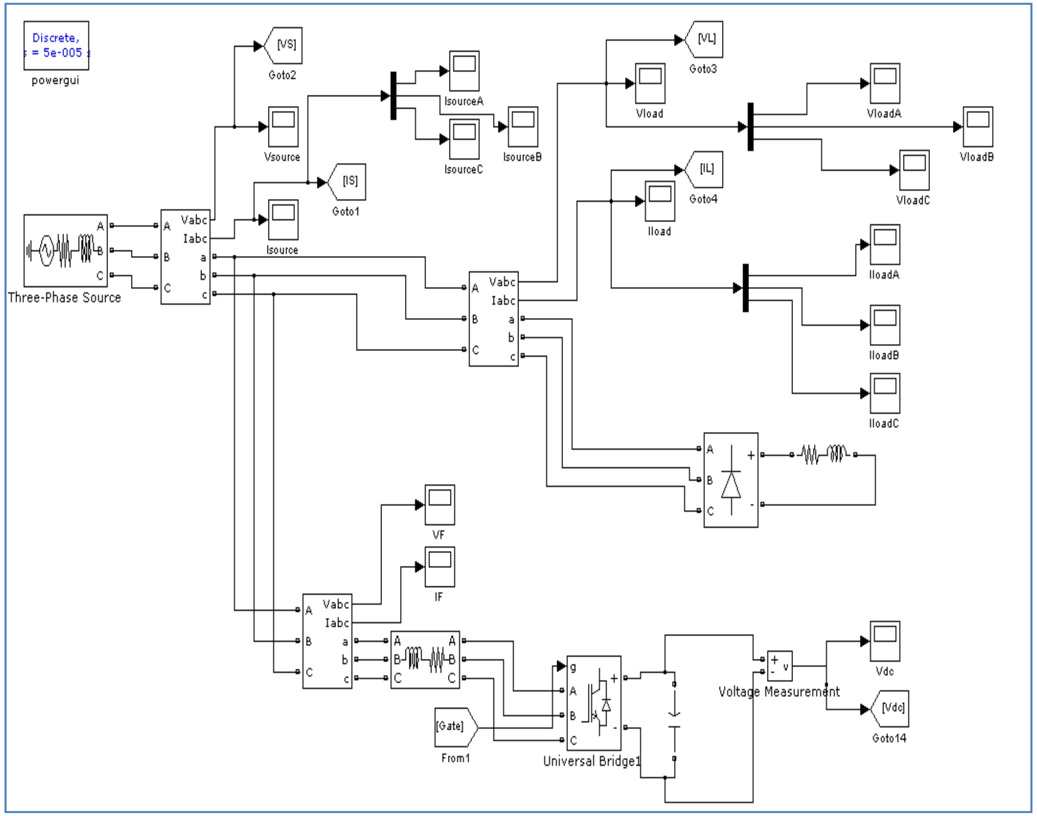
SAF : Shunt Active Power Filter

FLC: Fuzzy Logic Control

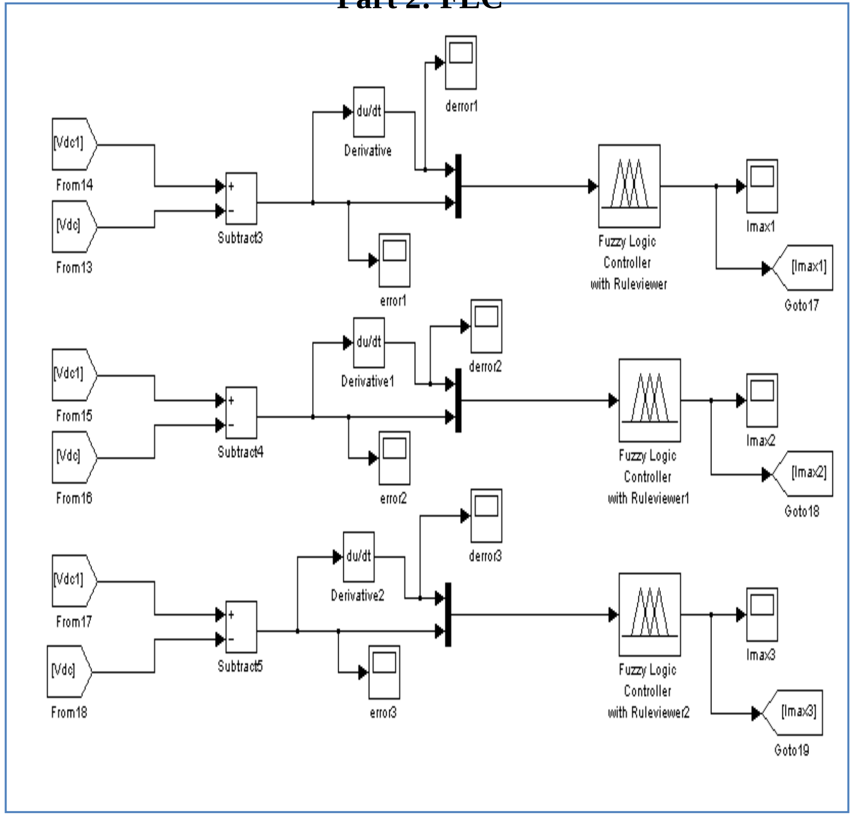
APPENDIX C

