I hereby declare that I have read through this report and found that is comply the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering (Industrial Power)

Signature: ………..……………………….....

Name : Prof. Madya Ir Dr Rosli Bin Omar

Date : ....

PERFORMANCE EVALUATION OF ACTIVE AND PASSIVE FILTERS FOR HARMONIC REDUCTION IN ELECTRICAL DISTRIBUTION SYSTEM BASED ON SYNCHRONOUS REFERENCE FRAME (SRF)

MUHAMMAD ASYRAF BIN MOHD HANAFI

A project report submitted in partial fulfilment of the requirement for the award of Bachelor of Electrical Engineering
(Industrial Power)

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2016

I declare that the project report entitled "Small Wind Energy Converter" is the results from my own research except as cited in the references.

Signature: ....

Name : Muhammad Asyraf bin Mohd Hanafi

Date : ....

To my beloved mother and father.

ACKNOWLEDGEMENT

In the name of Allah, the Most Beneficent and The Most Merciful. It is a deepest sense gratitude of the Almighty that give me strengh and ability to complete this Final Year Project report.

A special gratitude I give to my final year project supervisor , Prof. Madya IR DR Rosli Bin Omar , whose give me a valuable guidance and support and helped me to coordinate my project especially in writing this report.

A special thanks goes to my family for their moral support to me in the process to complete this project. Besides that, I would also like to acknowledge with much appreciation to all my friends who help me in order to complete my Final Year Project.

Futhermore I would also like to express my gratitude to staff of Univesiti Teknikal Malaysia Melaka (UTeM) , who gave me the permission to use all required equipment and necessary materials in laboratory to complete my Final Year Project.

ABSTRACT

The wide use of controlled power appliances such as personal computer, switch mode power supply, adjustable stepped drive inject a significance harmonic distortion in power system. These harmonic cause an increase in level of rms supply current which results an increase of power loss, heating of equipment and also deteriorates the quality of power. Passive filter have been used to suppress harmonics current conventionally. This kind of filter cannot modify their compensation due to non-linear loads and the filtering characteristics of active filters are affected by source impedance. To overcome the disadvantages of passive filter and active power filter combination with shunt active filter are introduced.

The project is to investigate the performance of active and shunt passive filters for harmonic reduction for power quality improvement in in electrical distribution system. The proposed system comprises of a power circuit of the shunt active filter. It involves the construction of the proposed filter topologies consists of transformer, Voltage Source Inverter (VSI) and shunt series passive filters. The main aim of this project is to cover design, modelling, construction and of active power combination with series passive filters using MATLAB/SIMULINK. The proposed controller based on Synchronous Reference frame (SRF) transformation technique is applied to the active power filter. The proposed system is capable to reduce current harmonics generated by non-linear loads.

ABSTRAK

Penggunaan meluas peralatan kuasa dikawal seperti komputer peribadi, suis mod bekalan kuasa, pemacu melangkah laras menyuntik herotan harmonik kepentingan dalam sistem kuasa. Ini menyebabkan harmonik peningkatan dalam tahap rms membekalkan arus yang menyebabkan peningkatan kehilangan kuasa, pemanasan peralatan dan juga merosot kualiti kuasa. penapis pasif telah digunakan untuk menindas konvensional semasa harmonik. Ini jenis penapis tidak boleh mengubah suai pampasan mereka kerana beban bukan linear dan ciri-ciri penapisan penapis aktif dipengaruhi oleh sumber galangan. Untuk mengatasi kelemahan penapis pasif dan gabungan penapis kuasa aktif dengan shunt penapis aktif diperkenalkan.

Projek ini adalah untuk menyiasat prestasi aktif dan shunt penapis pasif untuk mengurangkan harmonik untuk peningkatan kualiti kuasa di dalam sistem pengagihan elektrik. Sistem yang dicadangkan terdiri daripada litar kuasa penapis shunt aktif. Ia melibatkan pembinaan topologi penapis dicadangkan terdiri daripada pengubah, Voltan Source Inverter (VSI) dan siri shunt pasif penapis. Tujuan utama projek ini adalah untuk menampung reka bentuk, model, pembinaan dan gabungan kuasa aktif dengan siri penapis pasif menggunakan MATLAB / SIMULINK. Pengawal yang dicadangkan berdasarkan kerangka rujukan (SRF) teknik transformasi segerak digunakan untuk penapis kuasa aktif. Sistem yang dicadangkan mampu untuk mengurangkan harmonik semasa yang dijana oleh beban bukan linear.

TABLE OF CONTENTS

TITLE	PAGE
ACKNOWLEDGEMENT	**I**
ABSTRACT	**II**
CHAPTER 1	**1**
INTRODUCTION	**1**
1.1 Research background	1
1.2 Problem statement	2
1.3 Objectives	2
1.4 Scope of work	2
1.5 Expected project outcomes	3
CHAPTER 2	**4**
LITERATURE REVIEW	**4**
2.1 Theory and basic principles	4
2.1.1 The Concept of Harmonics Theory	4
2.1.2 Definition of Total Harmonics Distortion	5
2.2 Harmonic Sources	6
2.2.1 Effect of Harmonic	7
2.2.2 Harmonic Measurement	7
2.2.3 Harmonic Spectrum	8

2.3 Theory and basic principles 9

2.3.1 Advantages of active filter over shunt passive filter 9

2.3.2 Comparison of active filters and shunt passive filter 10

2.4 Review of previous related works 10

2.4.1 Active power filter 10

2.4.2 Passive shunt filters 11

2.4.3 Passive series filter 12

2.4.4 Passive shunt filter 13

2.4.5 Passive hybrid filter 13

2.4.6 Linear and Non-linear Load 14

2.4.7 P-Q Theory 16

2.5 Summary and discussion of the review 17

CHAPTER 3 **18**

RESEARCH METHODOLOGY **18**

3.1 Introduction 18

3.1.1 Harmonic filtering techniques 18

3.1.2 Flowchart for this project 19

3.2 Design process 20

3.2.1 Step 1 21

3.2.2 Step 2 21

3.2.3 Step 3 21

3.3 Proposed control scheme based on SRF by using MATLAB 21

3.3.1 Synchronous Reference Frame (SRF) 21

3.3.2 SRF controller applied to Active Power Filter 23

3.4 Simulation Model of the Three-Phase Active Power Filter Using SRF Controller based on MATLAB/SIMULINK 23

3.5 The Proposed configuration Using MATLAB/SIMULINK 25

CHAPTER 4 **30**

RESULT AND ANALYSIS **30**

4.1 Introduction 30

4.2 CASE STUDY 1: (linear Load R= 1000 ohm and L= 10uH), without filter 31

4.3 CASE STUDY 2: (non-linear Load R= 100 ohm and C= 1000uF), without filter 34

4.4 CASE STUDY 3: (non-linear and linear), with both passive and active filter. 40

CHAPTER 5 **47**

CONCLUSION AND RECOMMENDATION **47**

5.1 Introduction 47

5.2 Conclusion 47

REFERENCE

LIST OF TABLES

TABLE	TITLE	PAGE
Table 2.1	Comparison between active filter and passive filter.	10
Table 3.1.1	Parameter for LC passive filters.	29
Table 4.1.2	Simulation results.	46

LIST OF FIGURES

FIGURE	TITLE	PAGE
2.1	(a) Separated fundamental and harmonic waveforms, and (b) waveform resulting from summation.	5
2.10	Harmonic spectrum of a sample with distorted wave.	9
2.1.1	Schematic configuration of passive filter.	12
2.2	Schematic diagram of series connected passive filter.	12
2.3	Schematic diagram of shunt connected passive filter.	13
2.4	Voltage waveforms and current waveforms for the linear load.	14
2.5	Voltage waveform and current waveforms for the non-linear loads.	15
2.6	Waveform with symmetrical harmonic.	16
3.1.0	Flowchart for the project.	20
3.1.1	SRF Control scheme for Active power filter.	23
3.1.2	MATLAB/SIMULINK 7.120 (R2012a).	24
3.1.3	The circuit configuration.	26
3.1.4	The Proposed controller Applied to Active Power Filter.	28
4.1.1	The current waveform at the supply voltage.	31
4.1.2	The current waveform at the load.	32

4.1.3	The THD_I value at the voltage supply.	32
4.1.4	The THD_I value at the load.	33
4.1.5	The voltage waveform at the load.	33
4.1.6	The current waveform at the supply voltage.	34
4.1.7	The current waveform at the load.	35
4.1.8	The voltage waveform at the supply voltage.	36
4.1.9	The voltage waveform at the load.	36
4.1.10	The THD_I at the supply voltage.	37
4.1.11	The THD_V at the supply voltage.	38
4.1.12	The THD_V at the load.	38
4.1.13	The THD_I at the load.	39
4.1.14	The current waveform at the supply voltage.	40
4.1.15	The current waveform at the load.	41
4.1.16	The voltage waveform at the supply voltage.	41
4.1.17	The voltage waveform at the load.	42
4.1.18	The THD_I at the supply voltage.	43
4.1.19	The THD_V at the supply voltage.	43
4.1.20	The THD_I at the load.	44
4.1.21	The THD_V at the load .	45

LIST OF APPENDICES

APPENDIX	TITLE	PAGE

CHAPTER 1

INTRODUCTION

1.1 Research background

The one of the most power quality problem in electrical power system is the harmonic current pollution and voltage distortion. A circuit filter configuration is needed to solve and give the outstanding or superb power supply. The power quality is to make crucial thing in the distribution system. Other than that, the cause is because of various phenomena that can be an interruption and disturbance harmonic, voltage sags, overvoltage, and voltage surges.

In this report, due to the distribution system the current harmonic will be discovered. Not less than that, which the meaning of harmonic usually compares to the power quality in ideal world. Moreover how pure is the current and how clean is the voltage waveform is in the sinusoidal developing from the supply can be seen. For extra info, to have a perfect sinusoidal waveform is ideally electrical power supply should be zero variety of distortion.

Harmonic distortion in the system can be revealed when current or voltage waveform is of form from its ideal sinusoidal form. More than that, there are many problems that give harmonic distortion result. Nowadays, it becomes major challenge for an engineer to perform a something that related with this field to maintain or to find a new way for reducing the harmonic distortion. A further study of a good designs in the industry harmonic distortion will improved very excellently.

1.2 Problem statement

The problem the usually rise in the distribution is the harmonic due to the great number of non-linear load or static power switches [2]. Beyond that, disturbance of harmonic distortion will effect several electrical equipment. So with a combination of active filter and passive filter together will limit the harmonic distortion allowed on the electrical distribution system. Evaluation of the combination both filters is crucial to ensure that it is the optimum design for the circuit configuration. Overall of this project is to make sure the efficiency and power handling deliver in the electrical distribution system network is according to standard. It is most important in power transmission and distribution system.

1.3 Objectives

The objective of this project is to evaluating the performance of active and passive filter by analyzing the harmonic distortion that causes harmonic source in distribution system. Objectives that identified are as follows:

1. To study of active filter and passive shunt filter for harmonic reduction in electrical distribution system.
2. To model active power filter based on Synchronous Reference Frame (SRF) and shunt active filter using MATLAB/SIMULINK
3. To evaluate and analyse the performance of harmonic current for active and shunt passive active in electrical distribution system.

1.4 Scope of work

On this project the main focus is to study about harmonic source in distribution system. This project is a combination of active and shunt passive filter to reduce harmonic distortion. Not less than that, the total harmonic distortion (THD) had been discussed. Another focus has been made is to determine harmonic current that occur in distribution

system by manipulating total harmonic distortion of the current and voltage as the primary measures and as well wants to reduce the harmonic distortion caused by current and voltage waveform that occurs. In the meanwhile, to discover the finest result is to mitigate distortion in the current and voltage waveform by use up the selected technique. In addition, MATLAB Software is used to design the simulation circuit and analysis based on the result. This project as well is been used to the gather up the data and compare to the simulation result.

1.5 Expected project outcomes

The proposed topologies is capable to reduce harmonic contents generated by non-linear load in electrical distribution system that can give an excellent performance in improving power quality.

CHAPTER 2

LITERATURE REVIEW

2.1 Theory and basic principles

2.1.1 The Concept of Harmonics Theory

A periodic waveform can be described as a sum of sine waves with the frequency being multiple of the fundamental frequency.

$$f_h = (h) \times \text{fundamental frequency} \quad (2.1)$$

Where h is an integer.

For example, a fifth harmonic would yield a harmonic component:

$$f_h = (5) \times (50\text{Hz}) = 250\,\text{Hz} \text{ in 50Hz Systems} \quad (2.2)$$

The non-fundamental components are called “harmonic distortion”. In another view, the combination of any sine wave of simple multiplication of fundamental frequency with the fundamental waveform is a harmonically distorted waveform. Harmonic voltage distortion can be classified as voltage harmonic distortion and current harmonic distortion. Figure 2.9 (a) shows the fundamental frequency waveform component (f1) with the third harmonic frequency waveform (f3) and the fifth harmonic frequency waveform component (f5), the resultant of the above three waveforms, which is the major deviation from the fundamental waveform (f1), is shown in Figure 2.9(b).

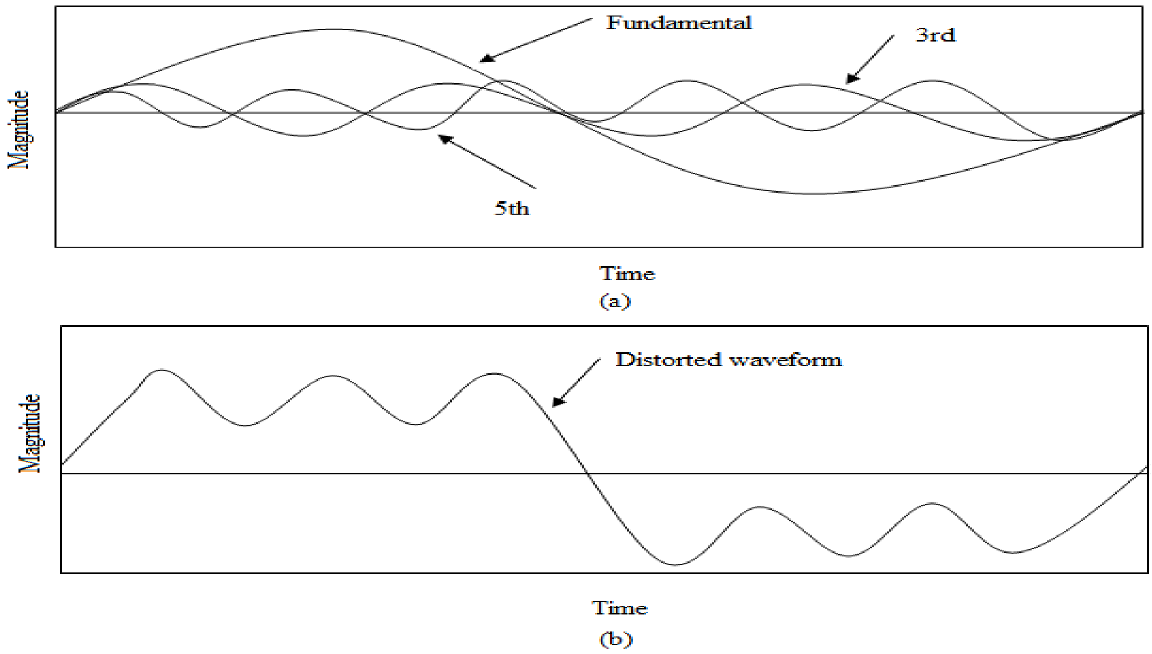

Figure 2.1: (a) Separated fundamental and harmonic waveforms, and (b) waveform resulting from summation.

2.1.2 Definition of Total Harmonics Distortion

Harmonics distortion is caused by non-linear devices in the power system. A non-linear device is one in which the current is not proportional to the source voltage. Harmonic distortion levels are described by the complete harmonics spectrum with magnitude and phase angle of each individual harmonic component. Besides, it is also common to use a single quantity, known as Total Harmonic Distortion (THD), as a measure of effective value for harmonic distortion (Roger et al., 2002). THD is defined for voltage and current signals, respectively, as follows:

$$\%THD = \left[\frac{1}{a_1^2}\sum_{n=5}^{\infty}\left(a_n{}^2\right)\right]^{\frac{1}{2}} \times 100 \qquad (2.7)$$

where n = 6i ± 1(i = 1,2,3….)

