FINAL YEAR PROJECT II

FINAL REPORT

Modelling and Simulation of Parallel/Series Hybrid Filter to Achieve Active Resonance Damping

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September 2014

CERTIFICATION OF ORIGINALITY

Certification of originality is to certify my responsibility on the paper submitted for this project, which that the work comes from my own unless it is specified in the references or acknowledgements. It is also to certify that the original work contained within this paper has not been undertaken or used by unspecified person or sources.

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NOR AMIRAH AFIQAH YAZID

CERTIFICATION OF APPROVAL

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Nor Amirah Afiqah binti Yazid

A project dissertation submitted to
Electrical and Electronic Engineering Department
Universiti Teknologi PETRONAS

In partial fulfillment of the requirements for the

BACHELOR OF ENGINEERING (Hons)

(ELECTRICAL AND ELECTRONIC ENGINEERING)

Approved :

- -
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UNIVERSITI TEKNOLOGI PETRONAS
September 2014

ABSTRACT

Hybrid power filters is widely known and acknowledged in the field of power quality improvement especially in mitigating harmonics and compensating the reactive power. Since it is the combination of the passive and active filter in a circuit, it is not only simple, but also found to be cost-effective. It has been tested in various scale of power distribution network and proven to be working efficiently. The quality of the power transferred to the load in improved by mitigating the harmonics and damping out the resonances present. This paper is discussing the most suitable and applicable type of hybrid filter for both of the case studies ; the small distribution network of source 630 kVA 400V and the wind farm with capacity of 2MW for each of the 20 wind turbines. Classified references presented in this paper would serve for a quick reference.

ACKNOWLEDGEMENT

First and foremost, the author would like to express the deepest gratitude to Allah S.W.T for gives strength and with His blessing the author managed to complete the Final Year Project.

The author would like to express greatest appreciation to her supervisor Mdm. Khairul Nisak Md Hasan for giving support and guidance by means of sharing her thought and knowledge throughout the completion of the project.

Many thanks and appreciation also goes to Universiti Teknologi PETRONAS especially Electrical and Electronic Engineering Department that have contributed directly and indirectly by providing the necessary assets and resources to the success of this Final Year Project.

Last but not least, the author would like to express a special thanks to her friends and family members for their priceless support, encouragement, valuable advices, and their understanding. Without all of them, the author would not be here where she is standing right now. Thank you very much.

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ABBREVIATION AND NOMENCLATURES

AC	*: Alternating Current*
APF	*: Active Power Filter*
HAPF	*: Hybrid Active Power Filter*
PCC	*: Point of Common Coupling*
RMS	*: Root Mean Square*
WPP	*: Wind Power Plant*

CHAPTER ONE : INTRODUCTION

1.1 BACKGROUND STUDY

The problem of power systems harmonics is not a new phenomenon by any means. Most people don't realize that harmonics have been around for a long time. It is as old as the power network itself, with the first studies on the subject traced back to the 1890's, which is more than 100 years ago. It is since the first usage of the AC generator that the electrical systems have experienced harmonics, and where transformers and rotating machinery were identified to be the main source of waveform harmonic distortion. However, the harmonics at that time was considered as minor problem with no detrimental effects in the network [1].

Nowadays, the usage of electronic converters, transformers and capacitor bank in power network, which constantly widen may also form a resonance circuit and cause large voltage distortions, overvoltage and high harmonic current. Prior to the installation of the transmission line, reactive power compensation equipment and power factor correction devices, and changing of system configuration in the distribution network such as Wind Power Plant (WPP), a harmonic analysis must be performed to ensure that resonance frequencies do not coincide with prominent harmonic components contained in the voltages and currents which can lead to severe harmonic resonances.

1.2 PROBLEM STATEMENT

Harmonic series resonance and harmonic parallel resonance occurs when there are capacitive and inductive element present within a system network. It is important for the harmonic resonances to be damped and mitigated as the parallel resonance can result in an amplification of the harmonic voltage distortion while the series resonance can further increase the high harmonic current at the resonant frequency. A certain amount of harmonic current and voltage can lead to equipment damage, malfunction, life-losses, and several other types of problems which can interfere with the other part of the network. It is also unacceptable if the standard limit set by the network operator which follows the international standard is exceeded due to the unsolved harmonic resonance issue.

In the big network such as WPP, it is even more important to ensure that there is no dangerous resonance present and avoid the propagation of harmonic into the grid-side. There are several method suggested in order to solve the harmonic resonance problem. One of the method is by implementing a resistance into the network. However, adding a resistance can lead to the power loss in the network. Passive filter alone is widely known to be used for mitigating harmonics, but it is only applicable for significant and low order harmonic and not reliable to completely damp the resonance. In some cases, passive filter elements form another resonances peak with the system impedance which can deteriorate the performance. The other possible solution is by applying an active damping. Active damping can be achieved with the implementation of the active and passive filter combined together, which also known as hybrid filter[2-3]. Plenty of studies shown that the hybrid filter is good for mitigating harmonic and resonance damping. The ability to solve these issues is very appealing and useful in the network system nowadays.

1.3 OBJECTIVES

i. **To analyze the common type of hybrid filter.**
   - Few common types of hybrid filters are selected based on the configuration of the passive and active filter either series or parallel.

ii. **To simulate and implement the reliable type of hybrid filter into the case studies provided.**
   - Simulate and implement the hybrid filter selected on the case studies provided which are small distribution network and an aggregated wind farm.

iii. **To analyze the performance of the filter implemented.**
   - Analyze the performance of the filter based on its damping capability on the case studies assigned.

1.4 SCOPE OF STUDIES

The study covers mainly on the scope Energy and Power field, focusing on the power quality improvement which by mitigating harmonics and at the same time compensating the reactive power. The research is fixed on a small distribution network and an aggregated wind farm with the specific amount of power, voltage and current source applied. The studies related to the project includes :

- The types of the harmonic resonances
- The causes and effects of harmonic resonance in a system network
- Commonly-used types of hybrid filter configuration
- Filtering control strategies
- Effects of the filter implementation in the network

CHAPTER TWO : LITERATURE REVIEW

2.1 RESONANCE

A network represents either series or parallel resonance circuit with the presence of capacitances, inductances, and resistances in it. Series resonances occurs in a series RLC circuit where there are equal inductive and capacitive reactance, so that the circuit impedance is low and a small exciting voltage will result in large current. Analogously, parallel resonance occurs in a parallel RLC circuit where the inductive and capacitive reactance are equal , which results in low circuit admittance and small exciting current, and thus developing a large voltage. Both arrangement are frequently found in the electrical power system network which enable their behavior to be analyzed in order to identify the harmonics and interharmonics in the current and voltage waveform, where harmonics are the components with frequencies that are multiples of the supplied fundamental frequency while interharmonics are defined as components having frequencies located between the harmonics of the supplied frequency [4-6].

