DECLARATION

I declare that this report entitled "Reduction of Harmonic Using Single Phase Shunt Active Power Filter Based on Fast Fourier Transform Method for PWM Cascaded Multilevel Inverter" is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ………………………………….

Name : Nur Izzati Binti Zolkifri

Date : 10/06/2016

DECLARATION

"I hereby declare that I have read through this report entitle "Reduction of Harmonic Using Single Phase Shunt Active Power Filter Based on Fast Fourier Transform Method for PWM Cascaded Multilevel Inverter" and found that it has comply the partial fulfilment for awarding the Bachelor Degree of Electrical Engineering (Industrial Power)."

Signature	:	....
Supervisor's Name	:	Musa Bin Yusup Lada
Date	:	10/06/2016

FINAL YEAR PROJECT REPORT

Submitted by:

NUR IZZATI BINTI ZOLKIFRI

This report is submitted to Faculty of Electrical Engineering, Universiti Teknikal Malaysia Melaka in partial fulfilment for Bachelor of Electrical Engineering

Faculty of Electrical Engineering

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To my beloved mother and father

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ABSTRACT

The usage of power electronic device has been widely used in industrial as well as in domestic system. Consequently, it will develop power quality problem in distribution system. High Total Harmonic Distortion (THD) and low power factor is a main problem that caused by non-linear loads. This is because non-linear load generate a non-sinusoidal waveform passes through the distribution system which leads to voltage and current harmonics. Indirectly, current harmonic can cause problem to the load itself such as losses, overheating and overloading. The main objective of this project is to improve the power quality as well as to simulate and analyze the performance of single phase shunt Active Power Filter (APF) based on Fast Fourier Transform (FFT) method. In this project Photovoltaic solar panel is the power supply and converted to alternating current (AC) by cascaded H-bridge Multilevel Inverter (MLI) which uses Pulse Width Modulation (PWM) technique as controller. Furthermore, MLI with PWM control scheme produced less harmonic output. However, non-linear loads installed in the system will causes increasing of harmonic. Thus, this project is about implement a single phase APF based on FFT to filter the harmonic and directly improve the power quality. The performance of APF based on FFT was evaluated in term of total harmonic distortion at line current with connection to the R, RL, RC and rectifier loads. The MATLAB/Simulink simulation has been used in this project in order to simulate and prove that the FFT technique is capable to reduce the harmonics generated by loads. At the end of this project, the performances of APF based on FFT technique were analysed. The simulation result shows that by injecting APF in the system, the THD line current was improved below than 5% even though THD load current show the high percentage of THD. In addition, the simulation result shows that THD line current of Unipolar MLI with R load and rectifier indicate lower percentage of THD at 0.24% after APF based on FFT technique was applied. The highest THD line current after injecting APF is trinary MLI with RC load and rectifier which is 4.81% and it still under the limit of IEEE 519 harmonic standard.