This means that the ratio between RMS values of signals, including harmonics and signals; considering only the fundamental frequency, define the THD.

2.2 Harmonic Sources

The harmonics cause disturbances to the utility, such as voltage distortion, power factor correction, capacitor parallel resonance, overheating, overloading power transformer, and communication line interference (Maset et al., 1996). Besides, there are many sources for the harmonics in the power utility. The main sources of harmonics in conventional power systems are summarised below (Nguyen et al., 2000):

• **Power Electronic Devices**: With the recent advances in power semiconductor technology, more electronics devices, such as phase controllers, inverters, and variable speed drivers, are widely used in the industry. These devices are sensitive to harmonics, and at the same time, they are a source of a high percentage of harmonic currents.

• **Electronic Switching Devices**: Electronic power processing equipment utilises switching devices. In general, a switching process in electronic devices are synchronized to the AC voltage, but this is unnecessary.

• **The voltage-current relationships with non-linear devices**: Two examples of such devices are Iron-core reactors and arcing loads. The non-linear V-I curve leads to produce harmonic currents when excited with a periodic input voltage.

• **Transformer and saturable reactors**: the non-linear magnetizing current of transformers and saturable reactors make them the major harmonic sources from the utility. They have a more pronounce impact during light load.

• **Arc Furnaces and Electric Arc Welders**: These non-continuous loads result in significant current distortion and the appearances of even harmonics in the transmission and distribution systems.

Harmonic standard level, IEEE 519-1992, is the recommended practices and requirements for the harmonics control of electrical power systems. It sets maximum THD limits on voltages and currents that a power system is allowed; therefore, the power conversion system cannot inject harmonics into the grid that causes the system to go above these limits set forth by the standard, and if at all possible; the power conversion system should filter these harmonics.

2.2.1 Effect of Harmonic

The RMS current level is increased due to harmonics, which can lead to an increase in power loss, equipment heating, and voltage sags, as well as the reduction of power factor, communication system interference, error in meter reading, mis-operation of utility relay, and also distortion of power quality (Don et al., 2000; Bhim et al., 1999). The conductors may cause heat as a result of the main effect of harmonics.

The conductors are heated as the current flows in it and this leads to an increase in temperature, due to additional current from the skin effect. Besides conductors, skin effect is also available in transformer due to its eddy current losses.

2.2.2 Harmonic Measurement

Ideally, power supplied by the utility should be a perfect sine wave of standard frequency and magnitude, but power converters add harmonic distortion to the system (Yukihiko et al., 1996). This disturbance has a certain limit for load and utilities. Hence, non-linear load current, I(t), can be represented by the following equation:

$$i(t) = \sum_{n=1}^{\infty} I_n \sin(n\omega t + \varphi) \qquad (2.8)$$

The total RMS current,

$$I = \sqrt{\frac{1}{T}\int_0^T i(t)dt} \tag{2.9}$$

$$= \sqrt{I_1^2 + \sum_{n=2}^{\infty} I_n^2}$$

Where, I_1 and I_n are the fundamental and harmonic component respectively, so the total harmonic current

$$I_{harmonic} = \sqrt{\sum_{n=2}^{\infty} I_n^2} \tag{2.10}$$

2.2.3 Harmonic Spectrum

When the contributions of individual frequency components of the composite wave are expressed in a graph, it is known as a harmonic spectrum. Harmonic contents are usually described as a percent of the fundamental for a certain component, as shown in Figure 2.10.

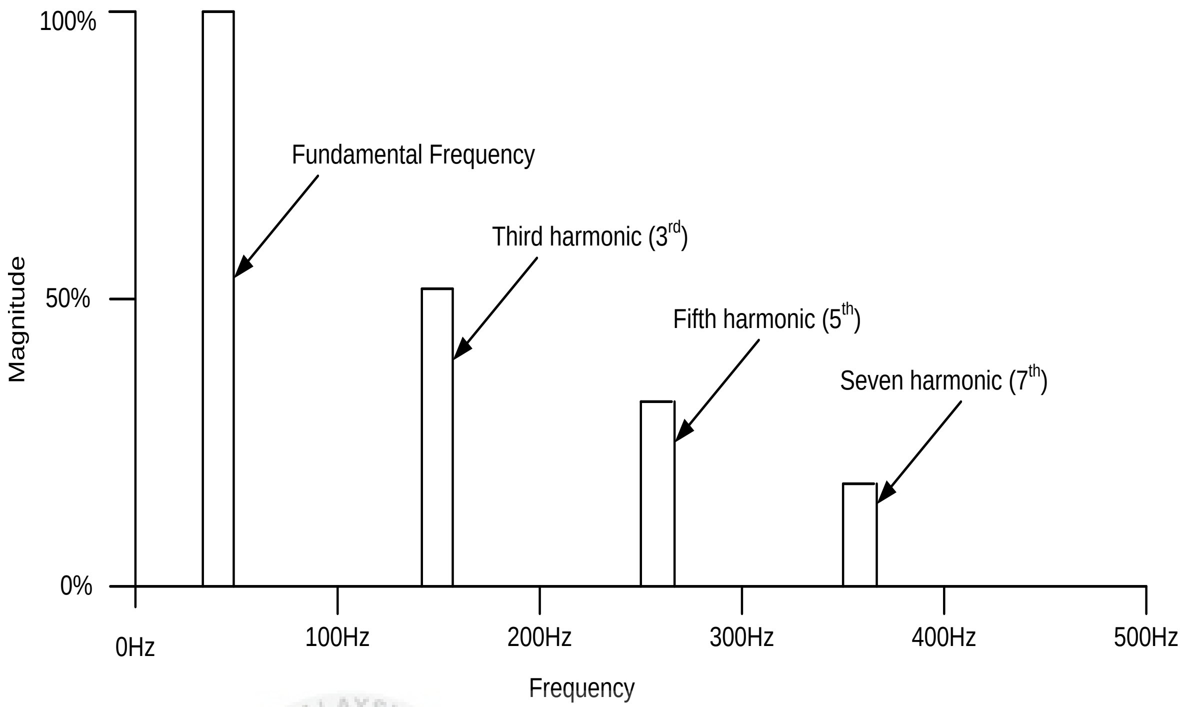

Figure 2.10: Harmonic spectrum of a sample with distorted wave.

2.3 Theory and basic principles

2.3.1 Advantages of active filter over shunt passive filter

1. When the active filter already in the circuit it not easier to perform both filter just injects the passive filter.
2. Both filters can work independently with several of load characteristic and together it are able to use up in demanding condition where passive filter cannot work excellently due to the parallel resonance problems.
3. Both filter can be used to reduce harmonic over one at a time and perform in power quality
4. Active and passive filter is important to reduce harmonic and also power factors.

2.3.2 Comparison of active filters and shunt passive filter

Table 2.1: Comparison between active filter and passive filter.

	Active filter	Passive filter
Harmonic control by command	Possible via parameters	Very hard
Harmonic current control	Simultaneously monitors many frequencies	Requires filter for each frequency
Dimension	Small scale	Large scale
Weight	Low	High
Encouragements of a frequency variation	No effect	Decrease the performance

2.4 Review of previous related works

2.4.1 Active power filter

To improve the power quality in harmonic reduction technique is using active filter, by injecting equivalent current or voltage distortion keen on the system, but in diametric value, which spontaneously offsets overcome the genuine distortion appeared on the lap. Active Power filter make use of fast-switching insulated gate bipolar transistors (IGBTs) bridge, which generates an output current of the preferred profile such that every time they are injected into the distribution system or AC lines, it offsets the fundamental load-generated harmonics. The controller part is the most important of the active power filter [3]. The execution and stability of the filter gate will improve when separate control strategies are put into operation to the active power filter. Moreover there are two types of active harmonic filter are designed fpr control scheme.

1. The filter will perform a fast Fourier transforms to calculate the amplitude and phase of each order of harmonics. The power device is use to produce a same or equal of current amplitude but indifferent phase angle for specific harmonic order.

2. In this method the control for the filter is usually referred to spectrum cancelling to full the current waveform. By eliminates the fundamental frequency components and for the filter to injecting the vice versa of the left over waveform.

Active power filters reduces harmonics which exist due to non-linear load in power system. The load are attached to the generators and motors which will be the source of harmonics to damage the current and voltage waveform, so with active filter will obligate the prescribed of mitigate distortion from the waveform and increase the power quality. Basically to improve the power quality in the system is to swap the current sine wave that absent in the non-linear load. To make the sinusoidal in current and voltage waveform it must have an electronic control monitor to monitor line voltage and current by correctly switching the power electronic equipments. A good way is to programme in various way to correct power factor and harmonic distortion as well.

2.4.2 Passive shunt filters

A standard of passive filter consists of resistance, capacitance and inductance elements. It also will impact to reduce the harmonic present in a system. There are various types of filter such as passive series filter, passive shunt filter and passive hybrid filter. Generally it need to be tuned and the configuration to have an excellent performance to reduce harmonic that generate from the power generation and power transmission [3]. It also provides reactive power compensation in terms of improve the power quality, so that it will give better reactive power to reduce the extra capacitor for supplying extra needed KVAR.

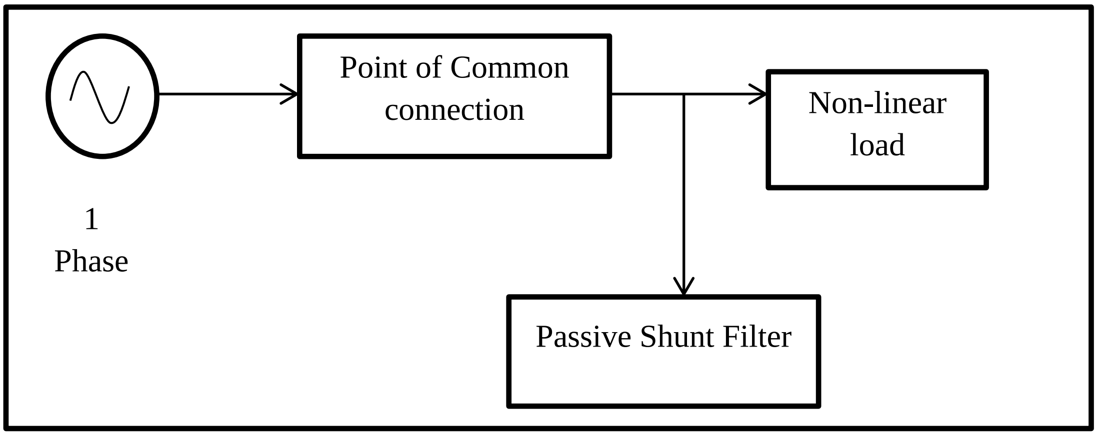

Figure 2.1: Schematic configuration of passive filter.

2.4.3 Passive series filter

A system that use voltage source that produce harmonic which a bi product of diode rectifier with R – C connected load it is refer to the series type passive filter so that it can repair to reduce harmonic that occurs. A part of passive series filter consists of purely inductive type or tuned LC characteristics. Furthermore, the main component of passive series filter AC line reactor and DC link filter. On the contrary, connections of the two components in series to become passive series filter and improve transmit power by changing the magnitude of inductance in system so that varies the current drawn in the rectifier.

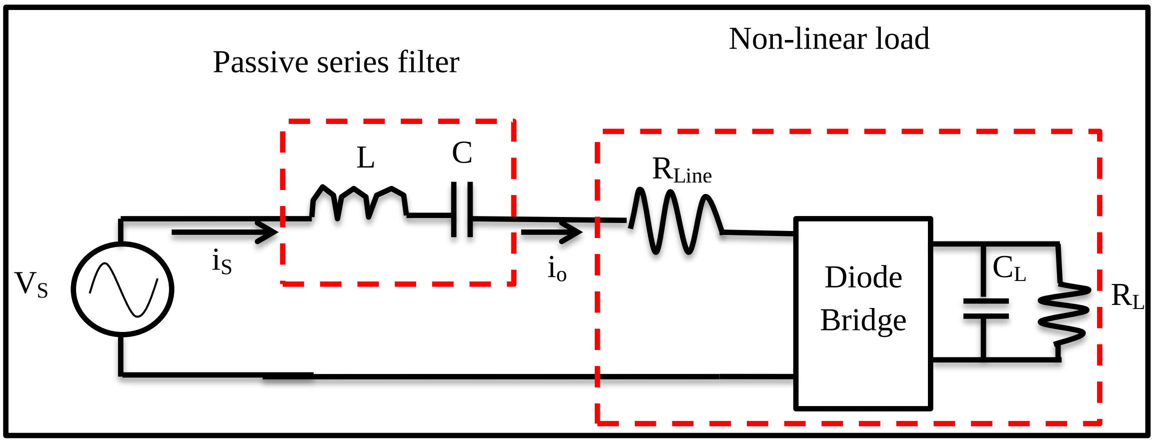

Figure 2.2: Schematic diagram of series connected passive filter.

2.4.4 Passive shunt filter

Passive Shunt filter in the distribution system is the nearly all common method for termination of harmonic current. They usually are designed either single tuned or band pass filter technology. Shunt type filter method is basically a parallel connection with load. The impedance of the passive filter is low and it use low amount of current to the whole system to reduce the AC power loss compare to series type filter.

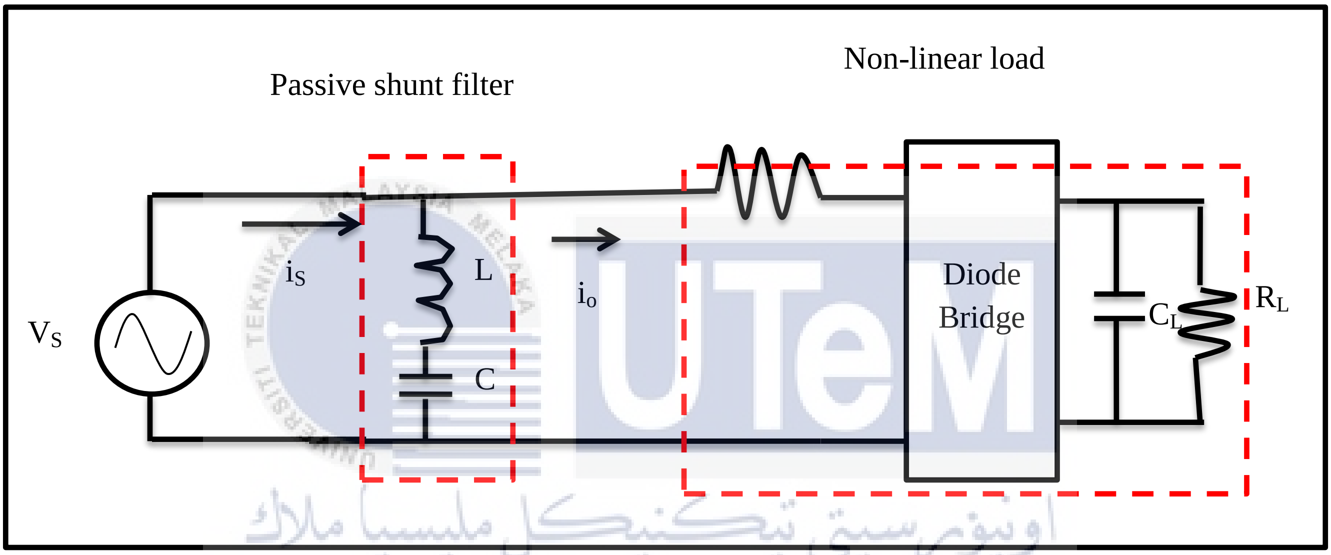

Figure 2.3: Schematic diagram of shunt connected passive filter.

2.4.5 Passive hybrid filter

Passive Hybrid is a combination of series type and shunt type of passive filter. It is used to supply the shortfall that occur from both passive filters and it will overcome to improve the harmonic compensation characteristics and distorted in distribution system.

2.4.6 Linear and Non-linear Load

In power system with a linear load the component in which current is proportional with the voltage. In other word the current and voltage will have a same shape of waveform. Usually the example of linear load is such as motors, heaters and incandescent lamps.