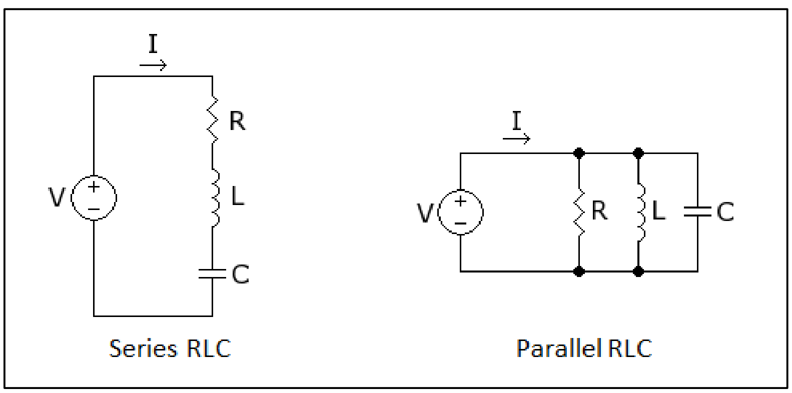


Figure 2.1 : Series and parallel resonance circuit

Theoretically, the resonance occurs when the capacitive reactance is equal to the inductive reactance

$$X_{Lr} = X_{Cr}$$

$$\omega_r L = \frac{1}{\omega_r C}$$

$$\omega_r = \frac{1}{\sqrt{LC}}$$

and at a resonant frequency.

$$f_r = \frac{1}{2\pi\sqrt{LC}} = \frac{f_o}{\omega_o\sqrt{LC}} = f_o\sqrt{\frac{X_c}{X_L}}$$

Thus, the harmonic order at resonance is

$$h_r = \frac{f_r}{f_o} = \frac{1}{\omega_o\sqrt{LC}} = \sqrt{\frac{X_C}{X_L}}$$

2.2 HARMONICS

A pure sinusoidal voltage is a conceptual quantity produced by an ideal AC generator built with finely distributed stator and field windings that operate in a uniform magnetic field. Since neither the winding distribution nor the magnetic field are uniform in a working AC machine, voltage waveform distortions are created, and the voltage-time relationship deviates from the pure sine function. The distortion at the point of generation is very small but nonetheless it exists. Because this is a deviation from a pure sine wave, the deviation is in the form of a periodic function, and by definition, the voltage distortion contains harmonics [7].

When a sinusoidal voltage is applied to a certain type of load, the current drawn by the load is proportional to the voltage and impedance and follows the envelope of the voltage waveform. These loads are referred to as linear loads, where the voltage and current follow one another without any distortion to their pure sine waves.

In contrast, some loads cause the current to vary disproportionately with the voltage during each half cycle. These loads are classified as nonlinear loads, and the current and voltage have waveforms that are non-sinusoidal, containing distortions, whereby the 60-Hz waveform has numerous additional waveforms superimposed upon it, creating multiple frequencies within the normal 60-Hz sine wave. The multiple frequencies are harmonics of the fundamental frequency.

Normally, current distortions produce voltage distortions. However, when there is a stiff sinusoidal voltage source, which is when there is a low impedance path from the power source, which has sufficient capacity so that loads placed upon it will not affect the voltage, one need not be concerned about current distortions producing voltage distortions.

Examples of nonlinear loads are battery chargers, electronic ballasts, variable frequency drives, and switching mode power supplies. As nonlinear currents flow through a facility's electrical system and the distribution-transmission lines, additional voltage distortions are produced due to the impedance associated with the electrical network. Thus, as electrical power is generated, distributed, and utilized, voltage and current waveform distortions are produced.

Power systems designed to function at the fundamental frequency, which is 60-Hz in the United States, are prone to unsatisfactory operation and, at times, failure when subjected to voltages and currents that contain substantial harmonic frequency elements. Very often, the operation of electrical equipment may seem normal, but under a certain combination of conditions, the impact of harmonics is enhanced, with damaging results.

On the other hand, the harmonic analysis also involves calculation of Total Harmonic Distortion (THD) in term of percentage. THD can be defined as the ration between the RMS value of the sum of all harmonic components and the RMS value of the fundamental component. The percentage of the THD can be calculated by :

$$\text{THD}\ (\%) = 100\ .\ \sqrt{\sum_{h=2}^{\infty}\left(\frac{Ih}{Il}\right)^2}$$

Where h is the harmonic order, and Ih is the harmonic current

2.3 FILTER CLASSIFICATION

Hybrid filters can be classified into several categories based on the topology, control strategies, signal generation and few other techniques related. Since this study will only focusing on the filter configuration, further classification is made which can be divided into two; series and shunt connection of the filter to the main transmission line from source to load. It can even be further divided based on the connection of passive and active filter within the filtering component part.

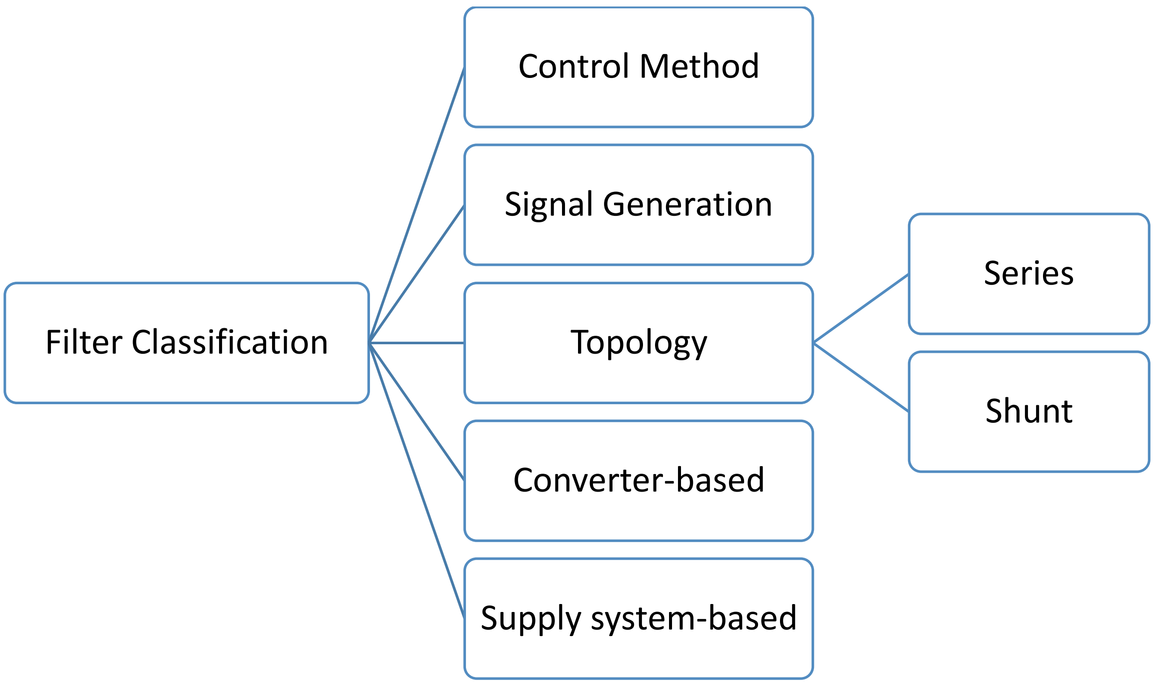


Figure 2.2 : Classification of Filters

Shown in Table 2.1 is the comparison of several types of Hybrid Filter configuration. It includes the Parallel combination of shunt-APF and shunt passive filter, Hybrid of series-APF and shunt passive filter, and Series combination of series-APF and shunt passive filter.

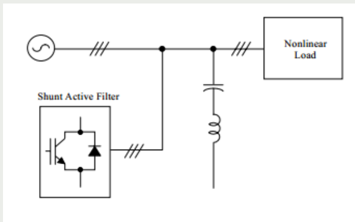
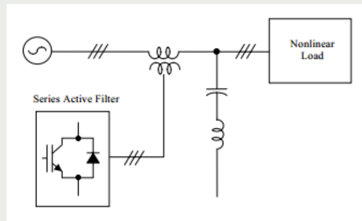
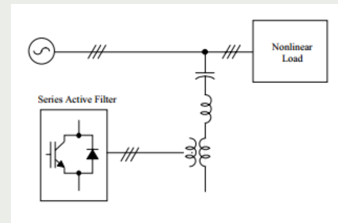
Parallel combination of shunt-APF and shunt passive filter	Hybrid of series-APF and shunt passive filter	Series combination of series-APF and shunt passive filter
		

Table 2.1 : Several types of Hybrid Filter Configuration

2.4 PASSIVE AND ACTIVE FILTER

The Passive LC filter traditionally used alone to eliminate the harmonics contained in the current. However, due to its large size, several tuning problem, power loss and unbalance issue, it is best to find another component that can compensate the drawbacks and limitation of the passive filter, but at the same time enhancing the damping capability. Active filter is well-known to be used to compensate the harmonic distortion problem and is able to cater the unbalance passive filter.