ABSTRAK

Penggunaan peranti elektronik kuasa telah digunakan secara meluas dalam industri dan juga di dalam sistem domestik. Oleh yang demikian, ia akan menyebabkan satu masalah yang besar iaitu kualiti kuasa dalam sistem pengedaran. Jumlah harmonik yang tinggi dan faktor kuasa yang rendah adalah masalah utama yang disebabkan oleh beban bukan linear. Ini kerana beban bukan linear menjana gelombang yang bukan berbentuk sinusoidal melalui sistem pengagihan yang akan membawa kepada harmonik voltan dan arus elektrik. Secara tidak langsung, harmonik arus elektrik boleh menyebabkan masalah kepada beban itu sendiri seperti kehilangan kuasa, suhu berlebihan dan terlebih bebanan. Objektif utama projek ini adalah untuk meningkatkan kualiti kuasa dan juga untuk mensimulasikan dan menganalisis prestasi satu fasa APF berdasarkan teknik FFT. Dalam projek ini mengambil kira tenaga solar sebagai sumber tenaga utama, dan PWM digunakan untuk mengawal MLI. Tambahan pula, MLI dengan skim kawalan PWM menghasilkan output yang kurang harmonik. Walau bagaimanapun, beban bukan linear yang dipasang dalam sistem telah menyebabkan peningkatan harmonik. Oleh itu, projek ini mengaplikasikan satu fasa APF menggunakan teknik FFT untuk menapis harmonik dan secara tidak langsung meningkatkan kualiti kuasa. Prestasi APF menggunakan teknik FFT dinilai dari segi jumlah ganguan harmonik di arus hantaran dengan menyambung kepada R, RL, RC dan beban penerus.MATLAB / Simulink telah digunakan dalam projek ini untuk mensimulasikan dan membuktikan bahawa teknik FFT ini mampu untuk mengurangkan harmonik yang telah dijana oleh beban. Di akhir projek ini, prestasi APF berdasarkan teknik FFT dianalisis. Hasil THD arus hantaran bertambah baik iaitu berada di bawah daripada 5% walaupun THD arus beban menunjukkan peratusan yang tinggi. Di samping itu, hasil simulasi menunjukkan bahawa THD arus hantaran unipolar MLI dengan beban R dan penerus menunjukkan peratusan THD yang lebih rendah dengan 0.24% selepas APF berdasarkan teknik FFT yang telah digunakan. THD arus hantaran yang tertinggi selepas menyuntik APF adalah trinary MLI dengan beban RC dan penerus iaitu 4.81% dan ia masih di bawah had IEEE 519 standard harmonik.

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LIST OF ABREVATIONS

MLI – Multilevel Inverter

CHB-MLI – Cascaded H-Bridge Multilevel Inverter

AC - Alternating Current

DC - Direct Current

PWM - Pulse Width Modulation

VSI - Voltage Source Inverter

CSI - Current Source Inverter

APF - Active Power Filter

PPF - Passive Power Filter

FFT - Fast Fourier Transform

VSAPF – Voltage Source Active Power Filter

CSAPF – Current Source Active Power Filter

CHAPTER 1

INTRODUCTION

1.1 Overview

Solar energy is one of renewable energy that has been widely used in recent years. The solar panels were converted into electrical energy in the form of Direct Current (DC). The rising demands of solar energy from several industrial companies have triggered industrial engineer to come up with ways to convert DC voltage into AC voltage for direct use with AC loads. Thus, electrical power inverter has been introduced and it was described as a circuit that convert Direct Current (DC) input signal into Alternating Current (AC) by which both magnitude and frequency can be controlled. There are several type of inverters exist and multilevel inverters (MLI) is one of the inverter that produce less harmonic compared to the two-level inverter that consists of four switches [1]. Multilevel inverter is a power electronic system that functions to synthesize a sinusoidal voltage from several levels of DC voltages.

The main purpose of MLI is to have better sinusoidal voltage and current in the output by applying switches in series. There are three types of MLI which are Cascaded H-Bridges MLI, Diode Clamped MLI, and Flying Capacitor MLI [3]. The concept of PWM Cascaded H-Bridges multilevel inverter is applied. Besides, by using pulse width modulation (PWM) technique, multilevel inverter (MLI) will generate better output power quality. Even though MLI can be design in harmonic less, the non-linear load current might undermine quality of energy supply in the system. Nonlinear loads are the reasons for the increasing harmonics and it causes very serious damage in power distribution system. The effects of harmonic are low power factor, overheating of neutral wire and overloading to the system [1]. Previously, passive filter is used to reduce the total harmonic distortion but there are several disadvantages in passive filter like resonance that affect the stability and fixed compensation [3]. Thus, Active Power Filter (APF) becomes a solution to improve grid power quality. Since APF have two major control techniques which are time domain and frequency domain, this project is dealing with frequency domain based on Fast Fourier Transformation (FFT) method by connected to MLI system. The APF performs the filtering action by injecting harmonic components which eliminate those from the load, thus the line current becomes less of harmonic distortion. The frequency methods that based on FFT are used because it provides accurate individual and multiple harmonic detection of load current. This model is simulating in MATLAB/Simulink, to mitigate harmonics of the load current.