Model of the Fuzzy Logic Controller for Three Phase Shunt Active Power Filter

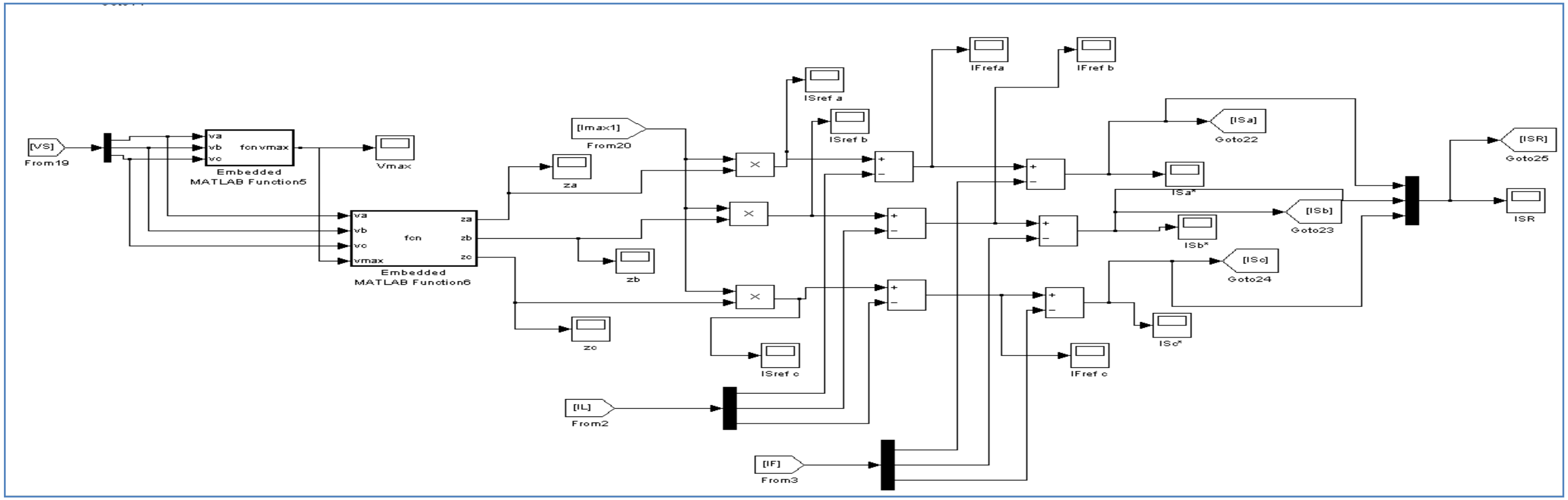
Part 1