The idea is by injecting the same amount of current but in opposite direction to the Point of Common Coupling (PCC). The same amount of current injected and the harmonic components will eliminate each other so that the only waveform left is the fundamental component. These combination of active and passive filter requires a very low power for mitigating harmonics compared to the usage of standing-alone filters. The task of eliminating harmonics is divided in these two filters. An active filter mitigates the lower order harmonics and passive filters eliminate the higher order harmonics. [8]

CHAPTER THREE : METHODOLOGY

3.1 RESEARCH METHODOLOGY

Figure 3.1 : Project Flow Chart

3.2 PROJECT ACTIVITIES

Select title and find information and materials related

Project title is chose. All the information and materials related to the topic are gathered and studied for better understanding.

↓

Identify the type of filter configuration

Problem statement and objectives of this project is outlined. The scope also is narrowed down by focusing on the types of hybrid filter based on the configuration

↓

Determine the control strategies and techniques

Data and information studied are extracted and the control strategies and techniques to be used are determined

↓

Design and simulate the selected filter

The selected configuration of hybrid filter is designed and simulated by using MATLAB Simulink and PSIM software

↓

Implement the filters on the case studies

The filter designed is then connected to the system network of the case studies provided. Previous step is repeated if the simulation did not work out.

↓

Damping performance evaluation

The performance of the filter is evaluated based on the damping capability. This can be seen by observing the THD percentage value reduced.

↓

Findings/ recommendation for further improvement

Other findings has been put into considertion for further studies/improvement due to time constraint and several other limitation.

3.3 KEY MILESTONE

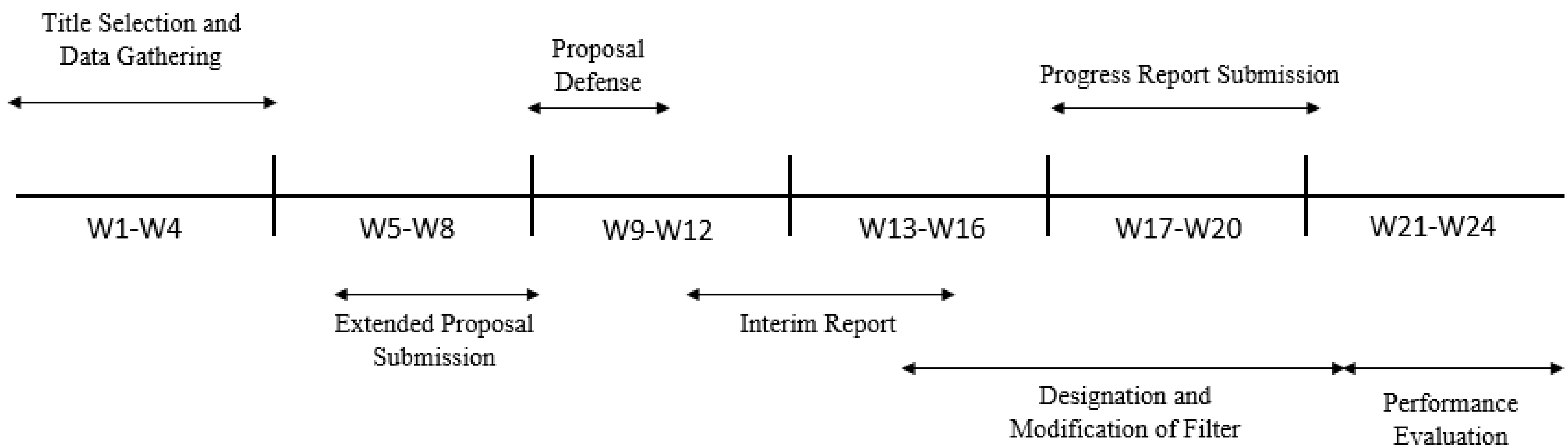


Figure 3.2 : FYP Key Milestone

3.4 GANTT CHART

ACTIVITTIES	FYP 1														FYP 2													
	Week :																											
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Title selection & data gathering	■	■	■	■	■	■																						
Submission of Extended Proposal							★																					
Proposal Defense								■	■																			
Designation and modification of filter network									■	■	■	■	■	■														
Submission of Interim Report														★														
Construct filter network in the software															■	■	■	■	■	■	■							
Submission of Progress Report																					★							
Filter implementation in the case studies																					■	■	■	■				
Pre-SEDEX / Electrex																								★				
Evaluate filter performance																								■	■			
Submission of Draft Final Report																									★			
Submission of Dissertation and Technical Paper																										★		
Viva																											★	

Table 3.1 : FYP Gantt Chart

3.5 SOFTWARE USED

There are two software that can be used for the purpose of designing and simulating the filters and the distribution systems, which are ;

1. MATLAB (Simulink)
   - This software can be used to design, analyze and implement the digital filter.

2. PSIM
   - This software is a general-purpose time domain simulation program for multi-phase power systems and control networks.
   - Allow the user to schematically construct the circuit, run a simulation, analyze the results, and manage the data.

CHAPTER FOUR : RESULT AND DISCCUSSION

The simulation of the hybrid filter is done by using shunt configuration network since it is proven to be the best filter topology for mitigating harmonics. The series active-passive filter is connected in shunt to the main transmission line that connect the source to the non-linear load as shown in the figure below.

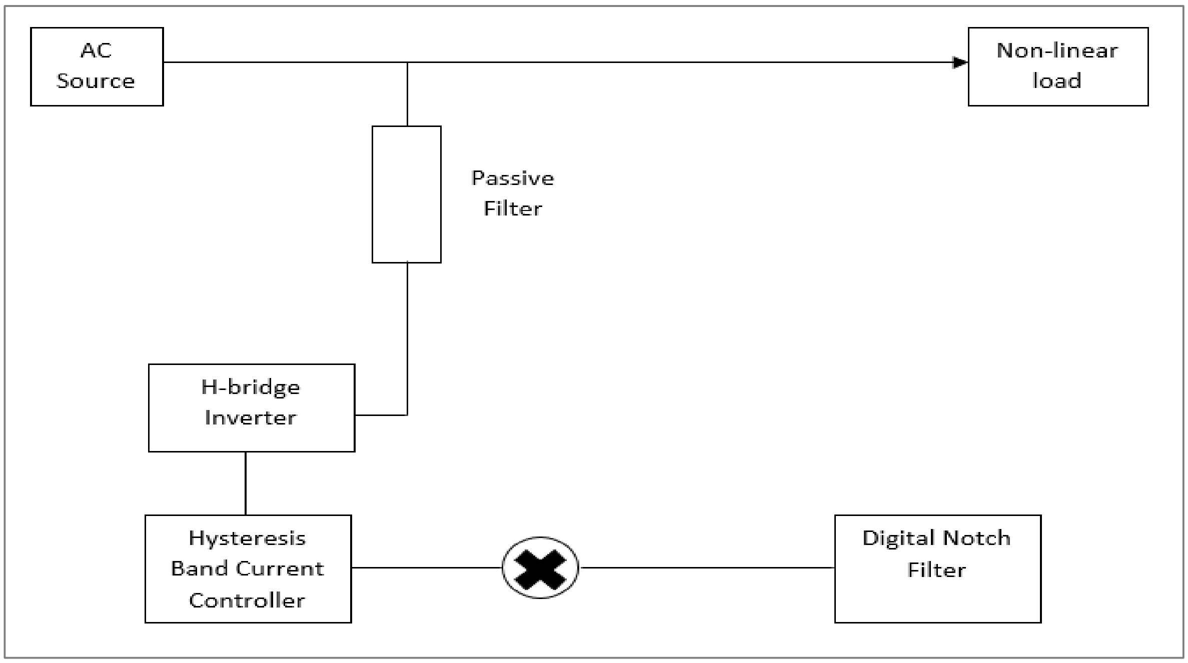


Figure 4.1 : Shunt configuration of Hybrid Filter

As for the active filter part, notch filter is used and connected to the Hysteresis Band Current Controller and H-Bridge Inverter. Figure 4.2 shows the Bode Diagram of the Frequency Response for notch filter.