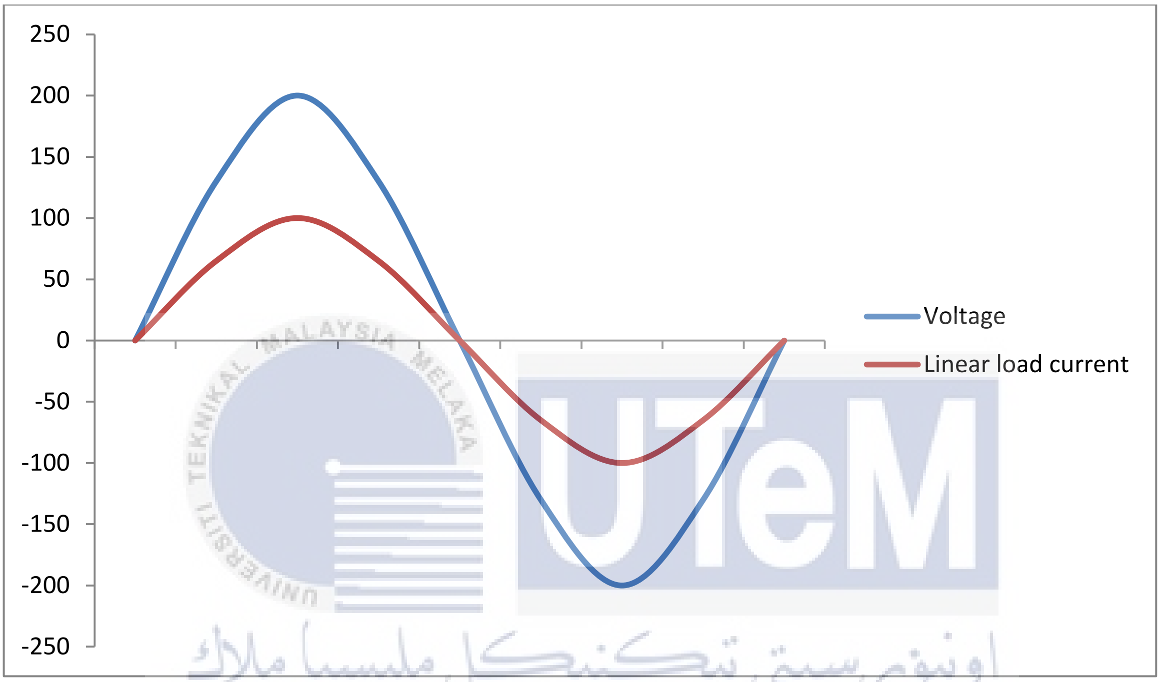

Figure 2.4 Voltage waveforms and current waveforms for the linear load.

In the other side, non-linear load will have different of current wave shape with the voltage. Usually the examples of non-linear loads such as rectifiers like power supplies discharge lighting, adjustable speed motor drives, ferromagnetic devices, DC motor drives and arcing equipment.

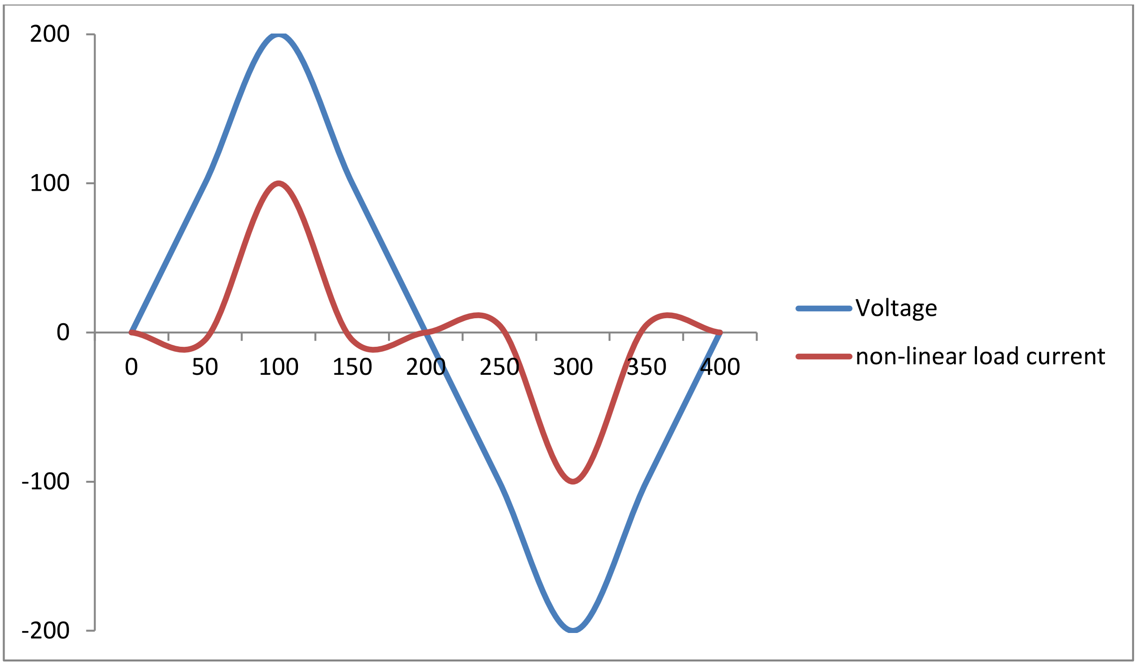

Figure 2.5 Voltage waveform and current waveforms for the non-linear loads.

The current drawn at non-linear loads is looks the same as cycle to cycle for the current wave but it is not in sinusoidal form. The series of sinusoidal waveforms is described in mathematically as periodic waveform that has been summed together. The form of sinusoidal component is an integer multiples of the fundamental where the fundamental frequency for Malaysia is 50 Hz. To measure the current and voltage harmonic by using the true-RMS reading meter. If an averaging meter is used, which is the common type, the error can be significant.

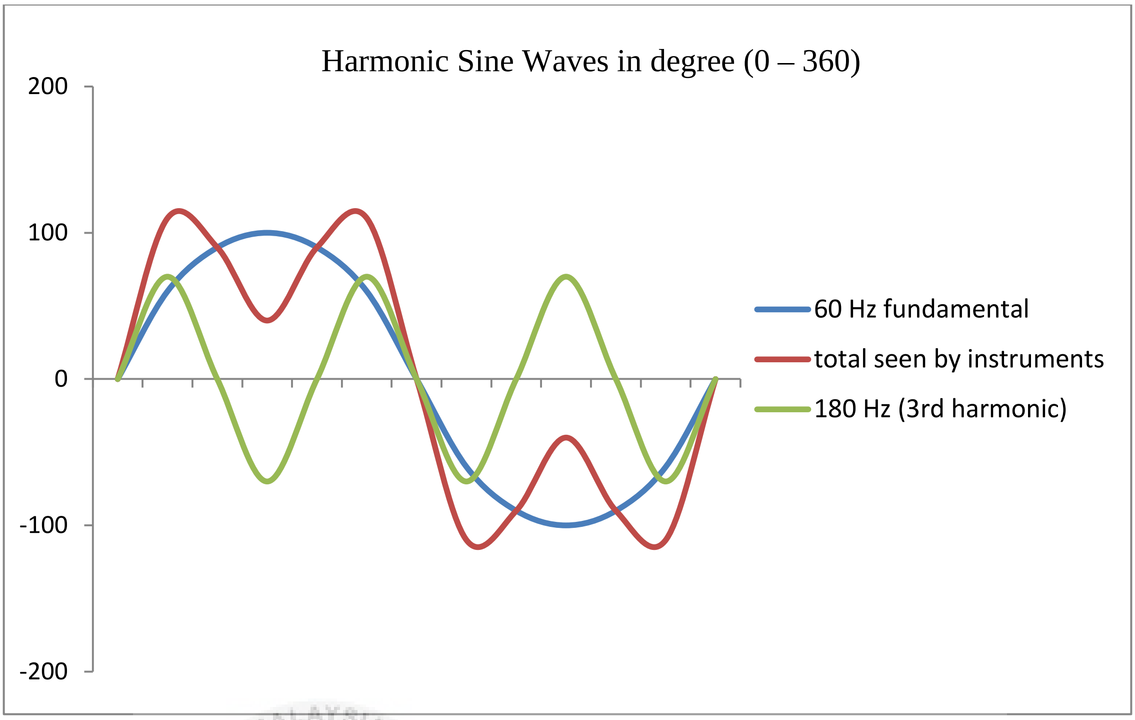

Figure 2.6: Waveform with symmetrical harmonic.

When the each term is in series it is referred to the harmonic of the fundamental. In symmetrical waves it only contains odd harmonics and un-symmetrical waveforms contain odd and even harmonics.

The positive portion in symmetrical wave is being used to identical the negative portion of the wave. An un-symmetrical wave contains a DC component or the load is such that the positive portion of the wave is different than the negative portion. The example of un-symmetrical wave would be a half wave rectifier.

2.4.7 P-Q Theory

The simple p-q theory is referring on the Instantaneous active and reactive power to set of instantaneous values of active and reactive power in the time domain. The voltage or current waveform will no restrict and it can be applied to the three phase distribution system with or without any neutral connection for three-phase to generate voltage and current waveform. It will not perform in the steady state and in the transient state.

The theory is easy and very efficient in designing controllers for power conditioners based on power electronic devices. It use to repair the three phase and single phase circuits.

$$\begin{pmatrix} \boldsymbol{v_0} \\ \boldsymbol{v_\alpha} \\ \boldsymbol{v_\beta} \end{pmatrix} = \mathbf{T}.\begin{pmatrix} \boldsymbol{v_a} \\ \boldsymbol{v_b} \\ \boldsymbol{v_c} \end{pmatrix} \qquad \begin{pmatrix} \boldsymbol{i_0} \\ \boldsymbol{i_\alpha} \\ \boldsymbol{i_\beta} \end{pmatrix} = \mathbf{T}.\begin{pmatrix} \boldsymbol{i_a} \\ \boldsymbol{i_b} \\ \boldsymbol{i_c} \end{pmatrix}$$

$$\mathrm{T} = \sqrt{\frac{2}{3}}\begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}$$

A. Instantaneous Zero-Sequence Power (p_0)

$$p_0 = v_0.i_0 = \overline{p_0} + \widetilde{p_0}$$

B. Instantaneous Real Power (p)

$$p = v_\alpha.i_\alpha + v_\beta.i_\beta = \bar{p} + \tilde{p}$$

C. Instantaneous Imaginary Power (q)

$$q = v_\beta.i_\alpha - v_\alpha.i_\beta = \bar{q} + \tilde{q}$$

2.5 Summary and discussion of the review

Based on the previous researcher, information and understanding in power quality transmission. It will guide to satisfy performance evaluation in reduction of harmonic distortion by using active and passive filter in distribution system.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

Power quality is a prime interest for the supplier as well as for the users. Any imperfection or deviation of voltage and current wave shape and power factor from the ideal is a burning question. Harmonic currents and voltages were simply hard to measure . Development of power electronic devices increased the power quality problem and also increased the probability of its control. In this work series connected active filter with shunt connected passive filter configuration is proposed.

3.1.1 Harmonic filtering techniques

Nowadays the administrative receiver who develops the electrical power is supplied all the way through to various electronic load stuffs such as AC- DC converter, Motor adjustable unit, and numerous switching way power supply system & computer process generator. All above reviewed terminology are handled on triode, diode, thyristor, transistor, which encourage the nonlinearity appearances and due to this nonlinear role the receiver will be the trigger of injecting the harmonic component in the distribution system and will correspondingly affect the other consumer by this pollution of harmonic in system. In common harmonic filter expertise is most significant for the power quality improvement of the system [4]. By using the combination of active and passive filter it will reduce the harmonic produce in the distribution system.

3.1.2 Flowchart for this project.

The project at first is to study from previous research what is the harmonics and what is the effect to distribution system or network. The circuit configuration is designed in MATLAB SIMULINK by combining both filters. The combination of both active and passive filters will reduce the total harmonic distortion (THD) in contrast to have an excellent power filter. The result from the simulation will be analysed to find a proper controller for active filter and parameter to tuned the passive filter.

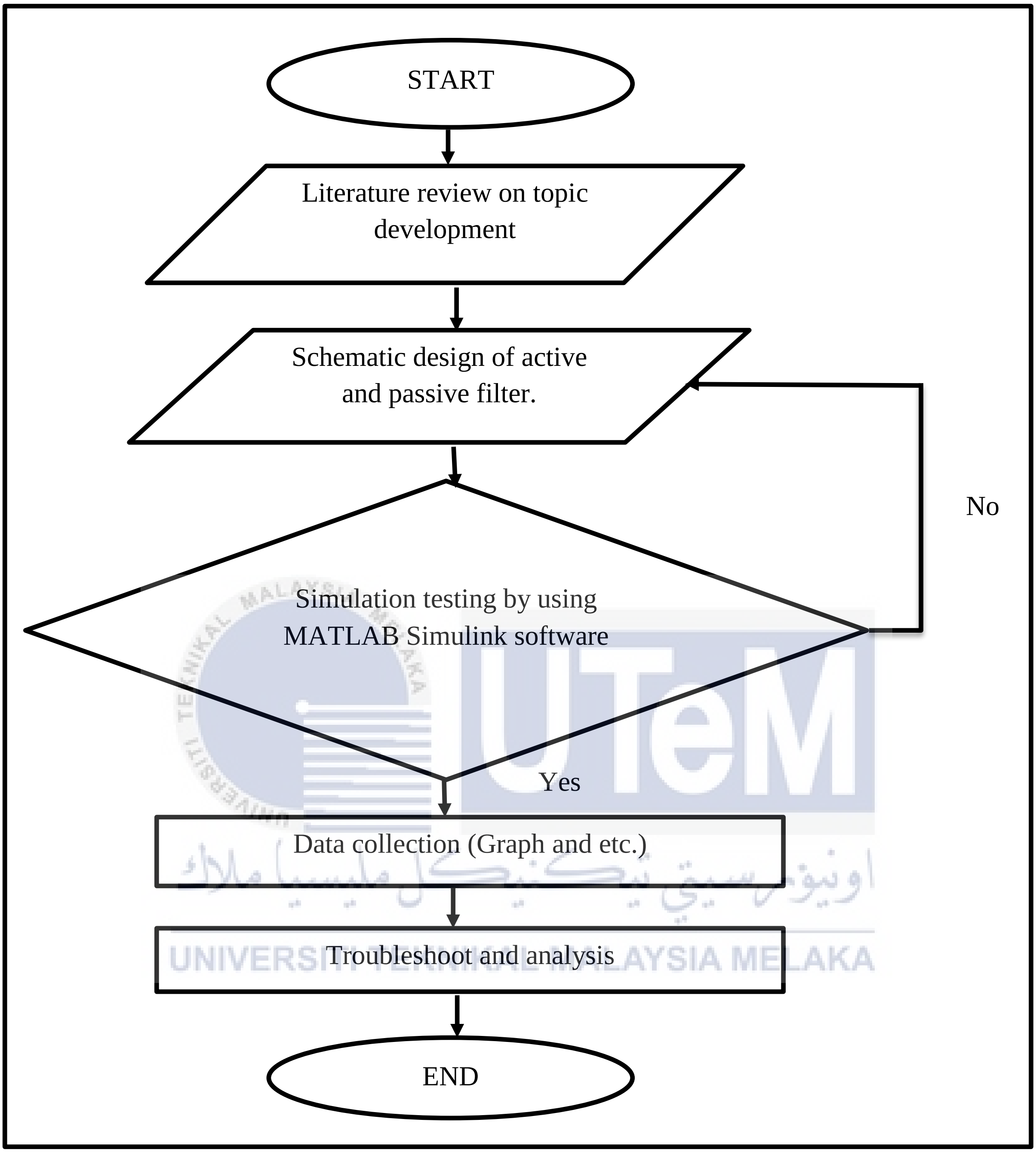

Figure 3.1.0: Flowchart for the project

3.2 Design process

The design process of the proposed method will be divided in to three stages as follows:

3.2.1 Step 1

In the initial stage the previous works on active and passive filters regarding topologies, control scheme and their applications has been reviewed. Types of controllers of active power filters will be studied.

3.2.2 Step 2

In the second stage, the proposed controller based on SRF for improving the output's harmonic profile will be developed. Using MATLAB/SIMULINK . The THD performance interm of current charasteristics will be analysed to achieve a final design that meets the objectives requirements.

3.2.3 Step 3

In the third stage is to implement the proposed controller for the active filter, data capture and analysis. Examine and test the simulation and various operating THD condition for non-linear load. The non-linear loads are the standard diode rectifier with capacitor-resistive load is in use as on the ac major for simulation in SIMULINK MATLAB.