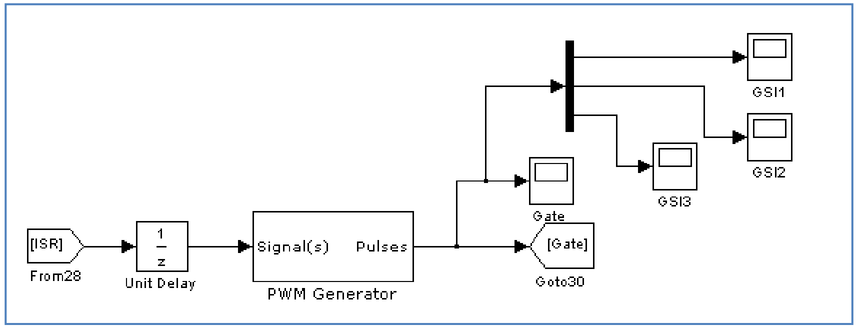
Part 2: FLC



Part 3: Peak Detector Method



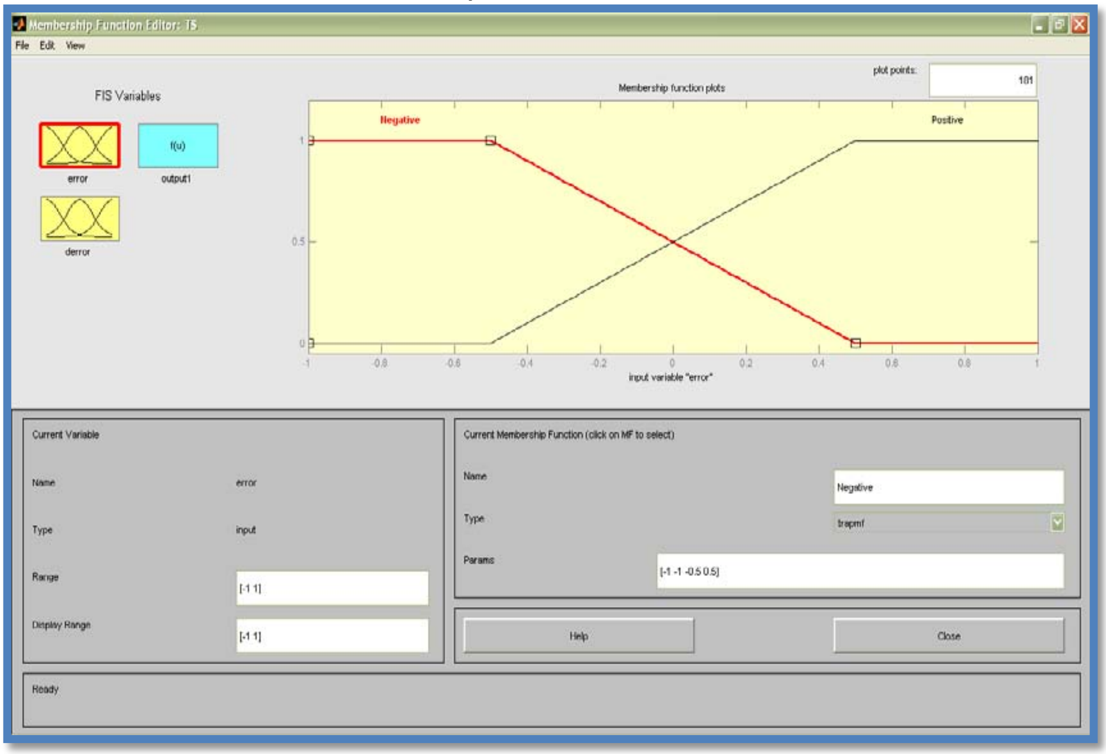
Part 4: PWM Controller