1.2 Motivation

Since late 1980s power quality problem has become priority in the distribution system. Harmonic distortion in power system has been a significant problem in order to maintain power quality. Furthermore, harmonic distortion have been presented for a decades. However, in these recent years Total Harmonic Distortion (THD) was increasing rapidly due to widely used of electronic device. High value of THD can causes overheating, overloading and losses in distribution system [2]. Electronic device such as home appliance, diodes, and silicon controlled rectifier (SCR) was categorized as non-linear loads. These non-linear loads contribute to high percentage of THD in the system. Since power electronic device have its own advantage in efficiency and controllability, it was expected to be on high demand in the future. Moreover, non-linear loads can be used for low-voltage appliance and high voltage. As for solar energy that have been converted to the electrical energy by using Multilevel Inverter (MLI) with harmonic less still drawn high percentage of THD whenever it connected to the non-linear load. Therefore, in order to maintain power quality and follow the standard of IEEE 519-1992 which is THD must be below than 5% in the distribution system with the presence of non-linear load, filter is needed [3].

1.3 Problem Statement

In recent years, solar energy is one of the most popular renewable energy. Hence, multilevel inverter (MLI) is used to convert variable direct current (DC) source from Photovoltaic solar panel into alternating current (AC). Even though MLI could be designed in harmonic less, but by connecting to the non-linear loads current may weaken quality of energy supply in the system. Electronic devices are well known as a non-linear load and generate current harmonic pass through the grid. Electrical power system which is power quality will face a serious damage in such situation. The characteristic of the power quality of the AC power system are divided into two which is Total Harmonic Distortion (THD) and Power Factor (PF). Harmonic distortion can cause long term effect and short term effect on power distribution system. Long term effects are related to excessive voltage distortion while short term effect are usually related to increased resistive losses or voltage stresses. Depending upon level of the harmonics, the non-linear load current may lead to the power quality problem. Harmonics can also be categorized as pollutant that pollutes the entire power system. Hence, harmonic filter is needed in order to eliminate them from the AC supply. There are various techniques for harmonics elimination that has been studied throughout the years. So far, using passive filter are not the best solution due to many demerits like fixed compensation, increased losses, and bulky in size. Therefore, APF become an applicable method to improve grid power quality. APF has fundamental competence to effectively adjust itself to reducing power line harmonics and at the same time minimizing effect of parasitic problems. Furthermore, improving power factor using APF would not change fault level of power system grid [5].

1.3 Objective

The objectives of this project are:

i. To improve the power quality using single phase shunt active power filter based on Fast Fourier Transform method for PWM cascaded multilevel inverter.

ii. To simulate and analyze a single phase shunt Active Power Filter based on Fast Fourier Transform method for PWM cascaded multilevel inverter by using MATLAB/Simulink software.

iii. To verify the performance of single phase shunt active power filter based on Fast Fourier Transform method for PWM cascaded multilevel inverter follow the requirement of harmonic standard IEEE 519 which is below than 5%.

1.4 Scope

The scope of this project is to conduct simulation of the conventional single phase shunt active power filter based on Fast Fourier Transform method for PWM cascaded multilevel inverter. The MATLAB/Simulink software is used to simulate and analyse the performance of single phase shunt active power filter for PWM cascaded Multilevel Inverter (MLI) using Fast Fourier Transform method. The control switching scheme was applied for MLI in this project are trinary seven levels, bipolar, and unipolar. The block simulator was developed based on FFT method algorithm and tested with several of non-linear loads which are R-load, RL-load, RC-load and Rectifier. Furthermore, this project aims to reveal the concept of harmonics reduction process and improving grid power quality in a single phase power system grid. This project deals with frequency domain which is Fast Fourier Transform method to reduce the THD and at the same time eliminate effect of the parasitic problems.

1.5 Report Outline

There are five chapters in this report. It is started with the introduction of the project and five others chapter are sorted as follows:

Chapter 1 is about the short explanation of this project, problem statement, objective and scope.

Chapter 2 cover the theoretical background of this project such as type of filter, topologies of APF, types of inverter, power quality, and total harmonic distortion.

Chapter 3 focuses in the project methodology. This chapter consist of flowchart of the project, milestone, Gantt chart, block diagram of the project, simulation model, and the switching method used in this project.