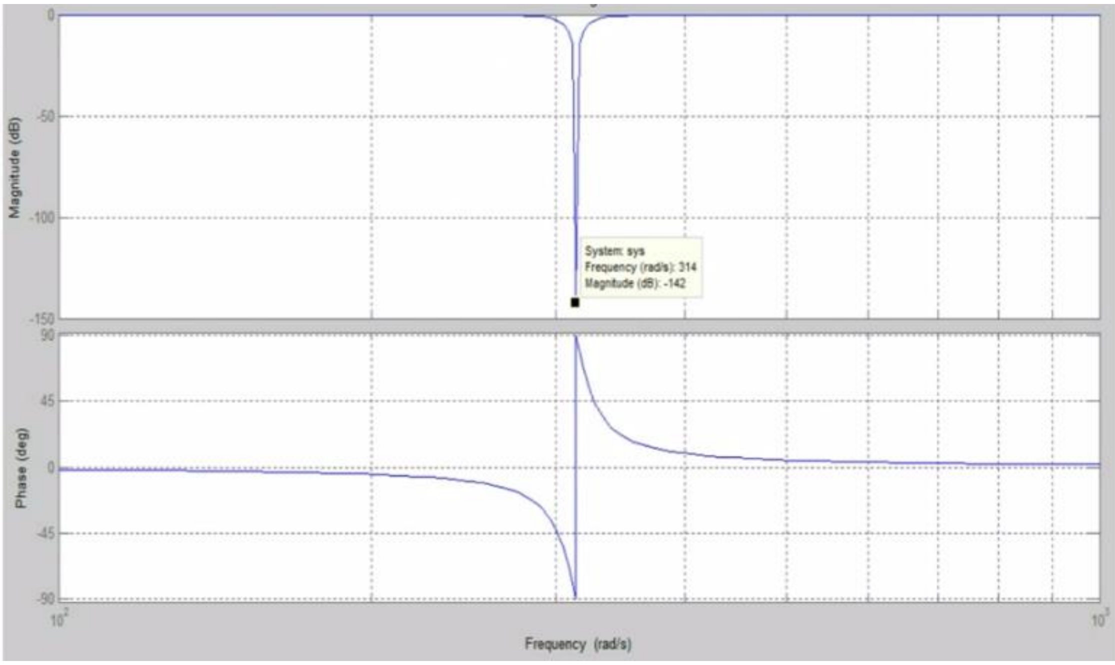


Figure 4.2 : Frequency Response of Notch Filter

The full schematic of the small distribution network together with the shunt hybrid filter connection is designed in the MATLAB Simulink software as shown below.

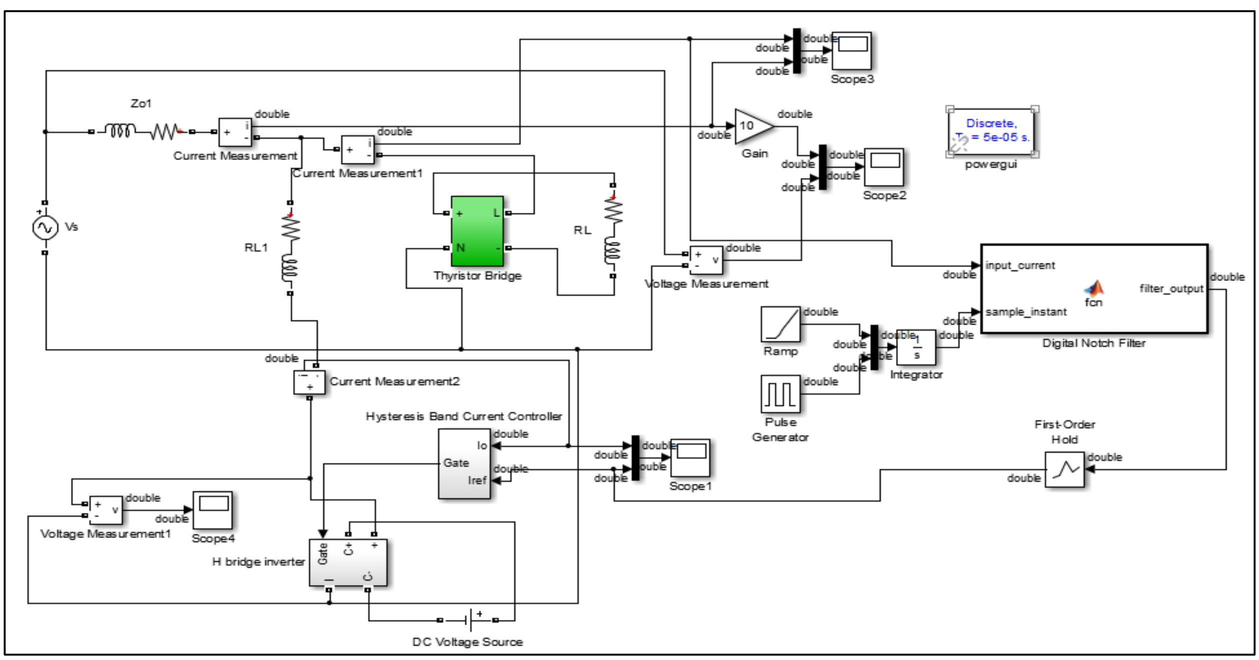


Figure 4.3 : Schematic Diagram of Small Distribution Network

Following figures are the subsystem contained in the functional block which include the Thyristor Bridge Subsystem (Figure 4.4), Notch Filter Subsystem (Figure 4.5), H-bridge Inverter Subsystem (Figure 4.6), and Hysteresis Band Current Controller Subsystem (Figure 4.7). The Thyristor Bridge Subsystem represented the non-linear load in the network and modelled using the Thyristor Bridge. The output of the Thyristor Bridge Subsystem is sent to the resistive inductive branch next to it.

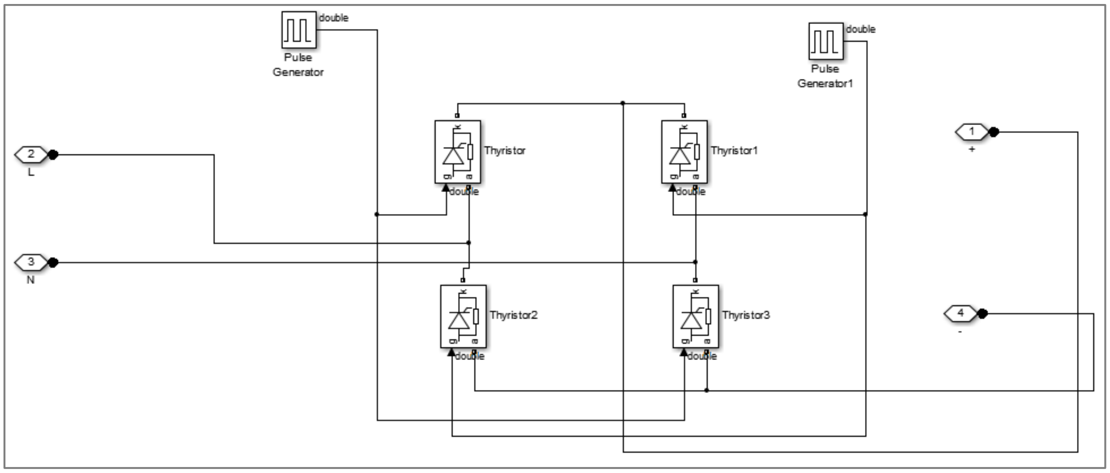


Figure 4.4 : Thyristor Bridge Subsystem

```
function filter_output    = fcn(input_current, sample_instant)
persistent x_t1 y_t1 y_t2 y_t x_t2;
%persistent value are equivalent to the static variable
%initialization of persistent variables to zero value.
    if isempty(x_t1)
        x_t1=0;
    end

    if isempty(x_t2)
        x_t2=0;
    end

    if isempty(y_t1)
        y_t1=0;
    end

    if isempty(y_t)
        y_t=0;
    end

    if isempty(y_t2)
        y_t2=0;
    end

  if (sample_instant == 0)
     y_t = (0.9975*x_t2-1.9911*x_t1+0.9975*input_current-0.9950*y_t2+1.9911*y_t1);
     y_t2 = y_t1;
     y_t1 = y_t;
     x_t2 = x_t1;
     x_t1 = input_current;
```

Figure 4.5 : Notch Filter Subsystem

The Digital Notch Filter is modelled in the MATLAB Function Block and serves as the active filter of the system. The digital output of the Digital Notch Filter is converted into analog signal through the First Order Hold circuit. On the other hand, the H-bridge Inverter Subsystem is designed by using two IGBT peer.