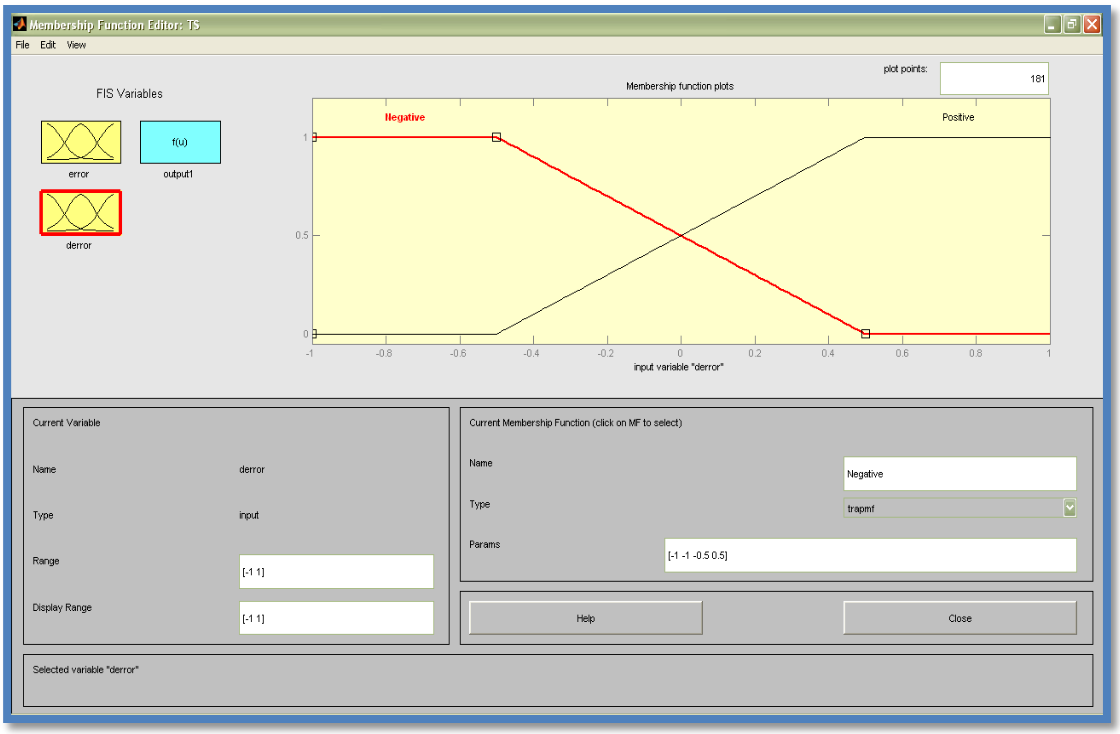
APPENDIX D

Fuzzy Logic Controller

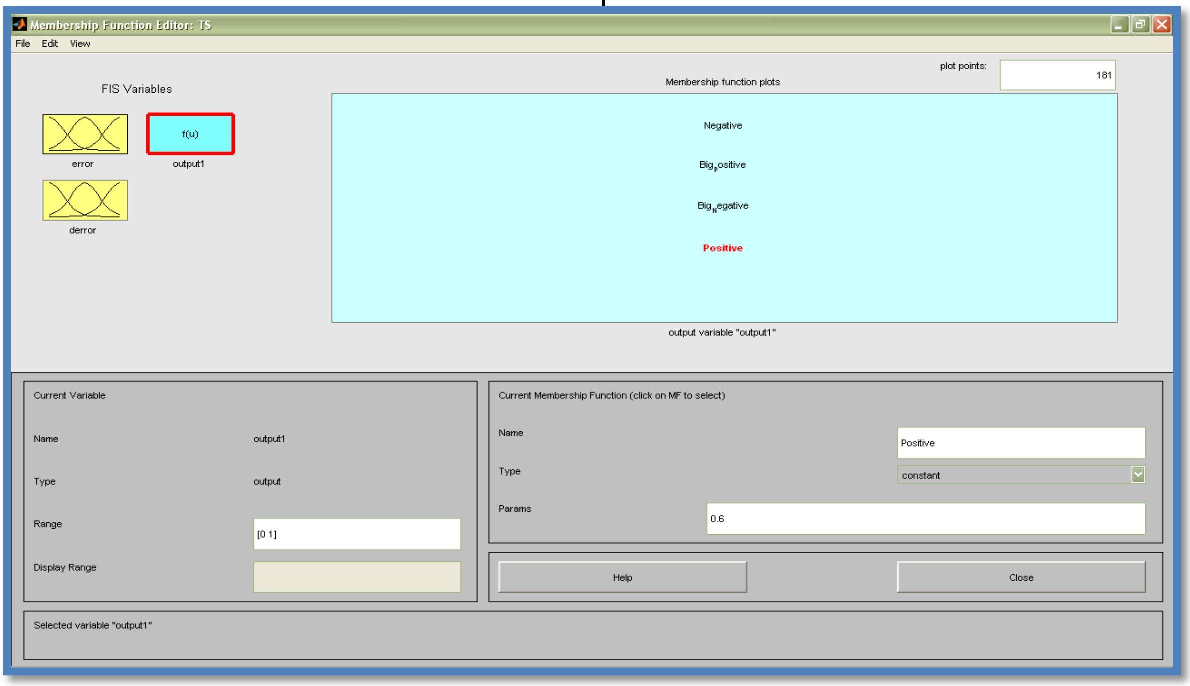
Input 1: Error



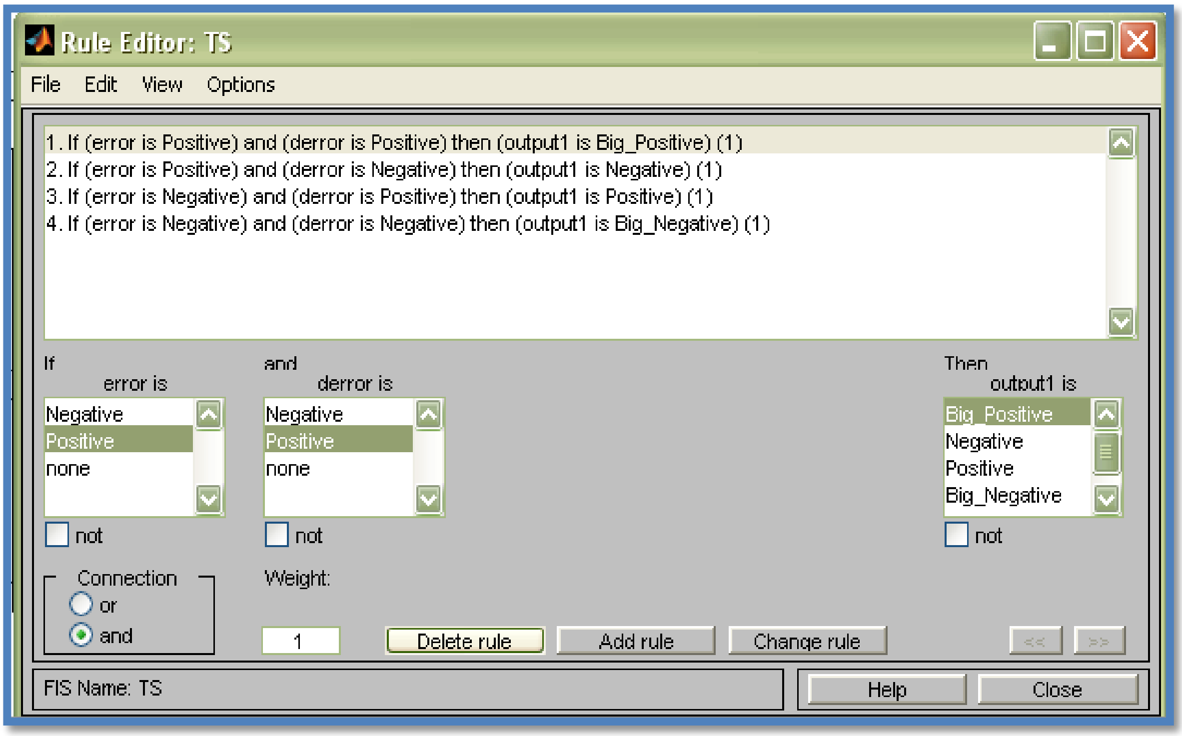