Chapter 4 contains all the simulation result and the discussion of the simulation result by using different non-linear loads.

Chapter 5 covers the summary of this project and the recommendation for the further research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Total Harmonic Distortion (THD) have been detected increasing rapidly due to the widely used of non-linear loads. Moreover, non-linear loads will generate harmonic even though MLI switching scheme is good enough in producing less harmonic output. Thus, this chapter reviews the previous work on filtering harmonic. Filtering is one of the solutions in order to mitigate the current and voltage harmonic. Filtering is important to improve power quality, power factor and reduce harmonic. Filtering can be done by using passive or active power filter. Since passive filter is limited in eliminating the harmonic, this project comes out with the most popular technique which is Active Power Filter [5].

2.2 Power Quality

Power quality is a general term used to represent the interaction of electrical power with electrical equipment. It is defined in the IEEE 100 Authoritative Dictionary of IEEE Standard Term as the concept of powering and grounding sensitive equipment in a manner that is suitable to the operation of that equipment [2]. Since late 1980s power quality problem has become priority in the distribution system. There are three parties that concern about power quality such as utility companies, equipment manufacturers and electric power consumers. The characteristic of the power quality of the AC power system are divided into two which is Total Harmonic Distortion (THD) and Power Factor (PF). Besides, there are two terms that widely used in power systems about the power quality. First it is called as good power quality which can be used to define a power supply that is always available, consistently within the voltage and frequency tolerance then any load connected to it will run smoothly and efficiently. In addition, having a pure noise-free sinusoidal wave shape is one of the characters of the good power quality. Whereas, the poor power quality in power system is define when the load connected to it fail or have a reduced lifetime and efficiency of the electrical installation [1]. Besides, poor power quality can affect the accuracy of utility metering and the equipment in use is vulnerable to damage or service disturbance which will cause equipment miss operation and premature failure.

Indeed, power quality is an important point in the relationship between suppliers and consumers [3]. The ideal power quality consist of two sorts of frequency that are utilized in power system which are 50 Hz and 60 Hz because these frequency are most minimal resonance frequencies and also acknowledge as fundamental frequency as shown in Figure 2.1 and Figure 2.2. The ideal power quality is represented by the waveform in single-phase and three phases.

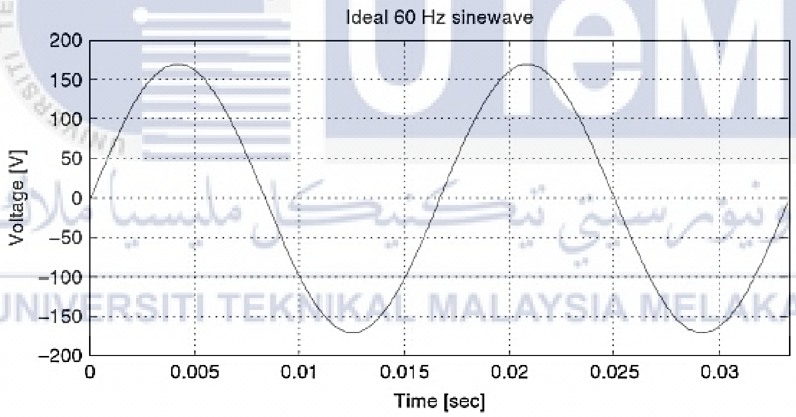


Figure 2.1: Ideal single-phase voltage waveform

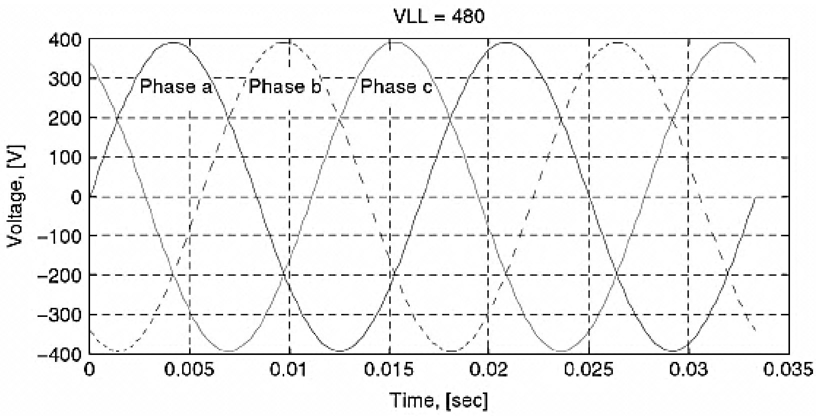


Figure 2.2: An ideal three-phase voltage waveform.