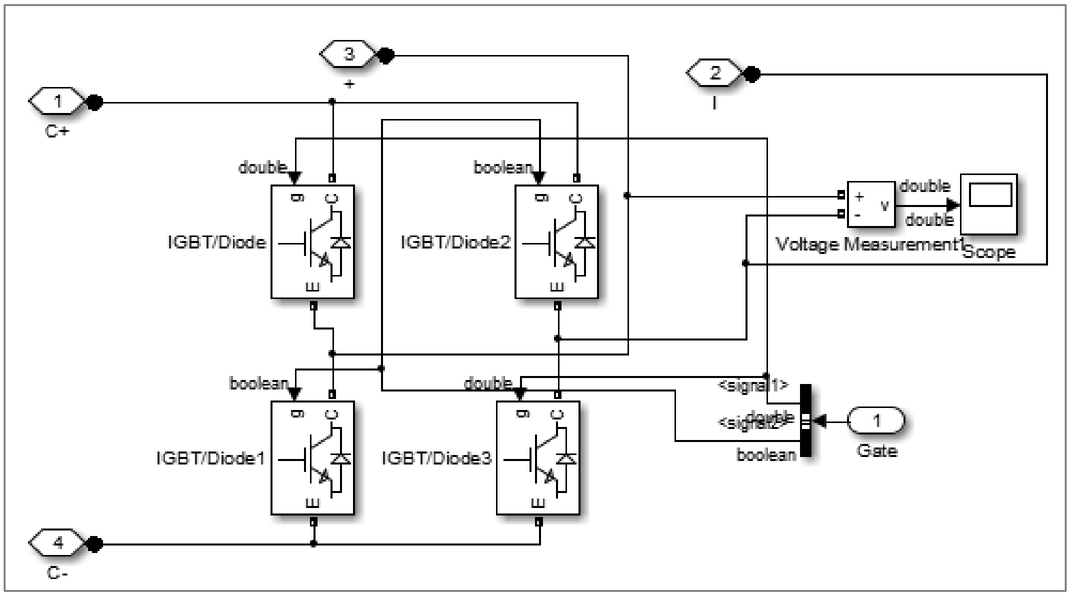


Figure 4.6 : H-Bridge Inverter Subsystem

As shown in the Figure 4.7 below, the Hysteresis Band Current Subsystem is modelled by using a relay block and the output of this subsystem serves as the switching pattern for the IGBT in the H-bridge Inverter Subsystem above.

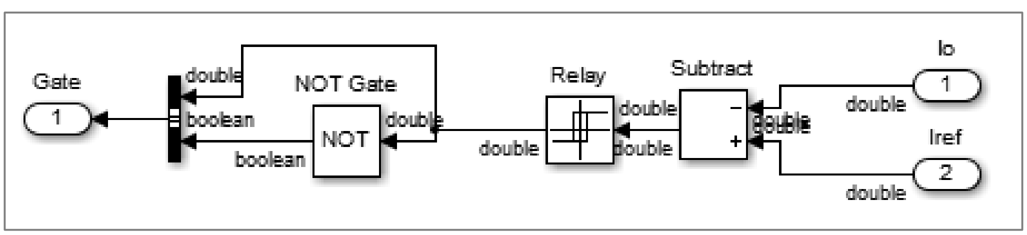


Figure 4.7 : Hysteresis Band Current Controller Subsystem

As shown in the main schematic diagram above, there are four scopes placed within the network. Each of the scopes provide different type of measurement. They are labelled as Scope 1, Scope 2, Scope 3, and Scope 4 accordingly and the wave pattern shown as the simulation is carried out are labelled as Figure 4.8 – Figure 4.11 below.

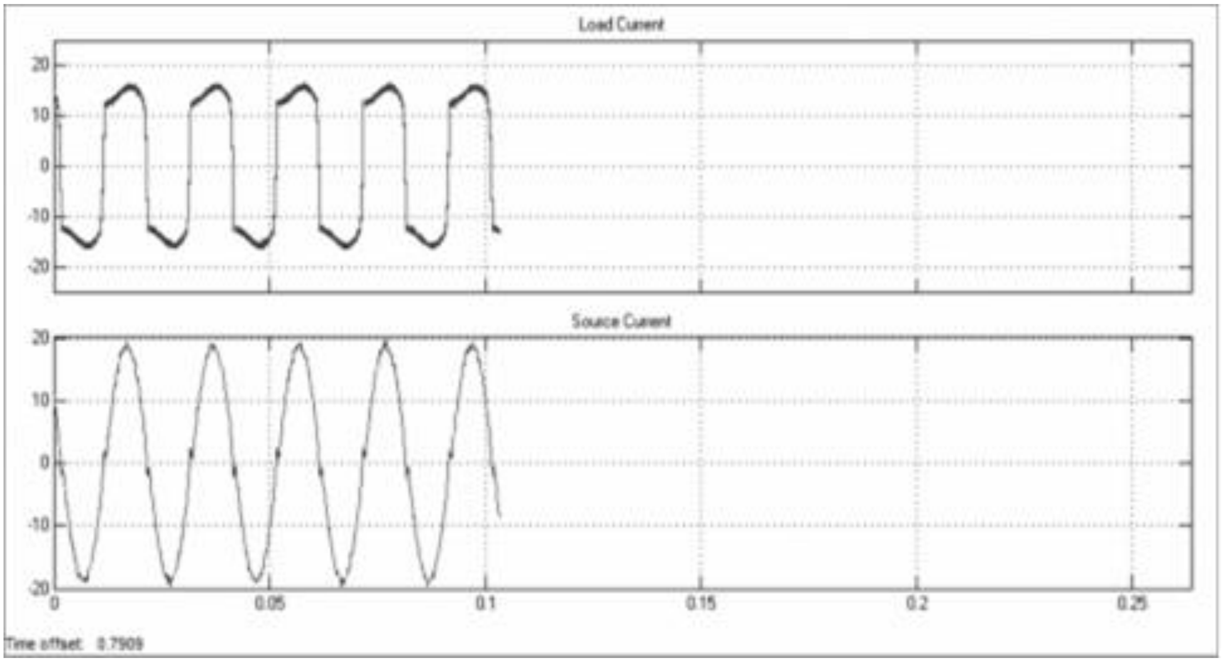


Figure 4.8 : Load Current and Source Current waveform (Scope 1)

Scope 1 shows the Load and Source Current waveform as above. Since the Load Current is in non-linear form, it indicates that the waveform contained both fundamental and harmonic component. Meanwhile the Source Current is in linear form as it only contained the fundamental component.

Scope 2 shows the difference between the Source Voltage and the Source Current, while Scope 3 shows the waveform of the Reference Current and the Injected Current. The Reference Current is the output of the notch filter and the Injected Current is the output of the overall module. Scope 4 provide the output of the inverter.