3.3 Proposed control scheme based on SRF by using MATLAB

3.3.1 Synchronous Reference Frame (SRF)

It is proposed to use SRF theory to extract instantaneously active components positive sequence of currents at the fundamental frequency. The SRF isolator extracts the fundamental component of the load current by transformation of load currents: iLa, iLb and iLc to d-q reference frame. In the synchronously rotating reference frame, the positive sequence components at fundamental frequency (ω1), are transformed to DC quantities and all harmonic and negative frequency components undergo a frequency shift of ω1(=50Hz).

$$\begin{pmatrix} i_\alpha \\ i_\beta \end{pmatrix} = \sqrt{\frac{2}{3}} \begin{pmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & -\frac{\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \end{pmatrix} \begin{pmatrix} i_a \\ i_b \\ i_c \end{pmatrix} \tag{1}$$

$$\begin{pmatrix} {i_{Ld}}^{+} \\ {i_{Lq}}^{+} \end{pmatrix} = \begin{pmatrix} \cos\omega_1 t & \sin\omega_1 t \\ -\sin\omega_1 t & \cos\omega_1 t \end{pmatrix} \begin{pmatrix} i_{L\alpha} \\ i_{L\beta} \end{pmatrix} \tag{2}$$

SRF isolator extracts the DC quantities by low pass filters (LPF) for each iLd and iLq. The extracted DC components iLdcD + and iLdcQ + are transformed back into first α-β frame and then into a-b-c coordinates to obtain net positive sequence fundamental components as shown below:

$$\begin{pmatrix} {i_{L1\alpha}}^{+} \\ {i_{L1\beta}}^{+} \end{pmatrix} = \begin{pmatrix} \cos\omega_1 t & -\sin\omega_1 t \\ \sin\omega_1 t & \cos\omega_1 t \end{pmatrix} \begin{pmatrix} {i_{LdcD}}^{+} \\ {i_{LdcQ}}^{+} \end{pmatrix} \tag{3}$$

Whereas, the real active component of the positive sequence fundamental frequency current at α-β frame ($iL1R\alpha^{+}$, $iL1R\beta^{+}$) can be easily made from d-q frame,thus the a-b-c coordinates of real active component at fundamental frequency($iL1Ra^{+}$, $iL1Rb^{+}$, $iL1Rc^{+}$) can be evaluated as below:

$$\begin{pmatrix} {i_{L1R\alpha}}^{+} \\ {i_{L1R\beta}}^{+} \end{pmatrix} = \begin{pmatrix} \cos\omega_1 t & -\sin\omega_1 t \\ \sin\omega_1 t & \cos\omega_1 t \end{pmatrix} \begin{pmatrix} 0 \\ {i_{LdcQ}}^{+} \end{pmatrix} \tag{4}$$

$$\begin{pmatrix} i_{L1Ra} \\ i_{L1Rb} \\ i_{L1Rc} \end{pmatrix} = \sqrt{\frac{2}{3}} \begin{pmatrix} 1 & 0 \\ -\frac{1}{\sqrt{2}} & -\frac{\sqrt{3}}{2} \\ -\frac{1}{\sqrt{2}} & \frac{\sqrt{3}}{2} \end{pmatrix} \begin{pmatrix} i_a \\ i_b \\ i_c \end{pmatrix} \tag{5}$$

3.3.2 SRF controller applied to Active Power Filter.

The control scheme for the proposed system is based on the SRF based current decomposition, discussed in the previous section. Figure 3.1.1 shows the flow of various control signals and control scheme based on the decomposed components. The control scheme depicted in Fig. 3.1.1 also incorporates the command for maintaining the constant average DC bus voltage at the VSI.

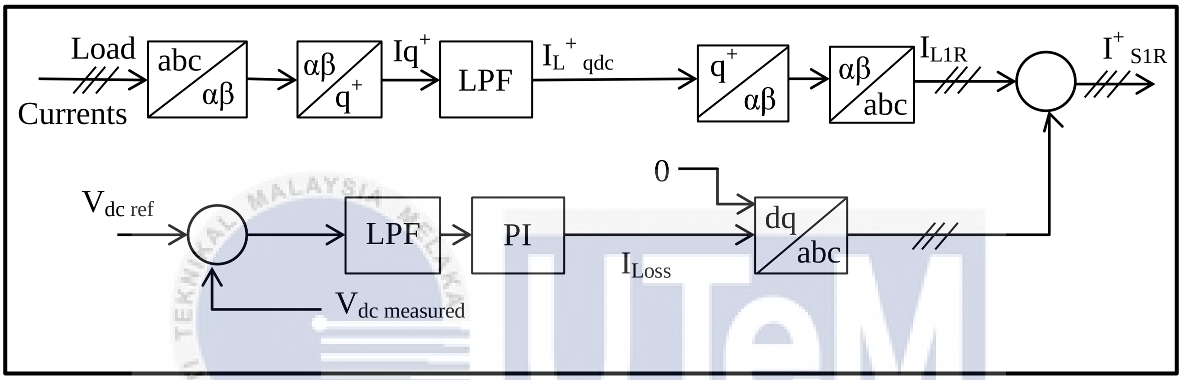

Figure 3.1.1: SRF Control scheme for Active power filter.

The command for desired compensation (isa*, isb*, isc*) is derived from taking difference of load current and the other decomposed components need to be compensated. This scheme facilitates the control of APF by indirect current control through hysteresis carrier-less PWM current controller.

3.4 Simulation Model of the Three-Phase Active Power Filter Using SRF Controller based on MATLAB/SIMULINK .

The proposed topology of The Three Phase Active Power Filter , as shown in Figure 3.1.3 was modelled via MATLAB/SIMULINK. Matlab is a software package that can be used to perform analysis, as well as solve mathematical and engineering problems. It has the characteristics of excellent programming and graphics capabilities. Meanwhile, Simulink is used to model, analyse, and stimulate dynamic system block diagram, which is fully integrated with MATLAB, easy and quick to learn, as well as flexible. It has a comprehensive library of blocks that can be used to simulate systems of linear, non-linear or discrete elements.

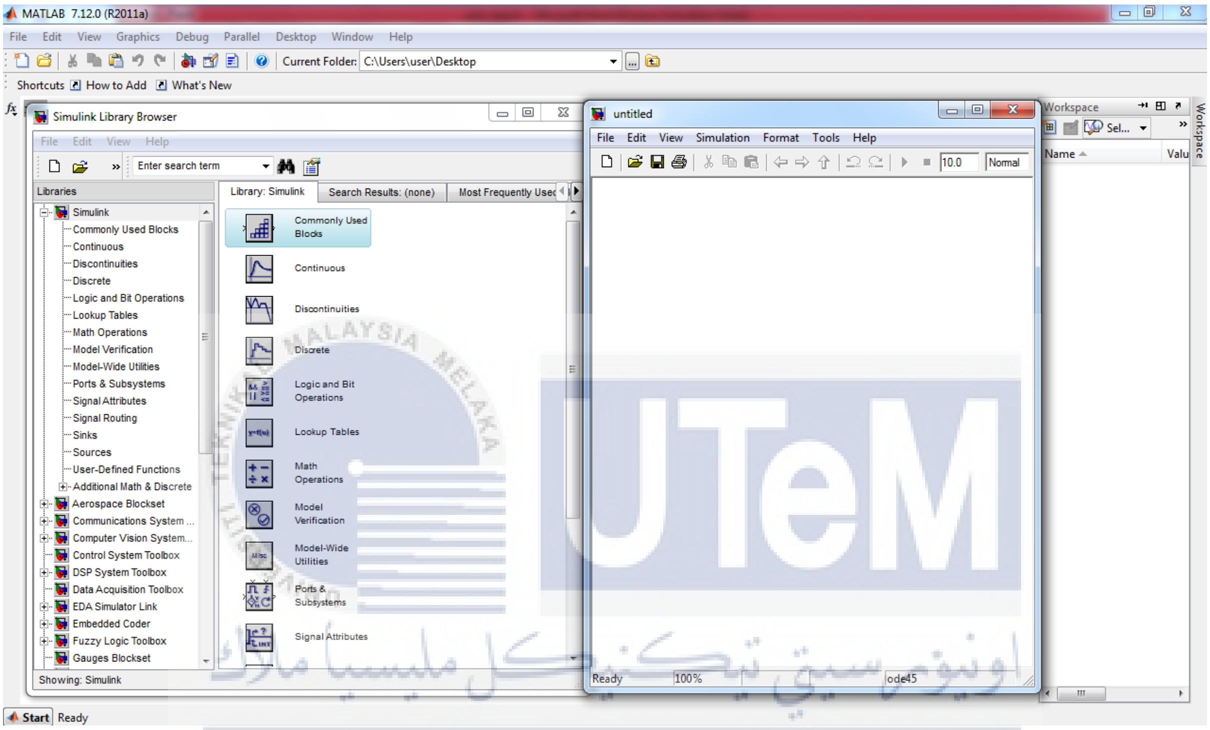

Figure 3.1.2: MATLAB/SIMULINK 7.120 (R2012a)

3.5 The Proposed configuration Using MATLAB/SIMULINK

Figure 3.1.3 shows the overall designed model of the three phases active power filters, combination with shunt passive filters. The sytem configuration comprises of as described below;

1. Source of the distribution system.
2. The non-linear load at the end of transmission line.
3. The linear load at the end of transmission line.
4. Passive filter: 5th harmonic filter and 7th harmonic filter.
5. Active power filter (injection).
6. Controllers based on SRF.

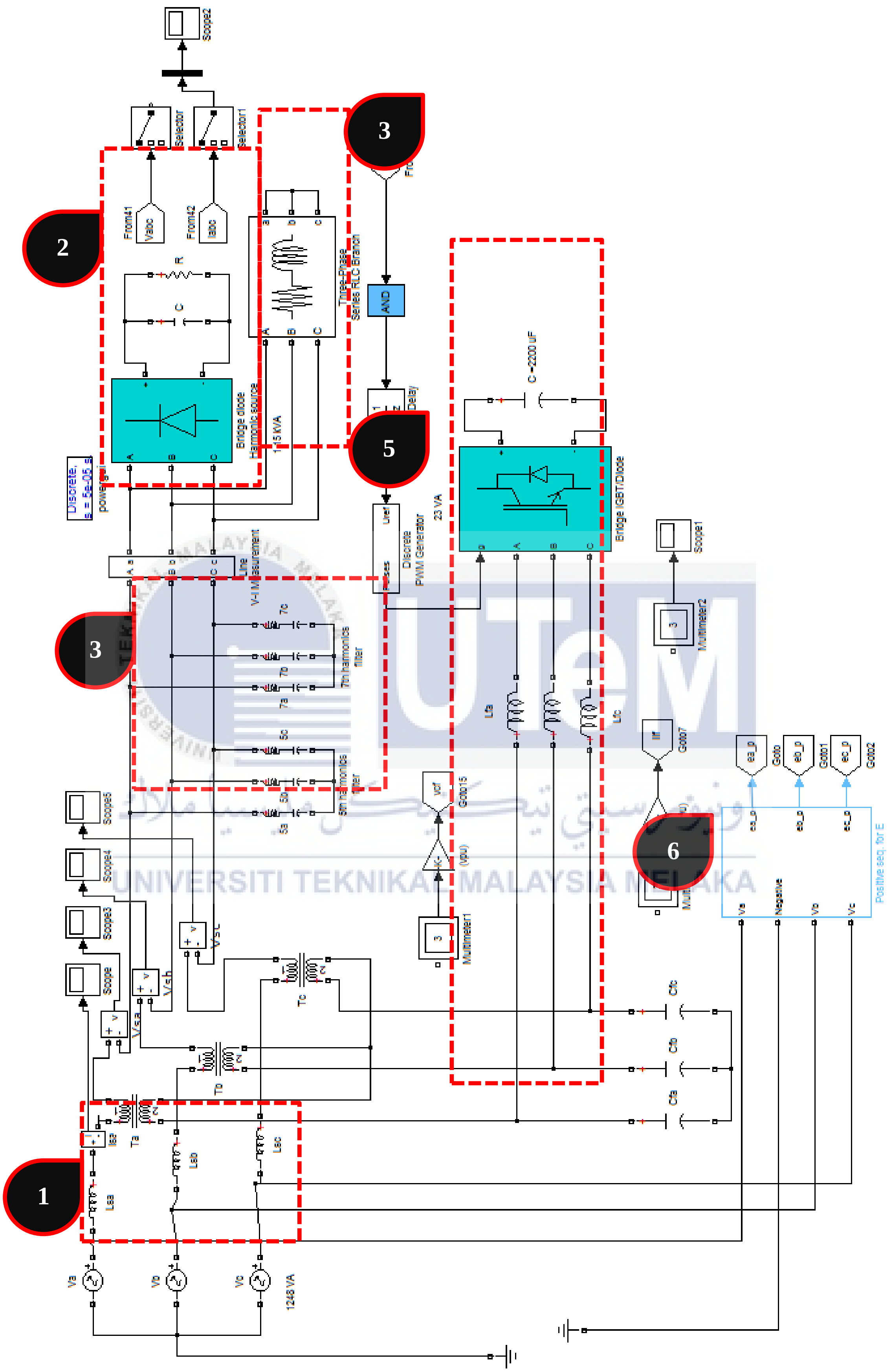

Figure 3.1.3: The circuit configuration.

Tuning parameters of the SRF Controller

A SRF controller was selected and designed to perform the control of the active power Filter. The SRF parameters were tuned in the MATLAB/SIMULINK Figure 3.1.3 to get a output of the active power filter.. The simulation results of the output Active Power Filter are shown in Chapter 4.

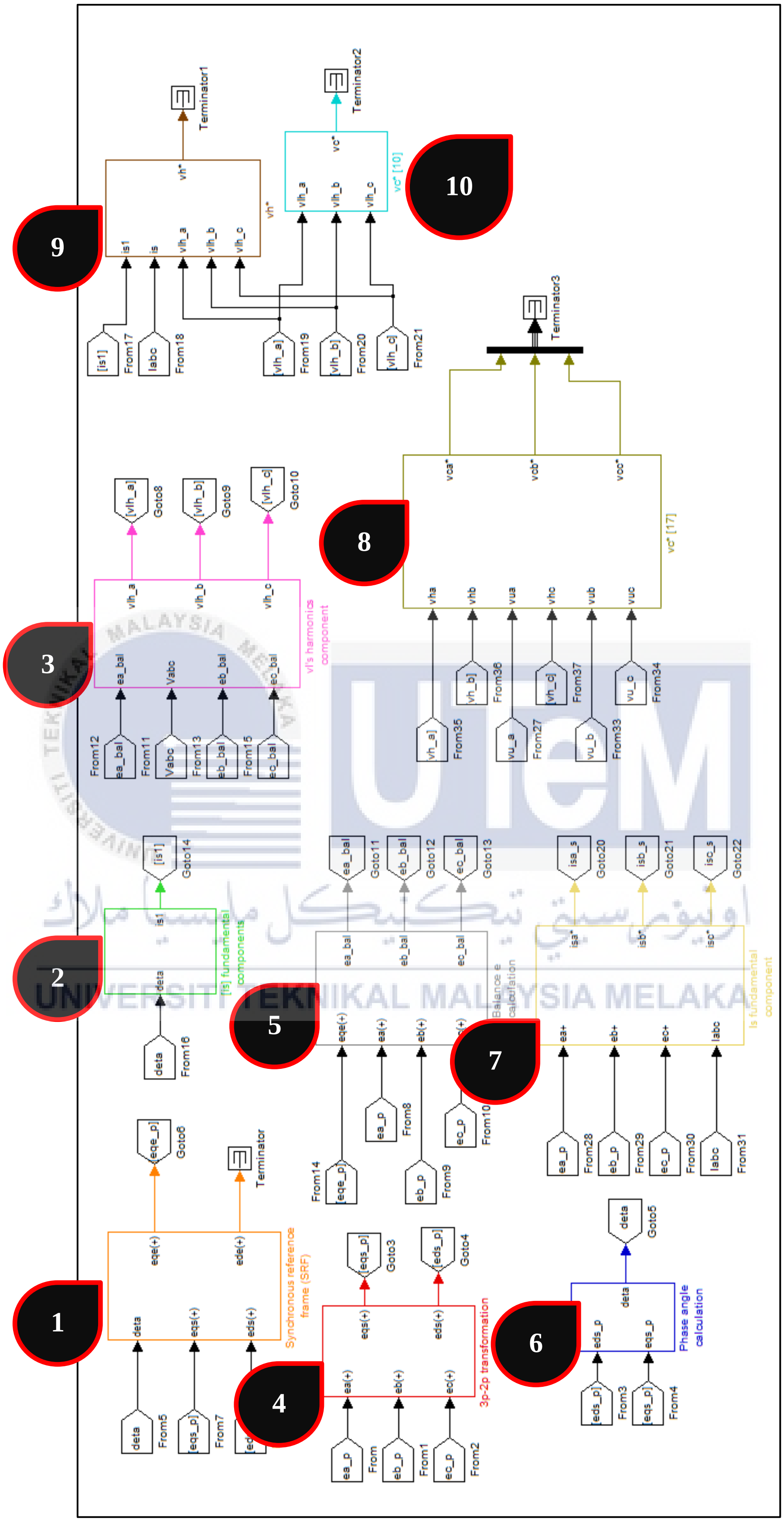

Figure 3.1.4: The Proposed controller Applied to Active Power Filter.