Input 2: Change of Error



Output



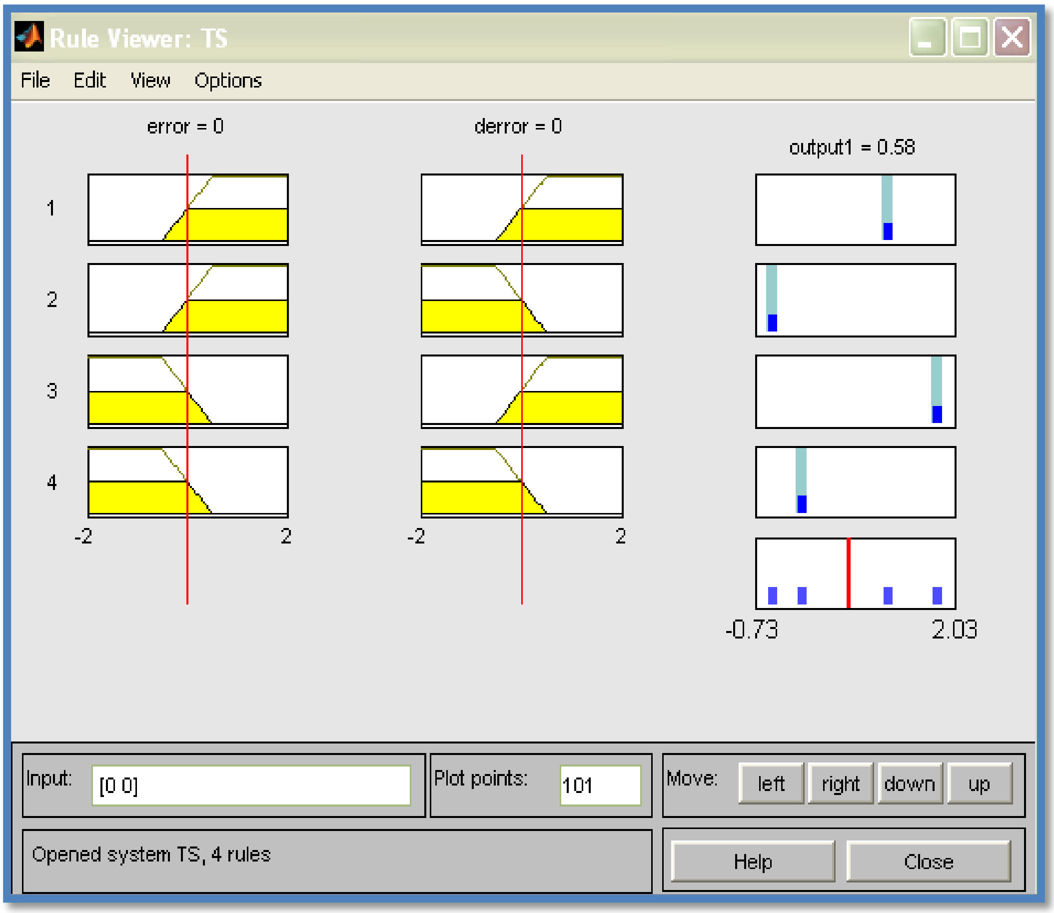
Rule Editor



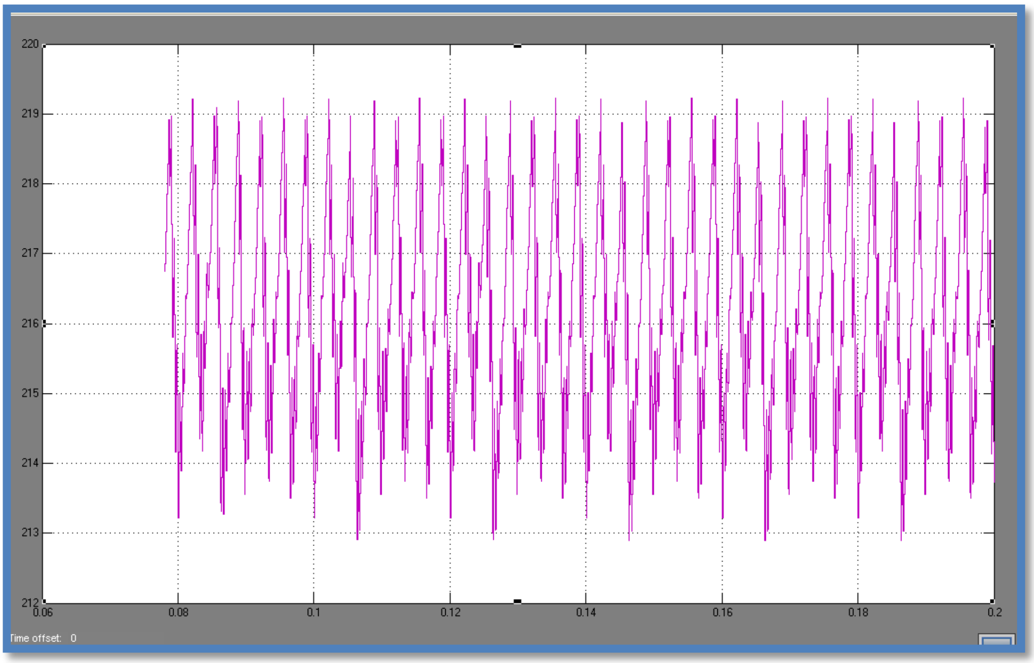