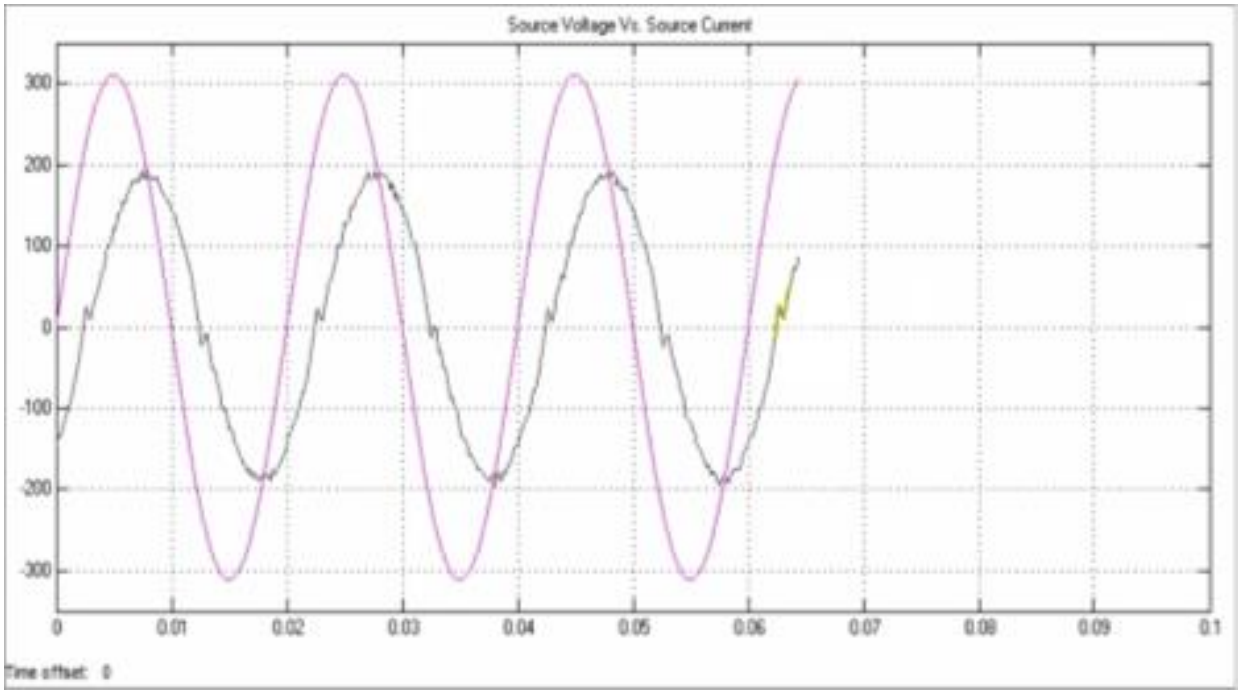


Figure 4.9 : Source Voltage vs Source Current waveform (Scope 2)

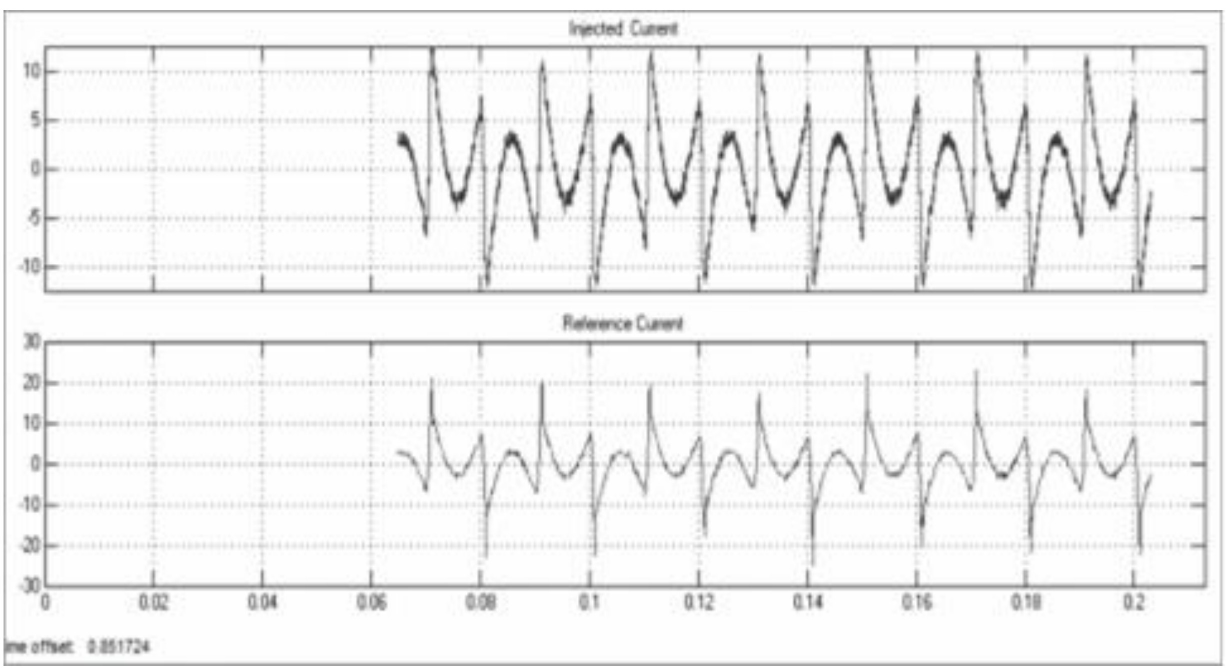


Figure 4.10 : Injected Current and Reference Current waveform (Scope 3)

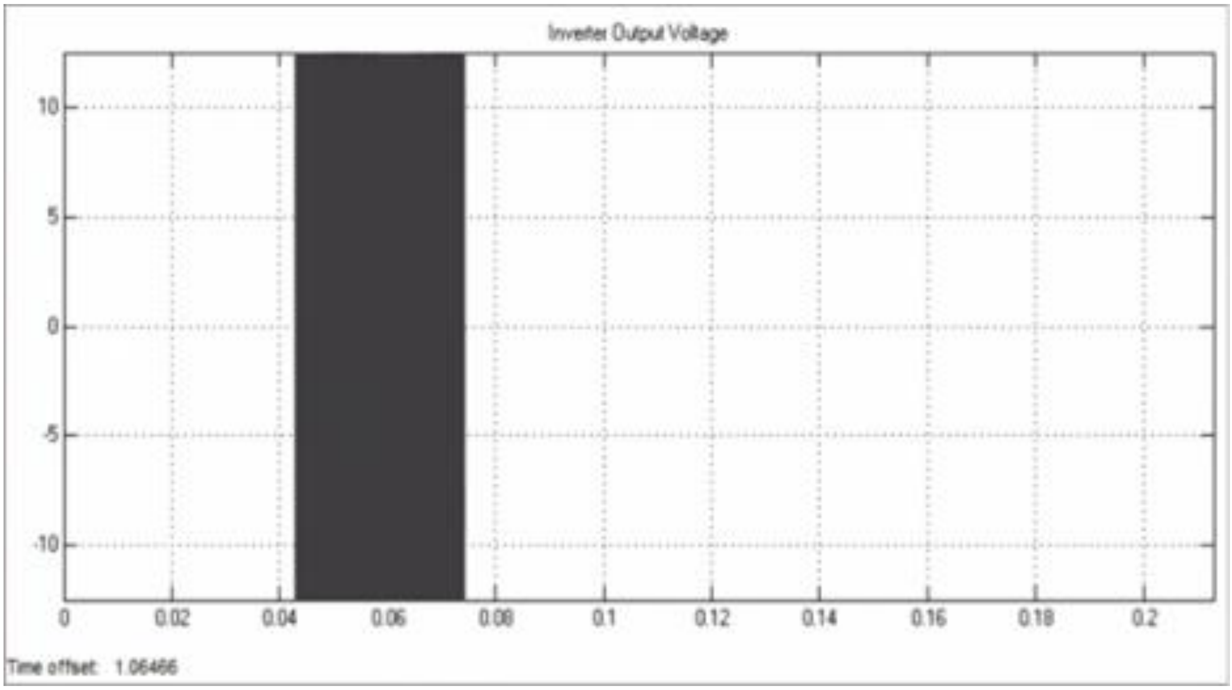


Figure 4.11 : Inverter Output Voltage waveform (Scope 4)

The THD analysis of the network can be observed from the MATLAB Powergui FFT Analysis Tool. Selection of Input 1 will provide the analysis of the Load Current, while selection of Input 2 will provide the analysis of the Source Current. THD percentage value is provided in both Figure 4.12 and Figure 4.13, which shown the decrement form 34.99% to 5.07%. This decrement indicates that harmonics component in the Load Current had been mitigated. It is accepted as long as the THD percentage does not exceed 5.0% as what had been stated according to the IEEE 519 Standard.