SRF Controller applied to Circuit configuration

1. Synchronous Reference Frame (SRF)
2. I_{source} (fundamental components)
3. Voltage at load side (harmonics component)
4. 3 phase to 2 phase transformation
5. Balance equation calculation
6. Phase angle calculation
7. I_{source} (fundamental components)
8. Vc^*
9. Vh^*
10. Vc^*

Tuning Shunt Passive Filter

Based on Figure 3.1.3 the shunt passive filter has been tuned to 5^{th} and 7^{th} of harmonic order. spectrum and their parameters value as shown in table 3.1.1 below:

Table 3.1.1: Parameter for LC passive filters.

Passive Power Filter	Values
5^{th} Harmonic Order	C = 200e-6 F , L = 2.03e-3 H
7^{th} Harmonic Order	C = 200e-6 F , L = 1.03e-3 H

CHAPTER 4

RESULT AND ANALYSIS

4.1 Introduction

The model as shown in Figure 3.1.3 has been simulated for the proposed active power filter combined with passive shunt filter using MATLAB/SIMULINK. Inductance,Capacitor, resistance and rectifier were used as linear load as a harmonic source. A closed loop control system based on SRF controller has been developed and tested to verify the performance of the proposed algorithm.

The source current and its spectrum before compensation by active and passive filter and after compensation by active and passive filter.

4.2 CASE STUDY 1: (linear Load R= 1000 ohm and L= 10uH), without filter

Case study as shown in Figure 3.1.3 has been simulated using MATLAB/SIMULIK without active and passive shunt filter. The connected load comprises of R-L load and their values is equal R=100 Ω and L= 100uH. The current waveform at the supply voltage as shown in Figure 4.1.1. From the the waveform of current is no has harmonic contents.

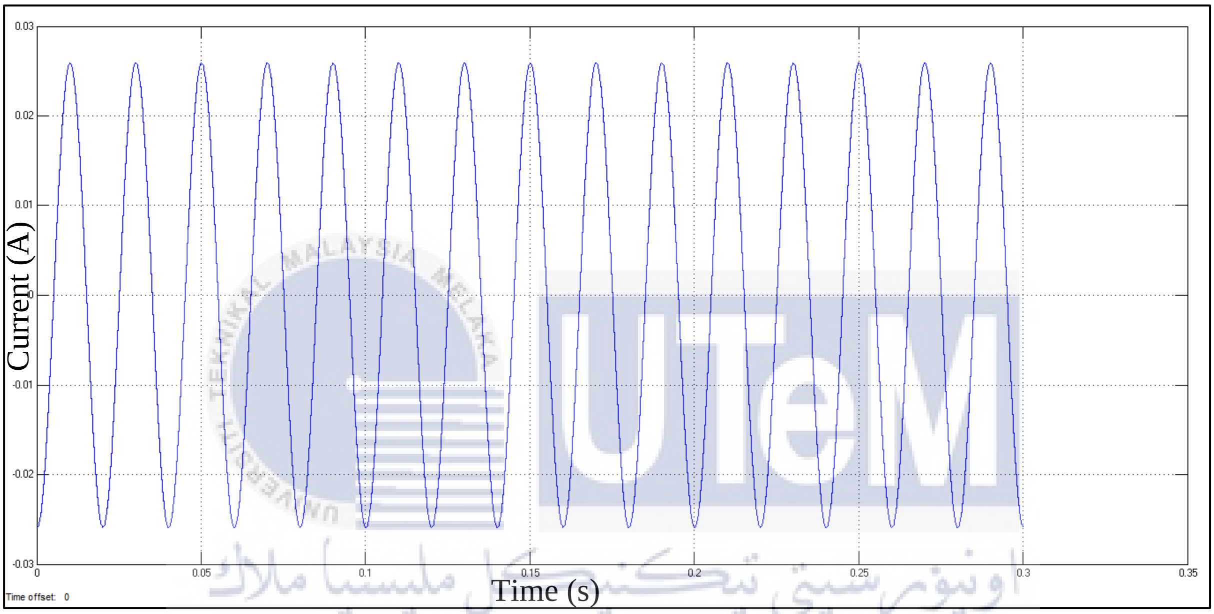

Figure 4.1.1: The current waveform at the supply voltage.

Figure 4.1.1 shows that the current waveform at the source is clean from distortion and get sinusoidal waveform. This waveform has no contamination of harmonic because of the linear load.

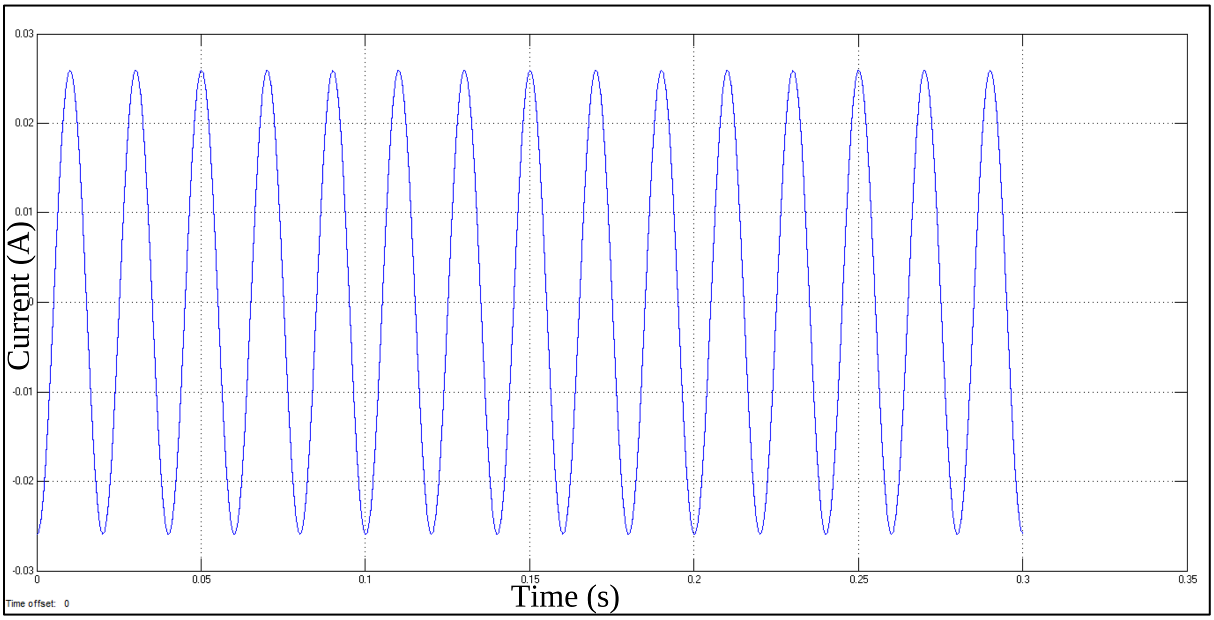

Figure 4.1.2: The current waveform at the load.

Figure 4.1.2 shows that the current waveform at the load is clean for distortion and get sinusoidal waveform. This waveform has no contamination of harmonic because of the load is linear load.

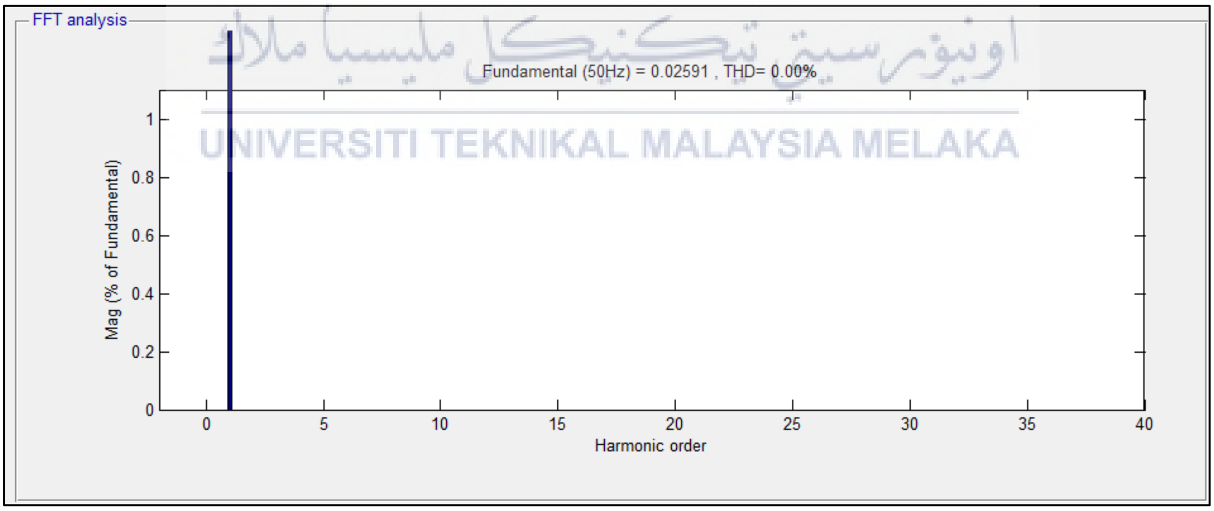

Figure 4.1.3: The THD_I value at the voltage supply.

Figure 4.1.3 shows the harmonic spectrum of the THD for current at the voltage supply is **0%**.

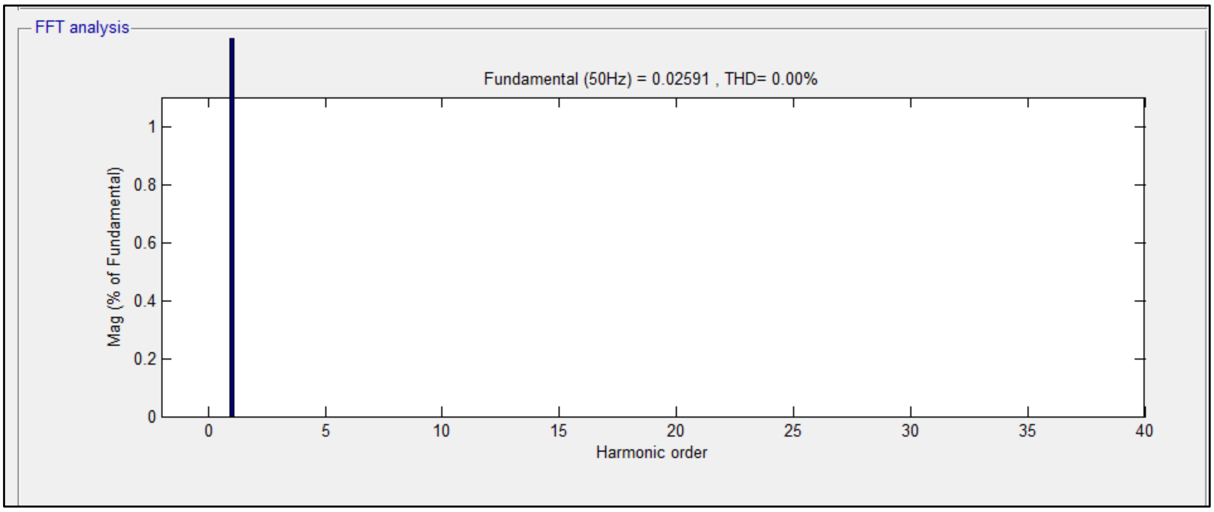

Figure 4.1.4: The THD_I value at the load.

Figure 4.1.4 shows the harmonic spectrum of the THD for current at the load is **0%**. It is because of the linear load does not produce harmonic in the system.

Figure 4.1.5 shows the voltage waveform at the load that no effect the system because of the load is linear load.

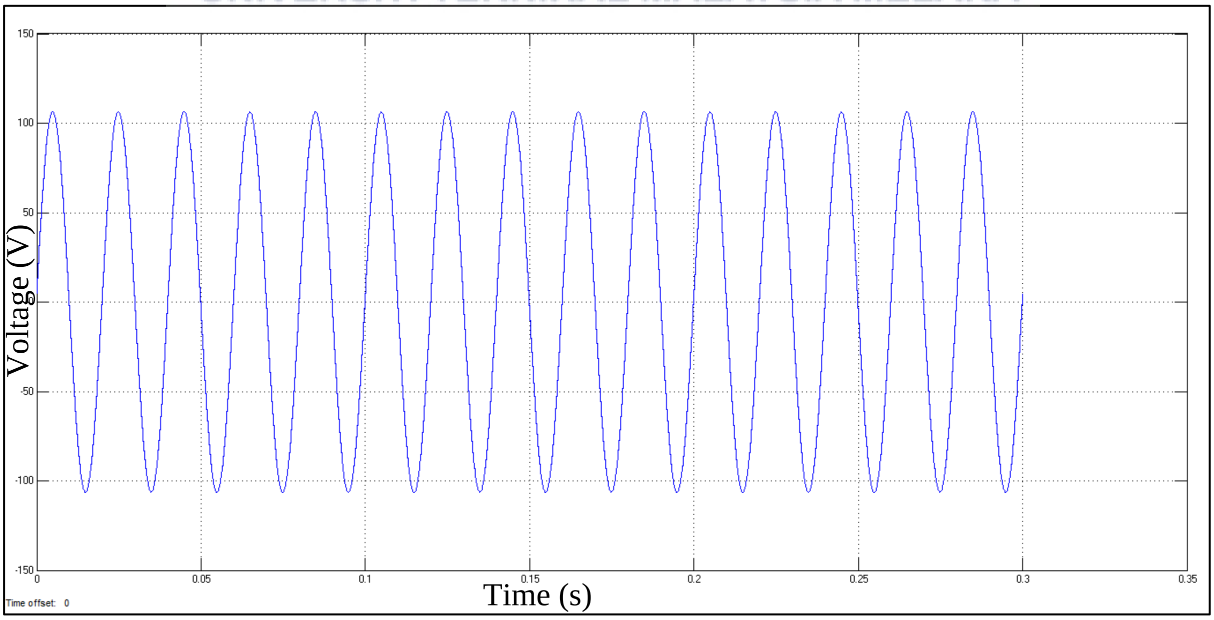

Figure 4.1.5: The voltage waveform at the load.