APPENDIX E

Fuzzy Logic Controller Result

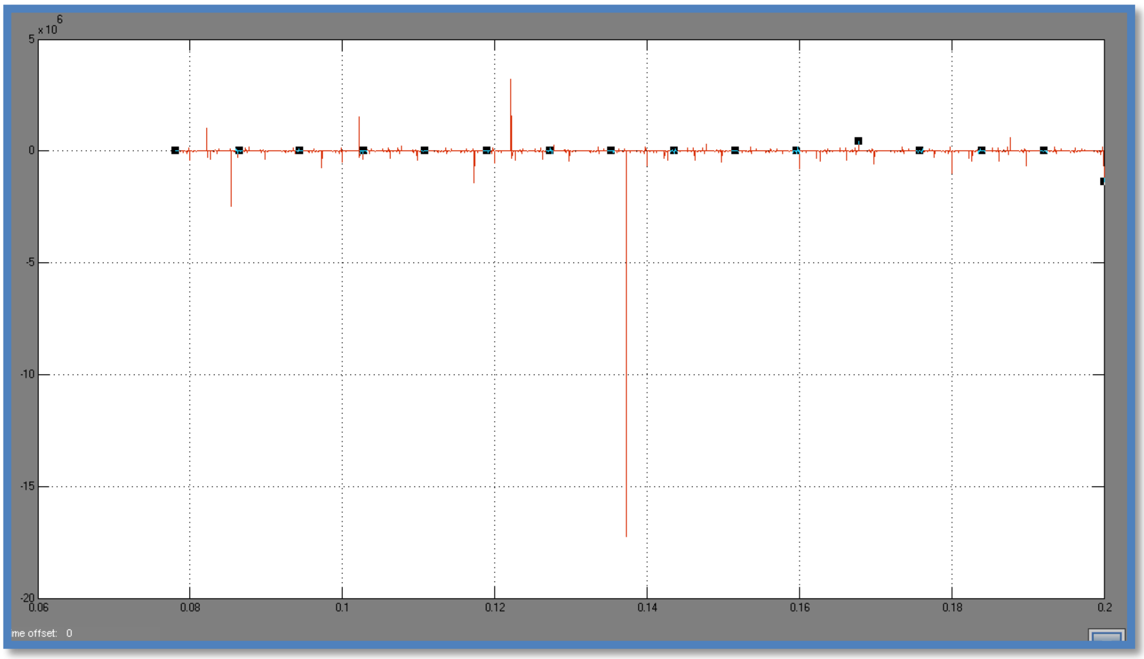
Rule Viewer



Error (Waveform)



Change of Error (Waveform)