The design of the hybrid filter network also was done using the PSIM software. However, due to certain problems and untraceable errors when the simulation is carried out, no result is obtained or even recorded.

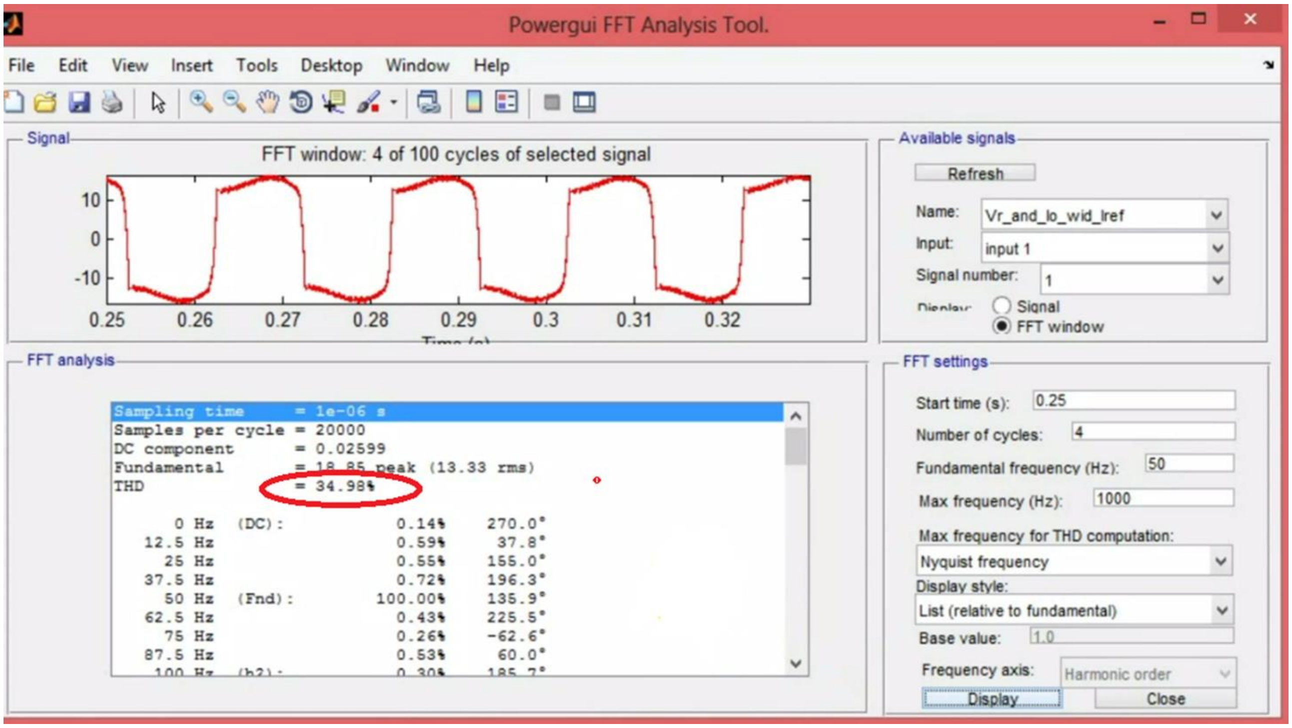


Figure 4.12 : THD Analysis of the Load Current

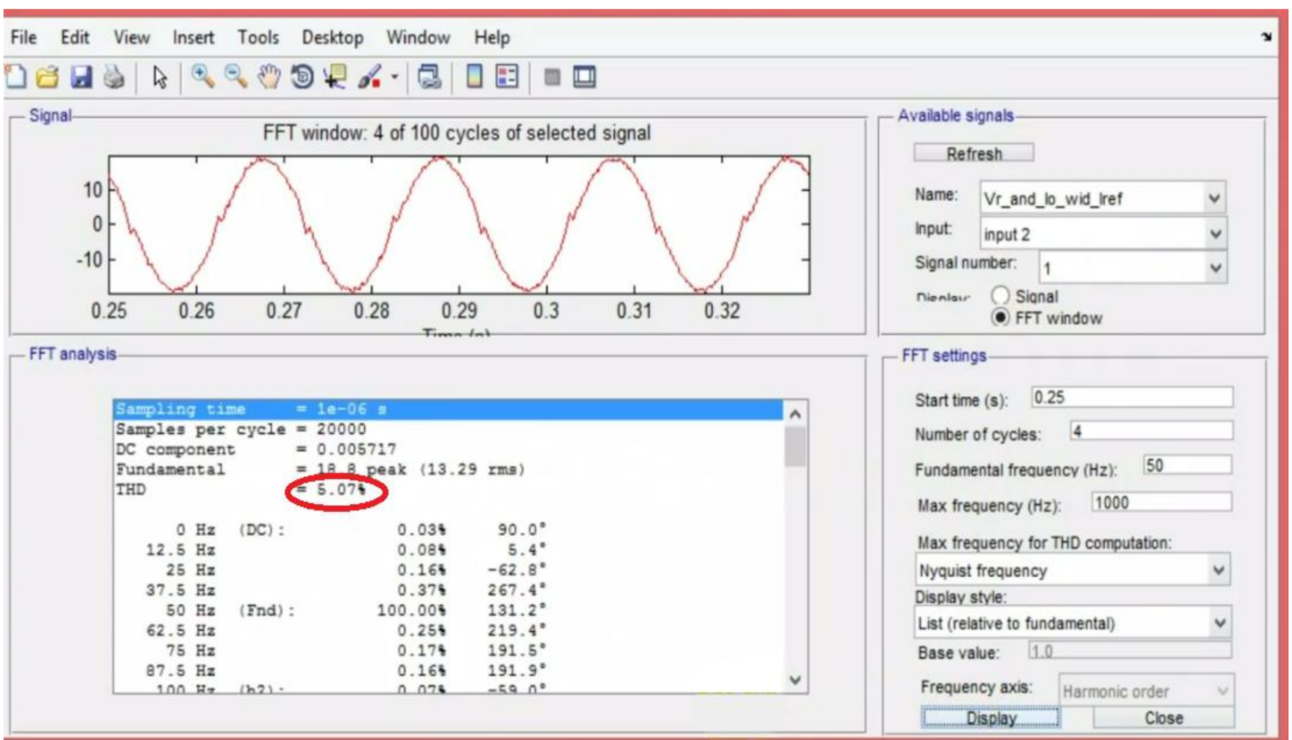


Figure 4.13 : THD Analysis of the Source Current

CHAPTER FIVE : CONCLUSION AND RECOMMENDATION

Nowadays, numerous of power quality issues had been put into attention. This is due to the rapid development of various power electronic non-linear devices. In order to overcome this matter, many filtering techniques with different strategies had been introduced including passive filtering, active filtering, and even the combination of both, hybrid filtering. The harmonic-contained current or voltage waveform will theoretically decreased in THD percentage after is passed through any filters implemented. The simulation results shows that the hybrid filter with shunt configuration provide a superior performance with the decrement of the THD percentage from 34.99% to 5.07%.

The author would like to recommend for different type of filter configuration to be further classified with more details that includes the control strategy and techniques. Apart from that, the filter designed also should be implemented in various scale and of distribution network with different application. These are important in order to further analyze the performance of the hybrid filter in term of damping capability.