4.3 CASE STUDY 2: (non-linear Load R= 100 ohm and C= 1000uF), without filter

The second simulation of the Case study 2 as shown in Figure 3.1.3 has been simulated using MATLAB/SIMULIK without active and passive shunt filter. The connected non-linear load comprises of R-C load and their values is equal R=100 Ω ohm and C=1000µF. The current waveform highly contents of harmonics

Figure 4.1.6 shows that the current waveform at the voltage supply. It contains distortion because the non-linear load.produced high contents of harmonics

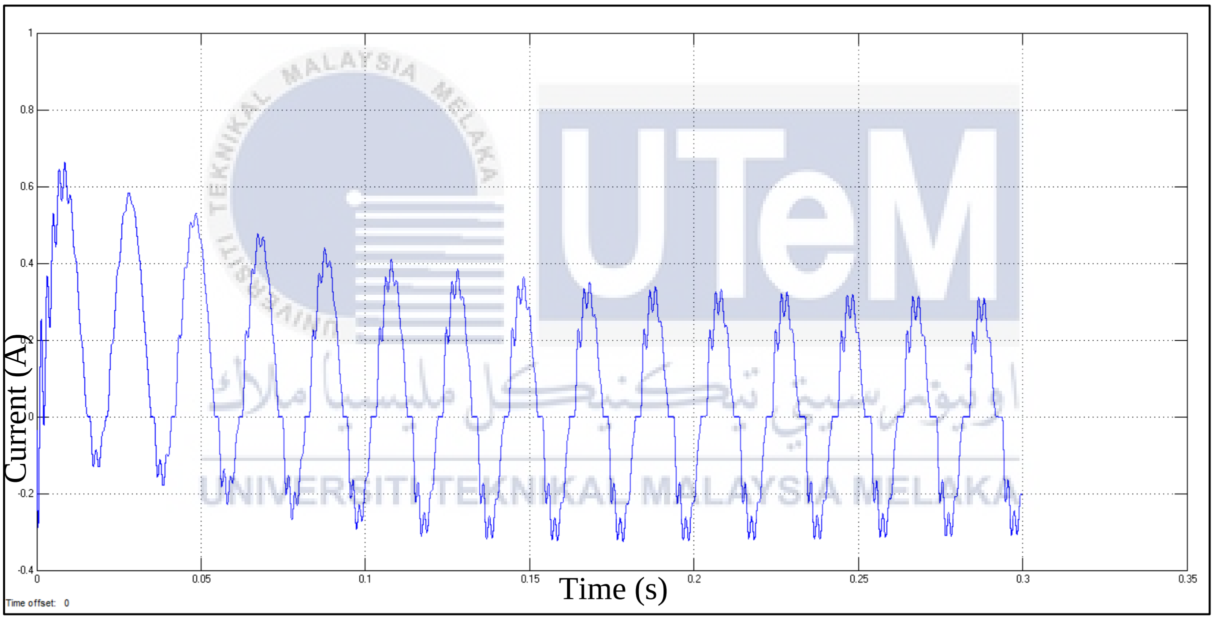

Figure 4.1.6: The current waveform at the supply voltage.

Figure 4.1.7 shows the current waveform at the load. It contains distortions that produce from the non-linear load.

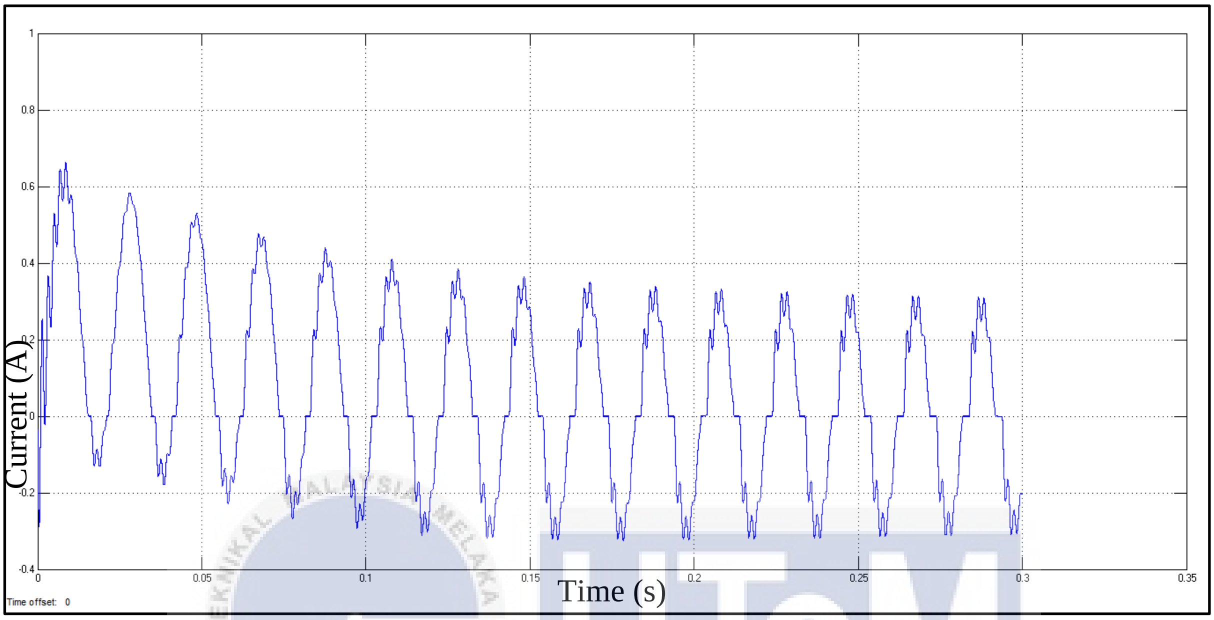

Figure 4.1.7: The current waveform at the load.

Figure 4.1.8 shows that the voltage waveform at the supply voltage is clean. It is because the distortion is not effected the voltage in system.

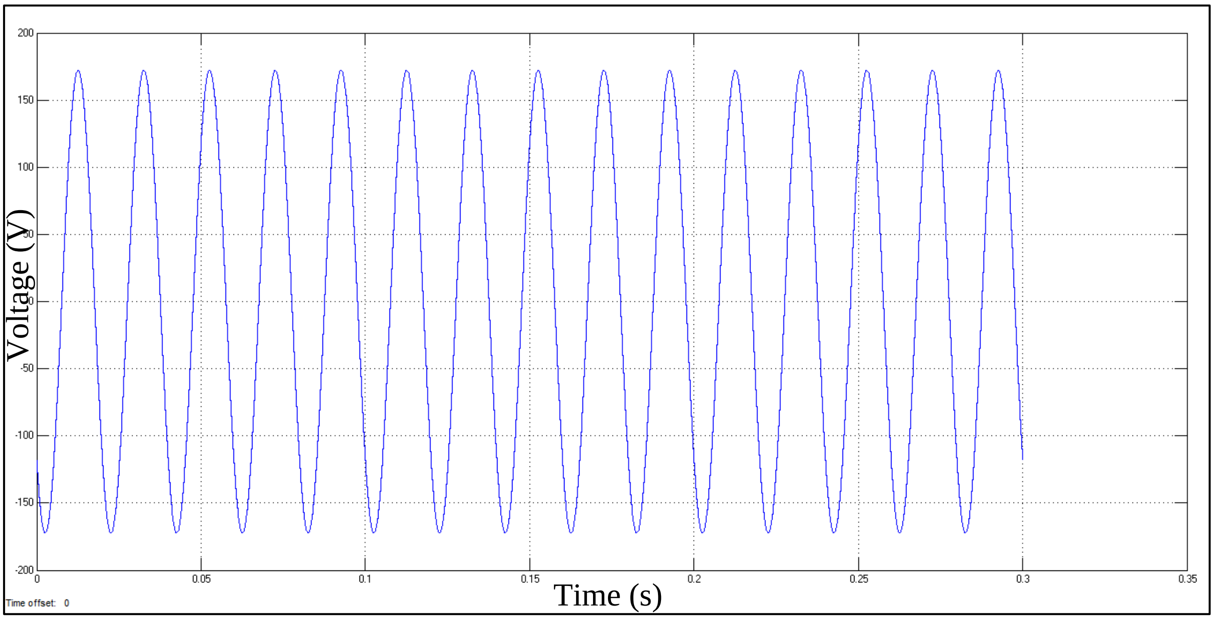

Figure 4.1.8: The voltage waveform at the supply voltage.

Figure 4.1.9 shows that the voltage waveform at the load had distortion that generates from the non-linear load

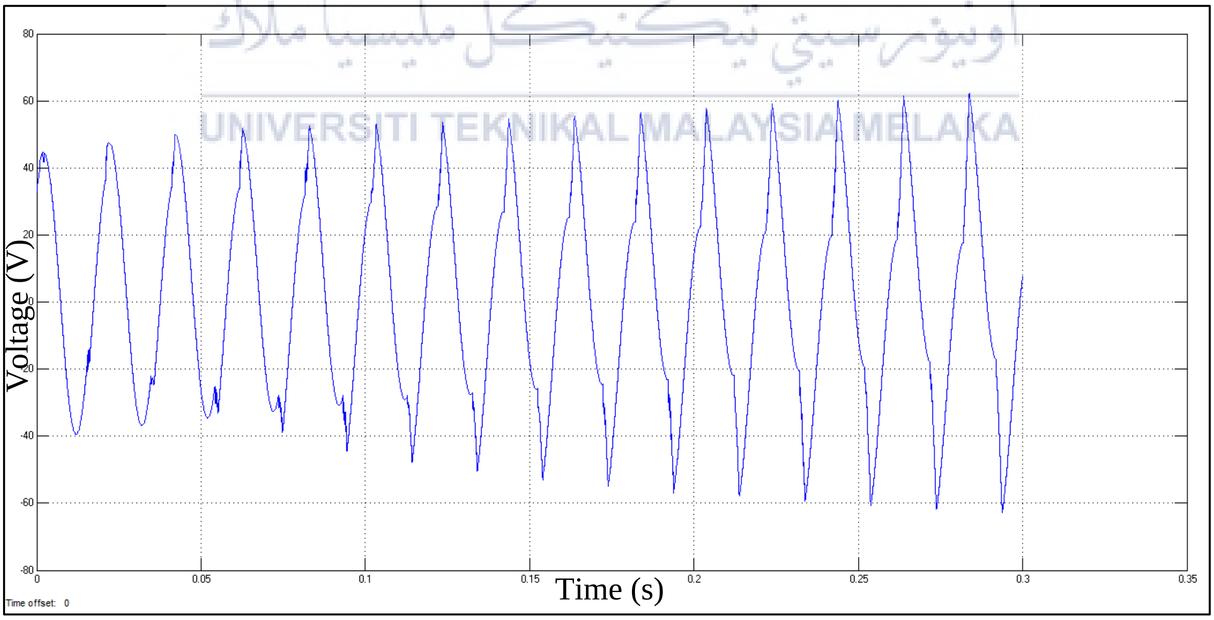

Figure 4.1.9: The voltage waveform at the load.

Figure 4.1.9 shows that the voltage waveform at the load had distortion that generates from the non-linear load. Figure 4.1.10 shows that the harmonic spectrum for the current THD at the supply voltage is 19.95%. It shows that the distortion is happen at the supply voltage. This is because of the supply voltage is not protected by the filter. Distortion that produces from the non-linear load returned to the supply voltage and effect the current at source.

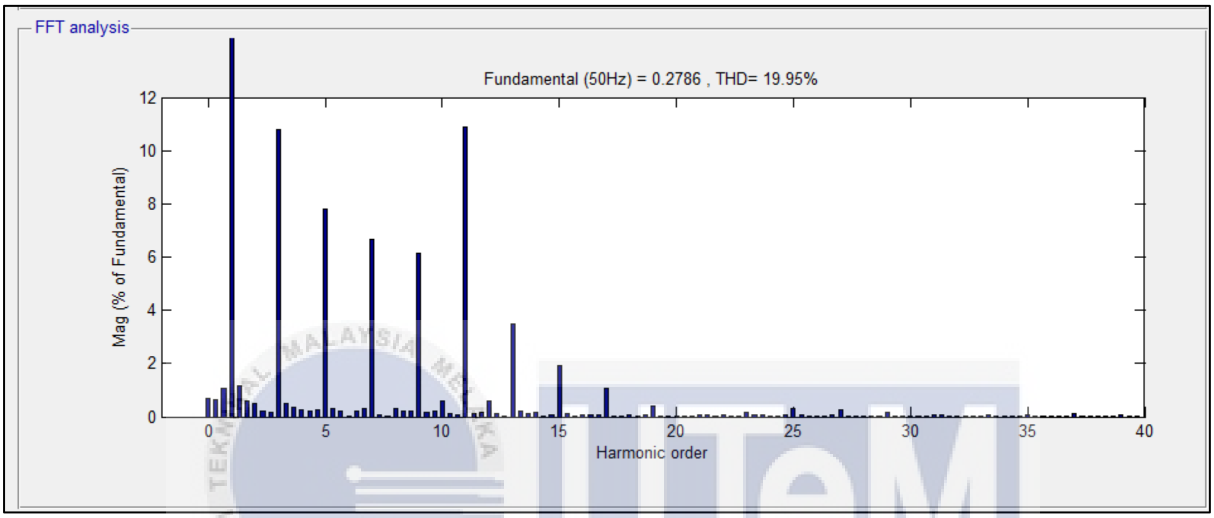

Figure 4.1.10: The THD_I at the supply voltage.

Figure 4.1.11 shows that harmonic spectrum for the voltage at the supply voltage is 0%. This is because distortion not produces in voltage at the supply voltage.

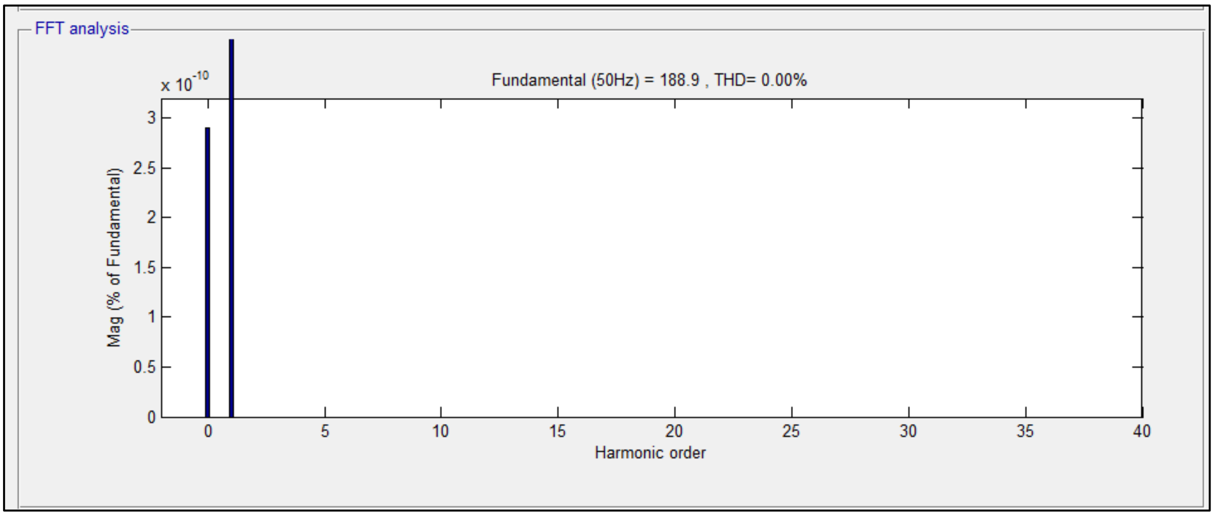

Figure 4.1.11: The THD_V at the supply voltage.

The harmonic spectrum for current at load can be described as shown in Figure 4.1.12 with THD value is equal 21.32%. .

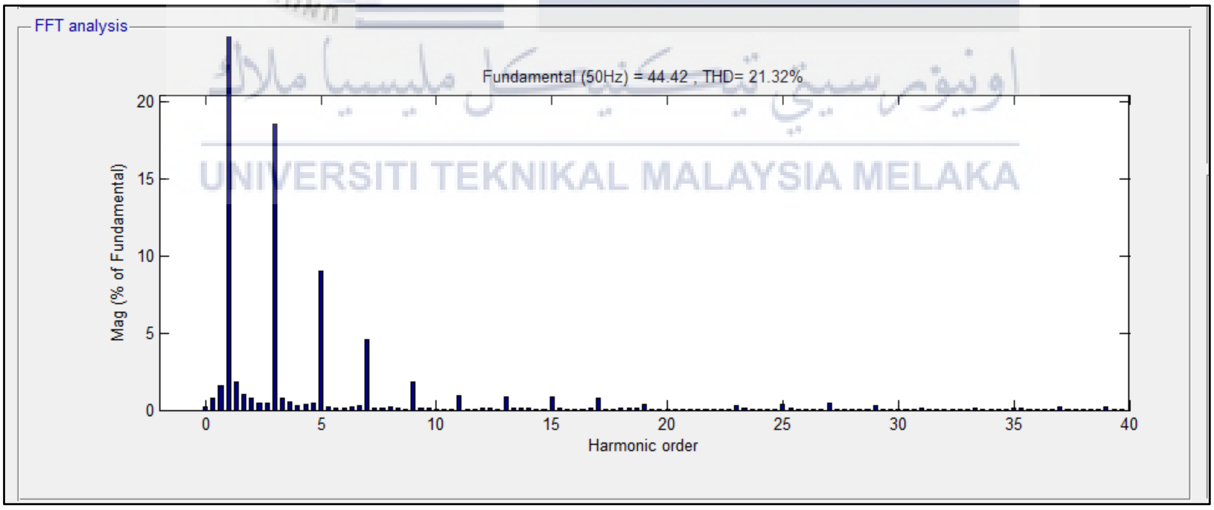

Figure 4.1.12: The THD_V at the load.