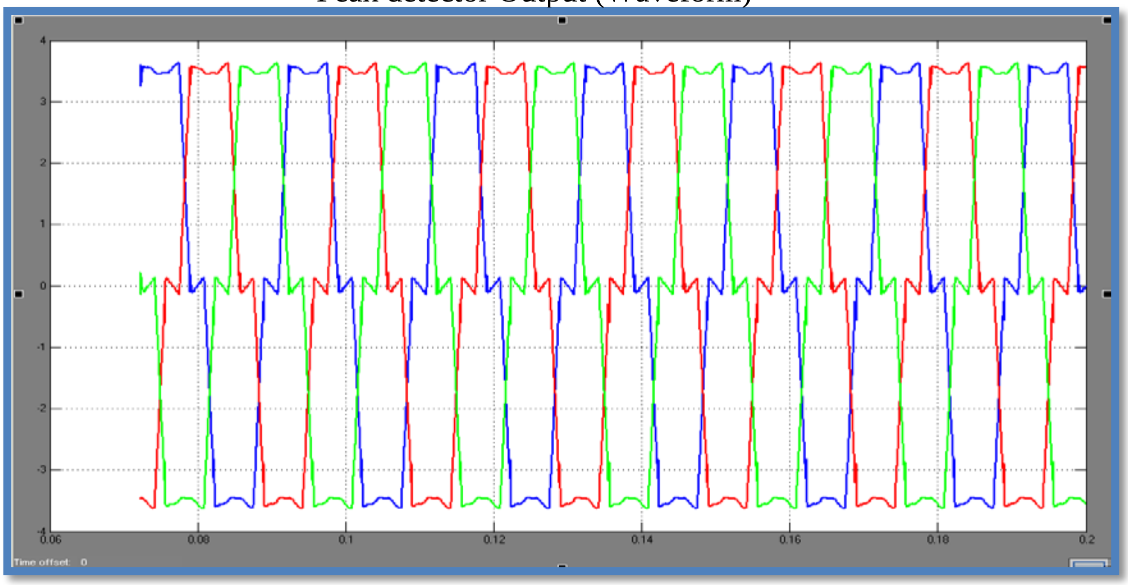
Appendix F
Peak Detector Method

Calculation for Peak Detector

```
function vmax  = fcn(va, vb, vc)

%#eml

vmax = sqrt((2/3)*(va.^2+vb.^2+vc.^2))
```

```
function  [za,  zb,  zc]   = fcn(va,  vb,  vc,
vmax)

%#eml

za = (va/vmax);
zb = (vb/vmax);
zc = (vc/vmax);
```

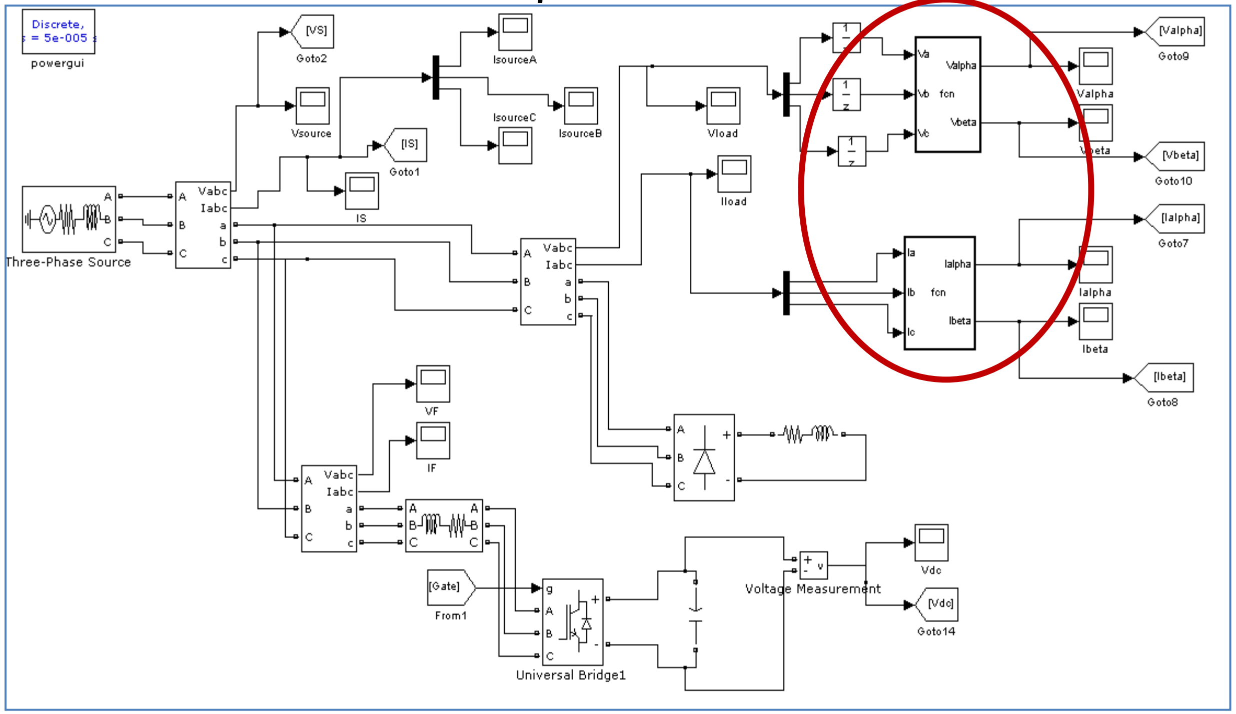
Peak detector Output (Waveform)