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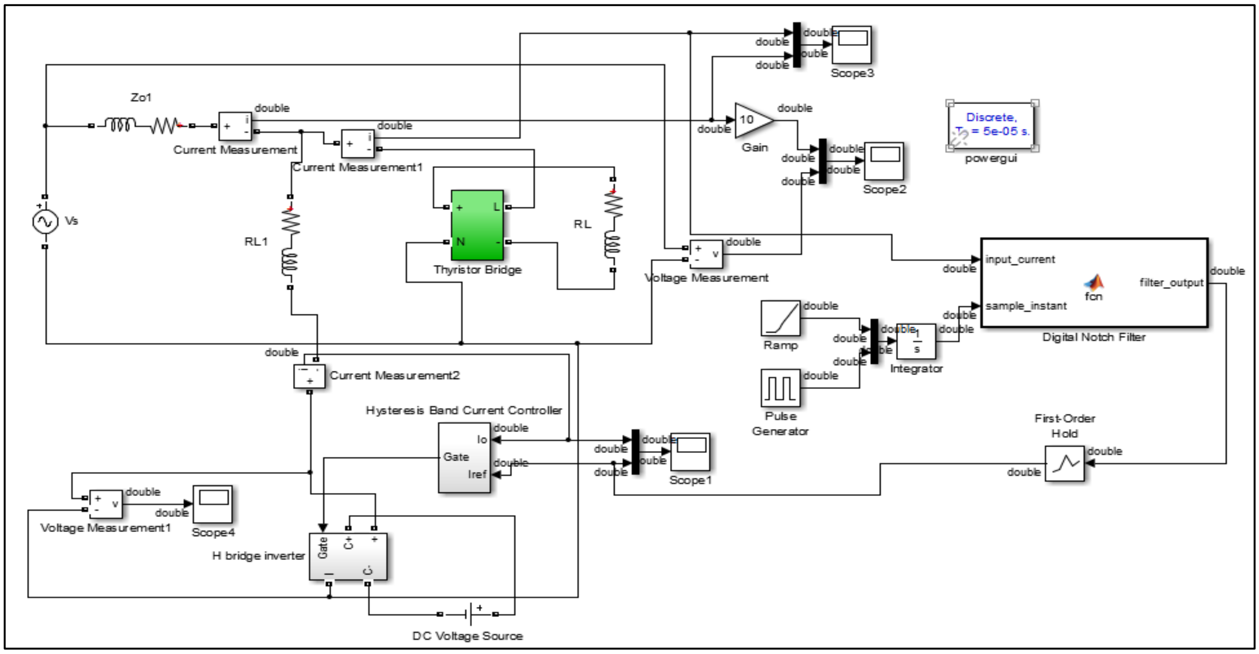
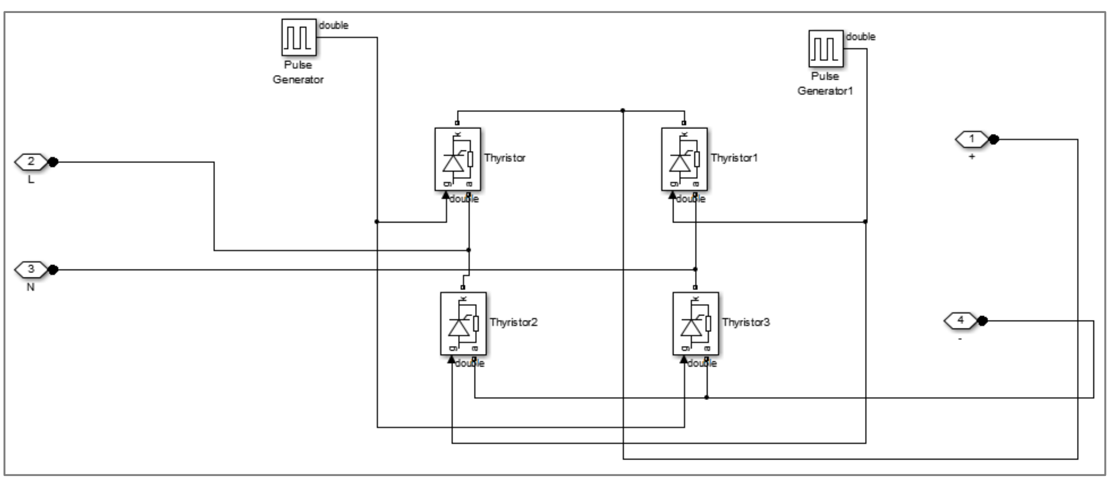
APPENDICES



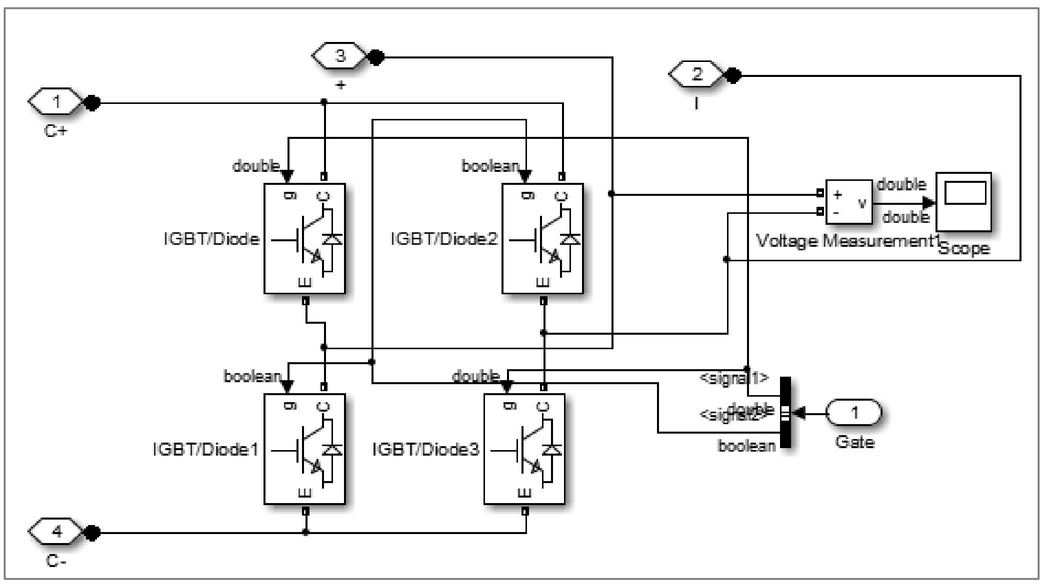
Schematic Diagram designed in MATLAB Simulink



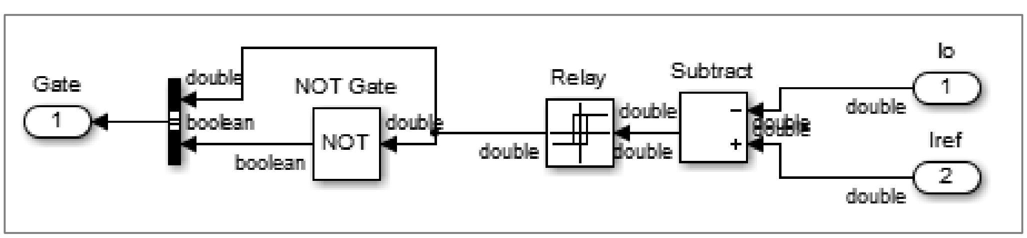
Thyristor Bridge Subsystem

```
function filter_output    = fcn(input_current, sample_instant)
persistent x_t1 y_t1 y_t2 y_t x_t2;
%persistent value are equivalent to the static variable
%initialization of persistent variables to zero value.
    if isempty(x_t1)
        x_t1=0;
    end

    if isempty(x_t2)
        x_t2=0;
    end

    if isempty(y_t1)
        y_t1=0;
    end

    if isempty(y_t)
        y_t=0;
    end

    if isempty(y_t2)
        y_t2=0;
    end

  if (sample_instant == 0)
     y_t = (0.9975*x_t2-1.9911*x_t1+0.9975*input_current-0.9950*y_t2+1.9911*y_t1);
     y_t2 = y_t1;
     y_t1 = y_t;
     x_t2 = x_t1;
     x_t1 = input_current;
```

Notch Filter Subsystem



H-Bridge Inverter Subsystem



Hysteresis Band Current Controller Subsystem