Figure 4.1.13 shows that the harmonic spectrum for the current at the load is 19.95%. The distortion is present because of the non-linear load.

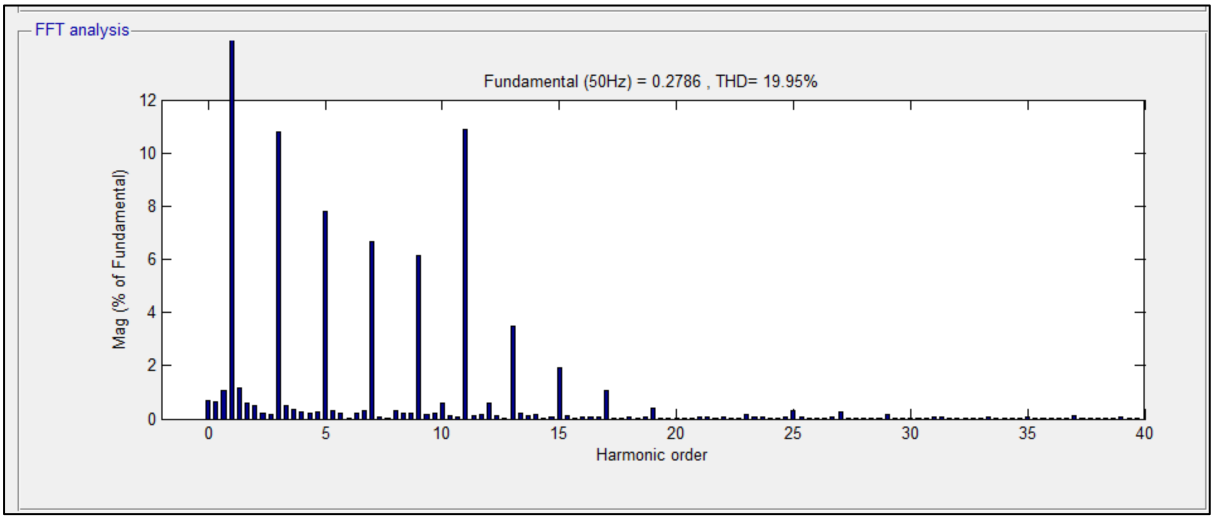

Figure 4.1.13: The THD_I at the load.

4.4 CASE STUDY 3: (non-linear and linear), with both passive and active filter.

The third simulation is about the case study as shown in Figure 3.1.3 has been simulated using MATLAB/SIMULIK with both active and passive shunt filter as a mitigation devices . The load is connected with both linear and non-linear load. The non linear load will produced highly contents harmonics. Figure 4.1.14 shows that the current waveform at the supply voltage is not have distortion present. Because of the filter is protecting the distortion that produces at the load to return to the supply voltage.

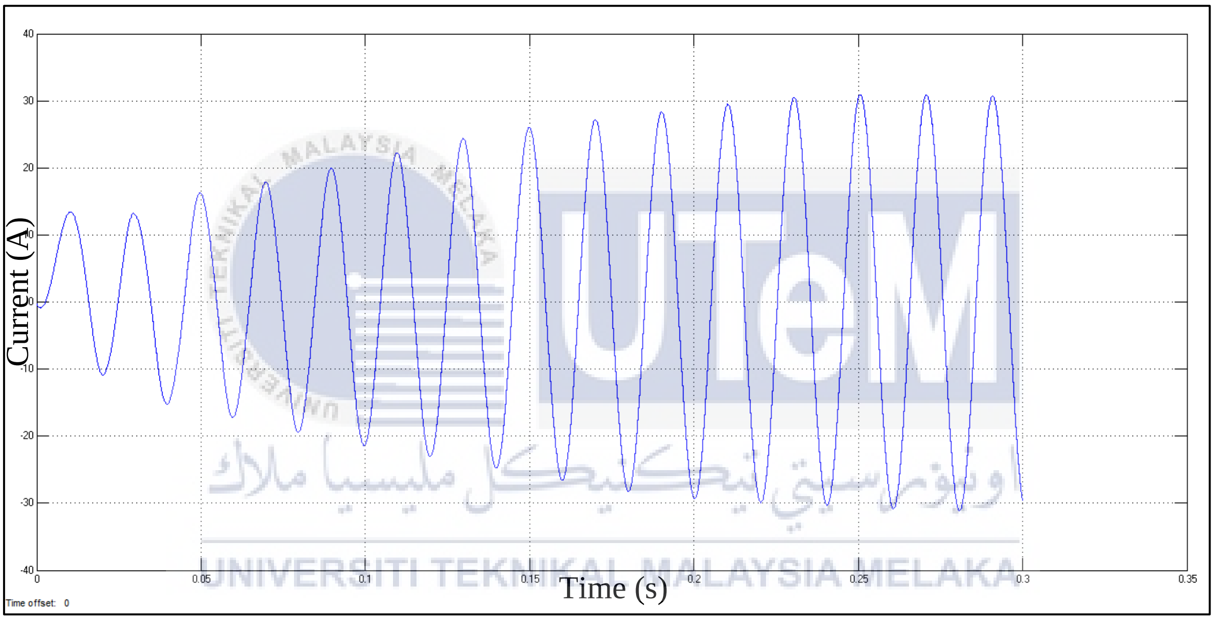

Figure 4.1.14: The current waveform at the supply voltage.

The current waveform with non linear load at the load side has been simulated The waveform of current can be seen in Figure 4.1.15 . From the figured showed that the waveform is highly distortion iIt is because the load produces harmonic and it affected much at the current in the system

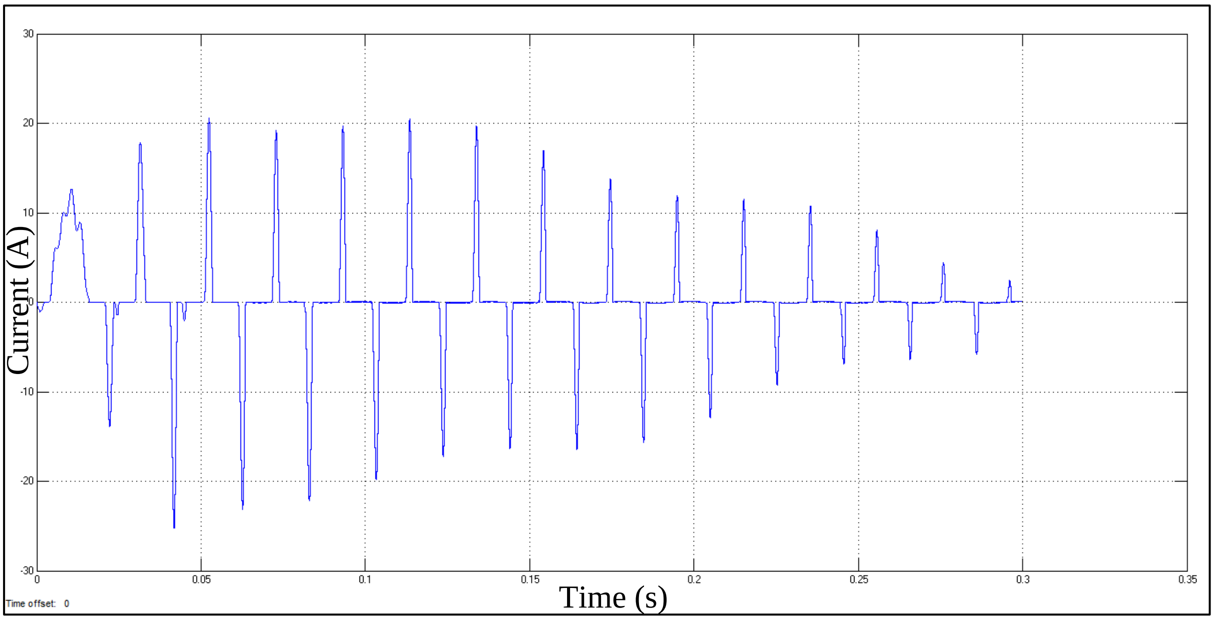

Figure 4.1.15: The current waveform at the load.

Figure 4.1.16 shows that the voltage waveform at the supply voltage have no distortion and pure sine. The distortion that produces at the load is not affecting the voltage at supply voltage because installation of the filter protected the system.

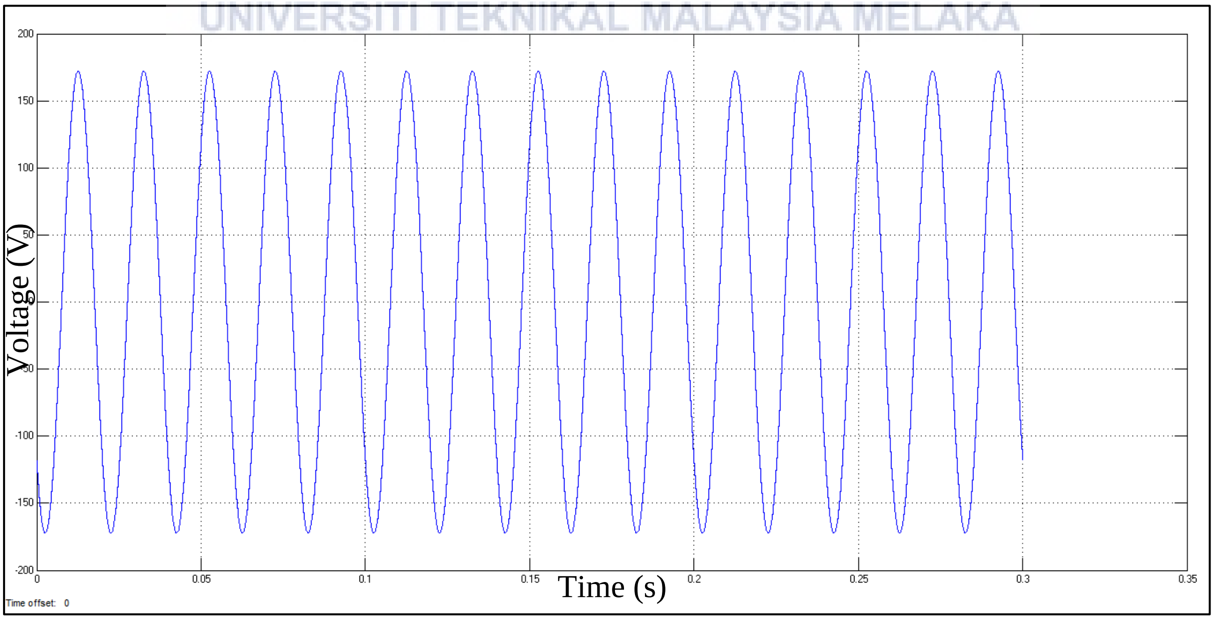

Figure 4.1.16: The voltage waveform at the supply voltage.

Figure 4.1.17 shows that the voltage waveform at the load is present and highly contains of distortion. This is because the load generates harmonic from the both linear load and non-linear load.

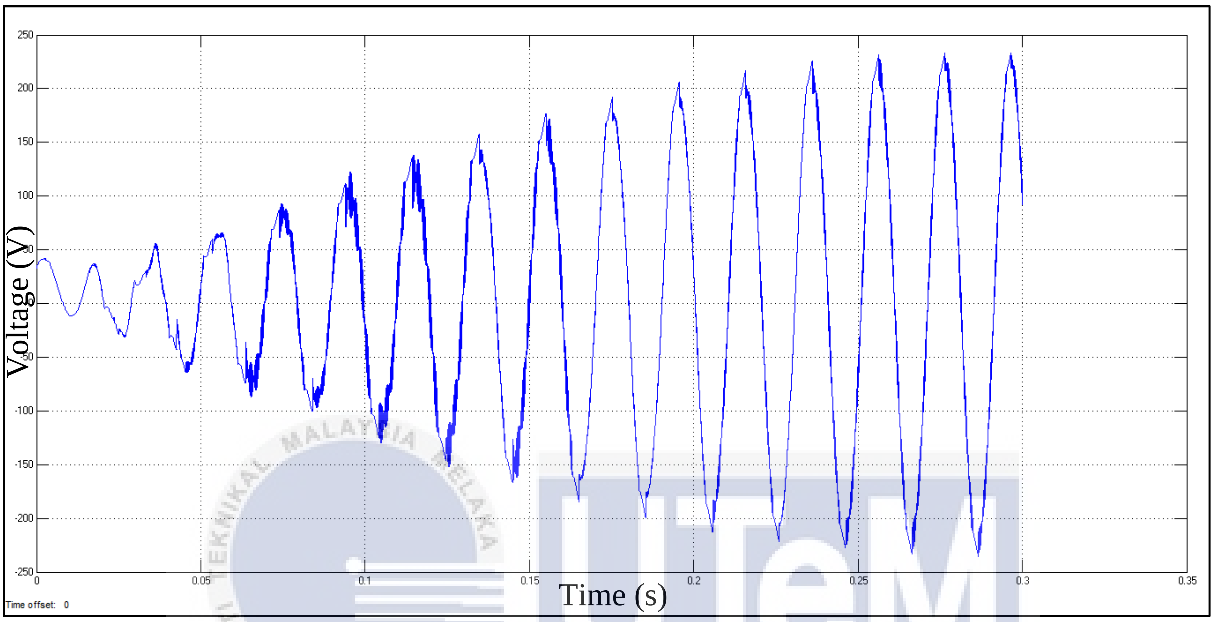

Figure 4.1.17: The voltage waveform at the load.

Figure 4.1.18 shows that the harmonic spectrum of the current at the supply voltage is 0.64%. It show that the both filter manage to reduce the harmonic distortion at the loads.

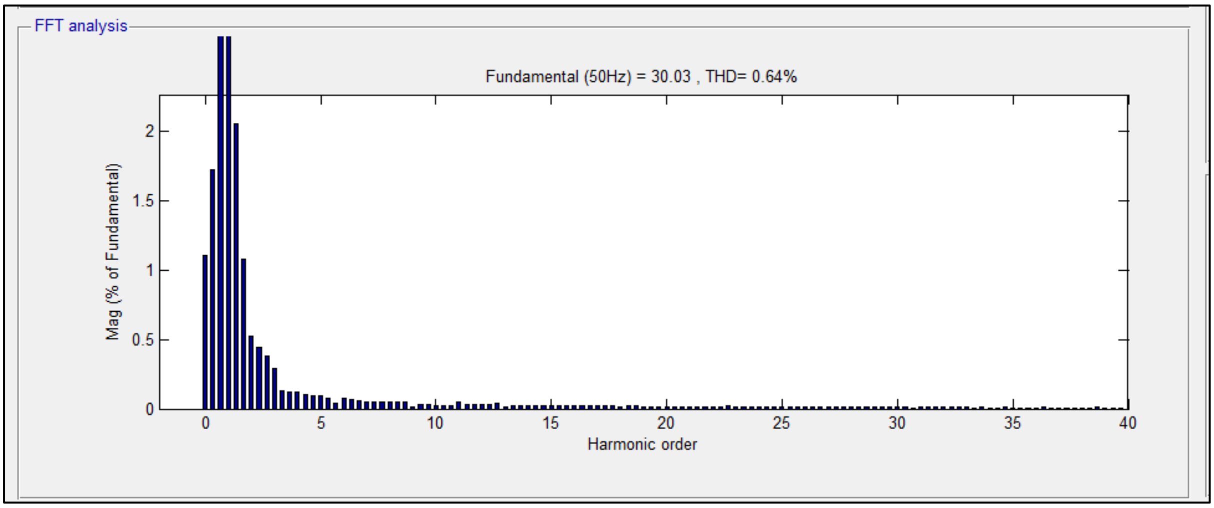

Figure 4.1.18: The THD_I at the supply voltage.

Figure 4.1.19 shows that the harmonic spectrum of the voltage at supply voltage is 0%. The distortion that produces at the load not affecting the voltage at the supply voltage.