APPENDIX G

Model for Instantaneous PQ Theorem

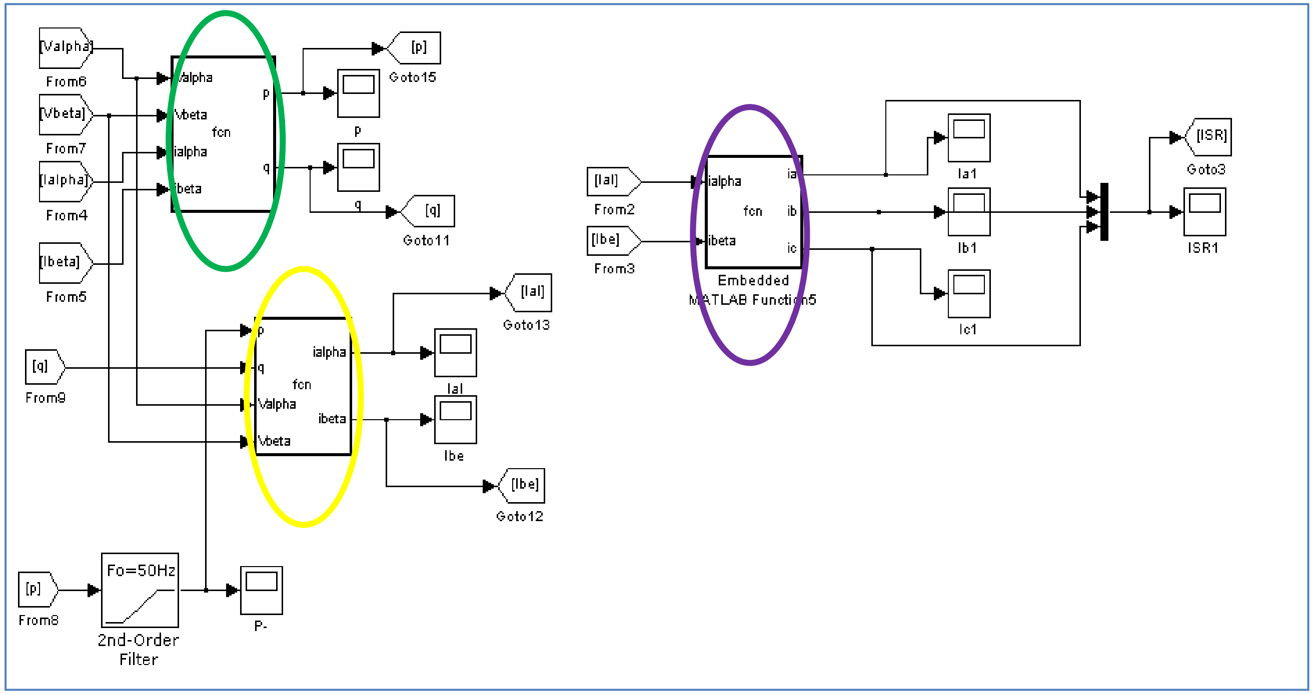
Part 1: αβ0 transformation




```
function [Valpha,Vbeta] = fcn(Va,Vb,Vc)
%#eml

Valpha    =    2/3*(u*sin(wt)+i*sin(wt-
2*pi/3)+o*sin(wt+2*pi/3));
Vbeta     =    2/3*(u*cos(wt)+i*cos(wt-
2*pi/3)+o*cos(wt+2*pi/3));
Vo = 1/3*(u+i+o);
```

```
function       [Ialpha,Ibeta]       =
fcn(Ia,Ib,Ic)
%#eml

Ialpha  =  2/3*(u*sin(wt)+i*sin(wt-
2*pi/3)+o*sin(wt+2*pi/3));
Ibeta   =  2/3*(u*cos(wt)+i*cos(wt-
2*pi/3)+o*cos(wt+2*pi/3));
Io = 1/3*(u+i+o);
```

Part 2: Inverse Transformation and Extract the AC




```
function      [ialpha,ibeta]          =
fcn(p,q,Valpha,Vbeta)
%#eml

mat= [Valpha Vbeta; Vbeta -Valpha];
%matrix= inv(mat);
matpwr= [-p;-q];
%matrix=matpwr.^-1;
cur= mat*matpwr;
current=(1/(Valpha.^2+Vbeta.^2))*cur
;
ialpha= current(1,1);
ibeta= current(2,1);
```

```
function        [p,q]                =
fcn(Valpha,Vbeta,ialpha,ibeta)
%#eml

p =(Valpha*ialpha)+(Vbeta*ibeta);
q =(Valpha*ibeta)-(Vbeta*ialpha);
delta= (Valpha.^2)+(Vbeta.^2);

ialphap=(Valpha*p)/delta;
ibetaq=(Vbeta*p)/delta;
```

```
function [ia,ib,ic]  = fcn(ialpha,ibeta)
%#eml


mat= [ialpha;ibeta];
matrix= [1 0; -1/2 sqrt(3)/2; -1/2 -sqrt(3)/2];
inew= matrix*mat;
iabc=sqrt(2/3)*inew;

ia= iabc(1,1);
ib= iabc(2,1);
ic= iabc(3,1);
```