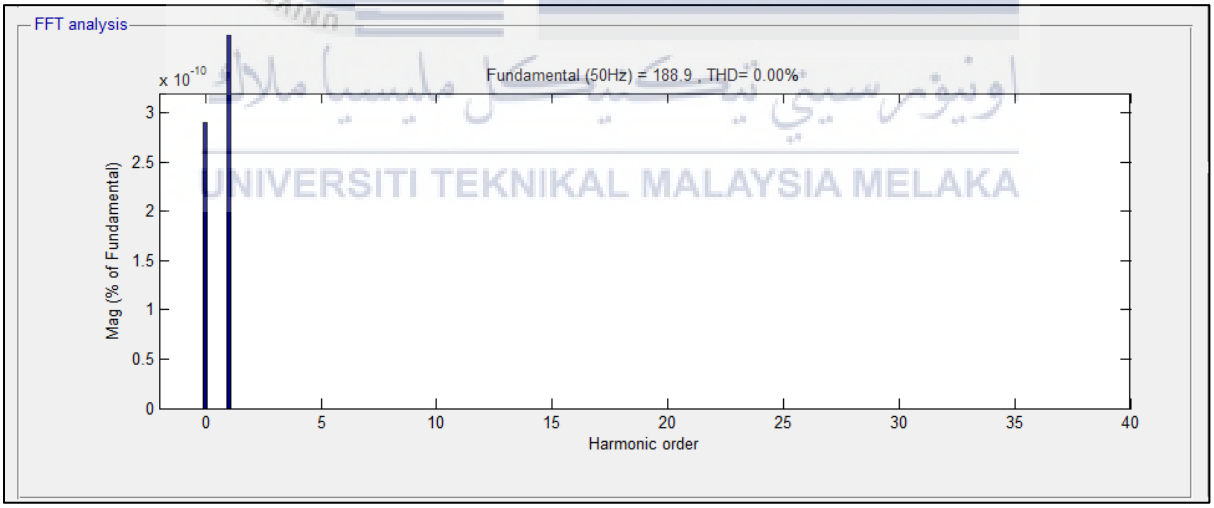

Figure 4.1.19: The THD_V at the supply voltage.

Figure 4.1.20 shows that the harmonic spectrum of the current at the load is 149.34%. The value of THD_A is high because of the distortion that generate at the load is affecting the current in the system.

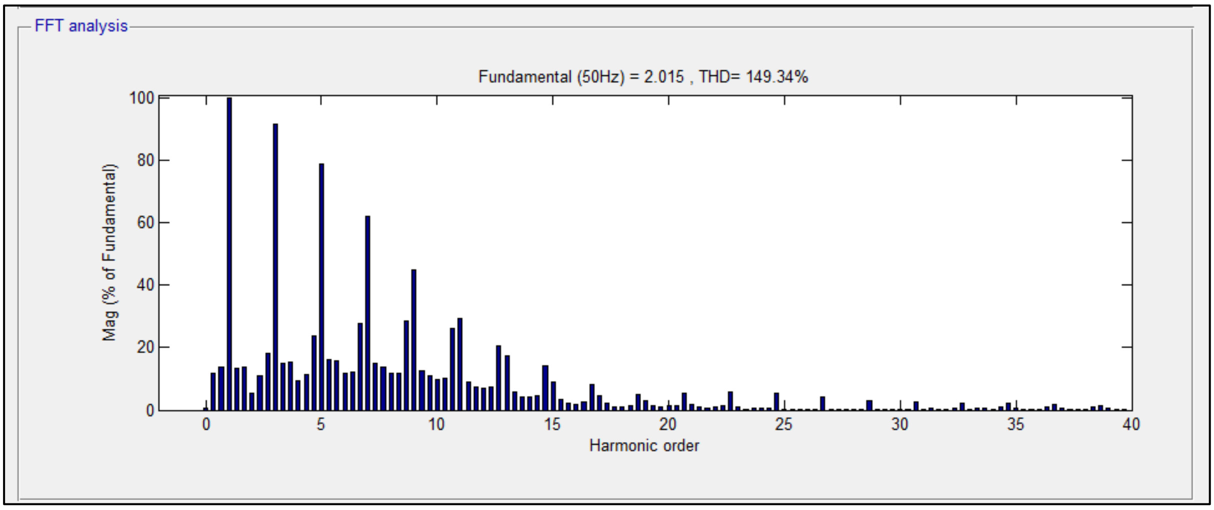

Figure 4.1.20: The THD_I at the load.

Figure 4.1.20 shows that the harmonic spectrum of the current at the load is 149.34%. The value of THD_I is high because of the distortion that generate at the load is affecting the current in the system.

Figure 4.1.21 shows that the harmonic spectrum of the voltage at the load is 3.68%. This is because the distortion that generates at the load is reduce because of the both filter manage to filter well.

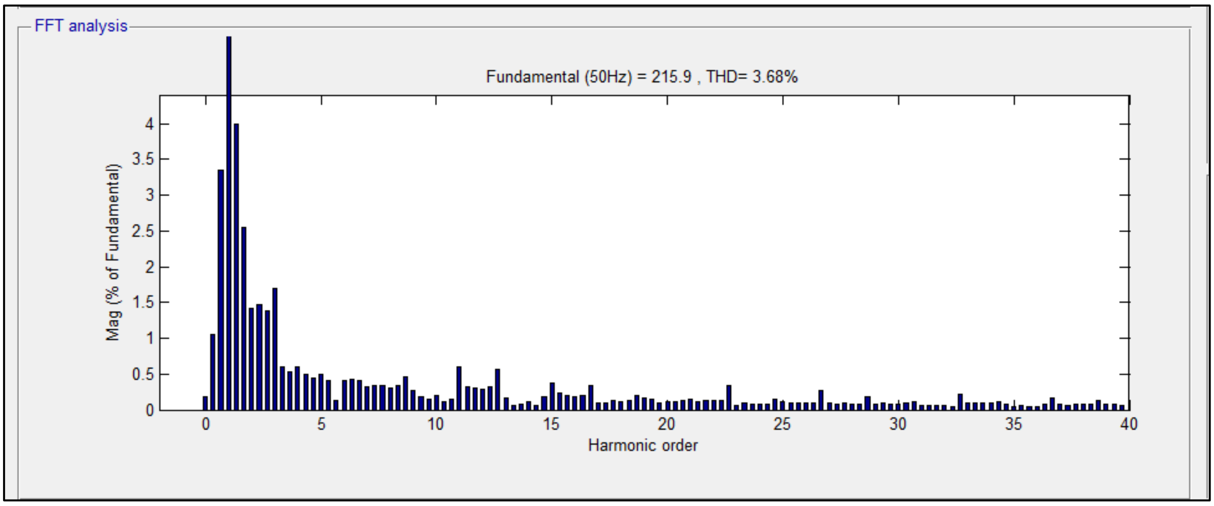

Figure 4.1.21: The THD_V at the load.

As the result, the distortion in the system is increase due to the load. The filter is use as the filtering device that manage to reduce the distortion and it can be seen that the compensation results respect the IEEE 519 standard for Harmonics [11] (THD ≤5%).

Table 4.1.2 shows that the every cases with THD_A and THD_V value at supply voltage and load in the system.

Table 4.1.2: Simulation results.

	Supply voltage		Load	
	THD_I	THD_V	THD_I	THD_V
Case study 1 -linear load -without filter	0.00%	0.00%	0.00%	0.00%
Case study 2 -non-linear load -without filter	19.95%	0.00%	21.32%	19.95%
Case study 3 -with both linear and non-linear load -with both active and passive shunt filter	0.64%	0.00%	149.34%	3.68%

From Table 4.1.2 the difference between Case 1, Case 2 and Case 3 in THD percentage. The highest THD percents is the THD_I at the non-linear load. By using the filtering the THD reduce to the IEEE 519 standard for Harmonics [11] (THD $\leq$5%).

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Introduction

This section is briefly explain about the conclusion of this performance evaluation of active and passive filter for harmonic reduction in electrical distribution system.

5.2 Conclusion

The utility power system is polluted by harmonics due to non linear load behaviour of many electronic equipments such as variable speed drives, computers rectifier and so on. In this work, theoretical, simulation, of a three-phase Active power filter combined with passive shunt filter , based on SRF controller , had been conducted. The first was the simulation study the effectiveness of the proposed system for harmonic reduction in electrical system. All the procedures and techniques are explained clearly in Chapters 3 and 4. The SRF control schemes operation can be considered to be implemented in the Active power filter comvined with passive shunt filter. Then, this research focused on harmonic reduction, which was harmonic distortion. It appeared that the industry can be divided into two; currents and voltages. Voltage and current harmonics within an electrical power system will cause power line carrier disorder, which leads to long distance operation of control devices, load control, and metering to be less precise. Verification of simulation results show good filtering characteristics of the proposed modelling of active power filter and passive shunt filter and the effectiveness of the proposed detecting approach by the SRF controller.

REFERENCE

[1] (1992). *IEEE Recommended Practice and Requirement for Harmonic Control in Electrical Power System.* IEEE Standard 519 .

[2] AvadhanamKartikeyaSarma, K. R. (2011). Optimal Capacitor Placement in Radial Distribution Systems using Artificial Bee Colony(ABC) Algorithm. *Innovative Systems Design and Engineering, Vol 2*, 4.

[3] Bafila, P. (June-2015). Power Quality improvement using. *International Journal of Enhanced Research in Science Technology & Engineering*, 371-378.

[4] Balaji, M. T. (March 2014). Harmonic Distortion Evaluation Ans Reduction in Radial Distribution System.

[5] Bhattacharya, S. D. (1991). Synchronous Frame Harmonic Isolator using Active Series Filter. *Proc. of EPE'9*, 3030-3035.

[6] Brahim B., C. B. (2010). Optimization of shunt active power filter system fuzzy logic controller based on ant colony algorithm. *Journal of Theoretical and Applied Information Technology*, 117-125.

[7] El-Mamlouk WM, E.-S. M. (2009). Harmonic currents circulation in electrical networks simulation and analysis. *9th IASTED European conference on power and energy systems, EuroPES 2009. Palma de Mallorca, Spain*, 67-72.

[8] El-Mamlouk WM, E.-S. M. (2009). Testing the Accuracy of ML-ANN for Harmonic Estimation in Balanced Industrial Distribution Power System Proceeding of the (WASET) World Academy of Science, Engineering and Technology Conference. *International Conference on Computer, Electrical, and Systems Science, and Engineering Amsterdam, Netherlands*, 23-25.

[9] Elsa Susan Daniel, G. (April 2013). SELECTIVE HARMONIC ELIMINATION USING SHUNT HYBRID ACTIVE POWER FILTERS OPERATING AT DIFFERENT SWITCHING FREQUENCIES. *INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN ELECTRICAL, ELECTRONICS, INSTRUMENTATION AND CONTROL ENGINEERING*, Vol. 1, Issue 1.

[10] F. Hamoudi., A. C. (2010). Sliding Mode Control of a Three-Phase Three-Leg Voltage Source Inverter Based Four-Wire Shunt Active Power Filter. *Journal of Electrical Systems*, 82-86.

[11] Hope, S. a. (2012). Harmonic Filter Design to Mitigate Two Resonant Points in a Distribution Network. *Journal of Energy and Power E ngineering 6*, 2018-2023.

[12] Javier Napoles, A. J. (2013). Selective Harmonic Mitigation Technique for Cascaded H-Bridge Converters With Nonequal DC Link Voltages. *ieee transactions on industrial electronics, vol. 60*, 5.

[13] JENA, S. (May-2014). *MATLAB SIMULATION OF SINGLE PHASE SHUNT ACTIVE POWER FILTER AND DEVELOPMENT OF EXPERIMENTAL SET UP.* ODISHA, INDIA: Department of Electrical Engineering National Institute of Technology Rourkela.

[14] Ke Z, Z. L. (2010). Control Strategy of Shunt Hybrid Active Power Filter in Distribution Network Containing Distributed Power. *2010 China International Conference on Electricity Distribution (CICED*, 1-10.

[15] L.M. Adesina, O. F. (September, 2015). Harmonic Mitigation on a 33kV Distribution Line using Passive Filters. *African Journal of Computing & ICT*, Vol 8. No. 3.

[16] Leonardo B. Garcia Campanhol, S. A. (2014). Application of shunt active power filter for harmonic reduction and reactive power compensation in three-phase four-wire systems. *IET Power Electronics*.

[17] Luo A., S. Z. (2010). Design and application of a hybrid active power filter with injection circuit. *Power Electronics, IET*, 54-64.

[18] M. Tarek, S. M. (2007). Application of Adaptive Notch Filter for Harmonics Currents Estimation. *the 8th IEEE International Power Engineering Conference IPEC 07*, 1690-1694.

[19] Mohamed R. Amer, O. A. (January 2013). A Simple Algorithm for SRF Theory with Three Phase Shunt Active Power Filter. *Journal of Engineering and Computer Sciences Qassim University, Vol. 6, No. 1*, 11-32.

[20] Mostafa HE, F. M. (2006). Neuro-swarm for correction of distorted secondary current of current transformer. *Scientific Bulletin, vol. 41(3). Cairo, Egypt: Ain Shams University*, 539-552.

[21] Mrs. M. Sindhubala, M. A. (Dec 2013). Harmonic Reduction in Power System. *Int. Journal of Engineering Research and Applications*, 712-714.

[22] Pucci M., V. M. (2009). Current harmonic compensation by a single-phase shunt active power filter controlled by adaptive neural filtering. *IEEE Transactions*, 3128-3143.

[23] Radzi M. A. M., R. N. (2009). Neural network and bandless hysteresis approach to control switched capacitor active power filter for reduction of harmonics. *IEEE Transactions on Industrial Electronics*, 1477-1484.

[24] Ram, S. K. (2011). FPGA Implementation of Digital Controller for Active Power Line Conditioner using SRF Theory. *IEEE conference on power electronics*.

[25] Saad Mekhilef, M. T. (2011). Single-phase Hybrid Active Power Filter with Adaptive Notch Filter for Harmonic Current Estimation. *IETE Journal of Research*, 20-28.

[26] Salmeron P., L. S. (2010). Improvement of the electric power quality using series active and shunt passive filters. *Power Delivery, IEEE Transactions*, 1058-1067.

[27] Salmeron Patricio, L. S. (2010). A control strategy for hybrid power filter to compensate four-wires three-phase systems. *IEEE Trans Power Electron*, 1923.

[28] Senturk O.S., H. A. (2009). High performance harmonic isolation and load voltage regulation of the three-phase series active filter utilizing the waveform reconstruction method. *IEEE Transactions on Industry Applications*, 2030-2038.

[29] Shahbaz, M. (September 2012). *Active Harmonics Filtering of Distributed AC System.* Norwegian University of Science and Technology Department of Electric Power Engineering.

[30] Singh, B. a. (April 2008). Selective Compensation of Power-Quality Problems Through Active Power Filter by Current Decomposition. *IEEE.Trans. Power Delivery, Vol. 23, No. 2,*, 792-799.

[31] T. Messikh, S. M. (2008). Adaptive Notch Filter for Harmonic Current Mitigation. *International Journal of Electrical and Electronics Engineering*, 240-246.

[32] Vodyakho O., K. T. (2009). Shunt active filter based on threelevel inverter for three-phase four-wire systems. *IET Power Electronics*, 216-226.

[33] Wael M. El-Mamlouk, H. E.-S. (2011). Active power filter controller for harmonic suppression in industrial distribution system. *Ain Shams Engineering Journal*, 161–172.

[34] Yinan GUO, J. C. (2011). Optimal Design of Asymmetry Passive Power Filters Based on Adaptive Cultural Algorithm with Hybrid Mutation. *Journal of Computation Information Systems, Vol 10*, 3730-3738.

[35] Yong Li, F. L. (2014). Hybrid inductive and active filtering method for damping harmonic resonance in distribution network with non-linear loads. *IET Power Electronics*.

[36] YUSEH, A. S. (NOVEMBER 2010). *EVALUATION OF FILTER DESIGN AND HARMONIC ANALYSIS USING.* Faculty of Electrical & Electronics Engineering Universiti Malaysia Pahang.

[37] Zynal, H. I. (2013). Harmonic Current Reduction of Three-Phase Rectifier Based on Modified Line Injection Technique. *The First International Conference of Electrical, Communication, Computer, Power and Control Engineering*.