2.2.1 Harmonic Distortion Definition

The increasing usage of non-linear load will tend toward to the power quality issues with much attention in harmonic distortion. Harmonic distortion has been gaining endless attention due to the increasing of non-linear loads that use in daily life. The main source of voltage and current harmonic is power electronic device that have been widely use in electric component such as chopper, rectifier and cyclo-converter which is characterized as non-linear. The non-linear loads affected the flow of power by drawing currents only during certain intervals of the fundamental period [4]. Thus the current supplied are not drawn linearly as in sinusoidal waveform and will draw higher percentage of harmonic distortion.

Figure 2.3 shows that the sum of the pure sinusoids that can produce non-sinusoidal signal. Harmonic distortion also can be classified as pollution in the electrical system which causes problems if the sum of the harmonic currents exceeds certain limits [5]. The summation of sinusoids is indicating in Fourier series form. By using Fourier analysis that was presented by the French mathematician Jean Baptiste Joseph Fourier (1768-1830), a periodic distorted waveform can be decomposed into an infinite series containing DC component, fundamental component and its integer multiples called the harmonic components [4]. Equation 2.1 and Equation 2.2 shows the Fourier series equation for current and voltage respectively.

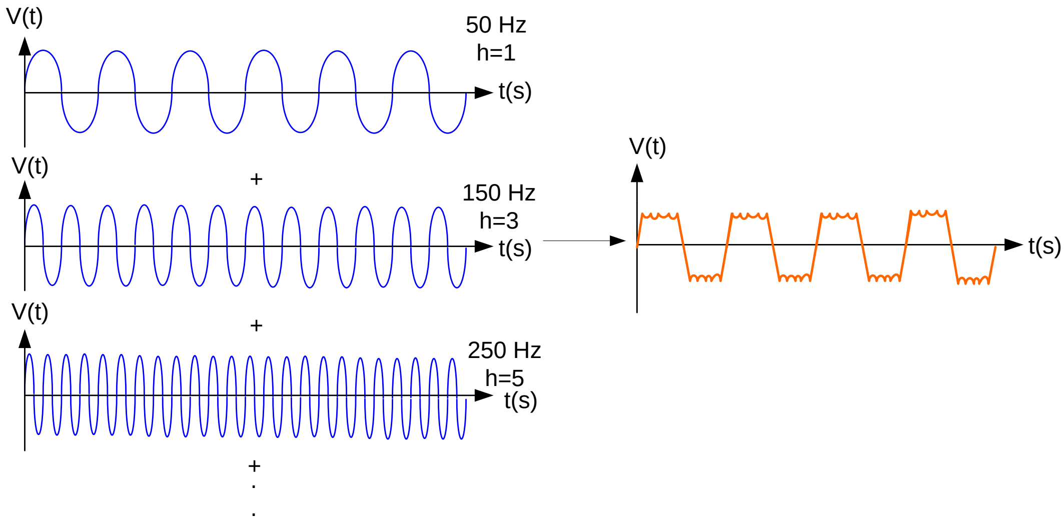


Figure 2.3: The sum of the pure sinusoids that can produce non-sinusoidal signal

$$i(t) = I_0 + \sum_{n=1}^{\infty} I_n \cos(nw_0 t + \emptyset_{I_n}) \tag{2.1}$$

$$v(t) = V_0 + \sum_{n=1}^{\infty} V_n \cos(nw_0 t + \emptyset_{V_n}) \tag{2.2}$$

The summation of all harmonic component of the voltage or current waveform is defined as the root-mean-square (rms) value divided by the rms value of the fundamental component of the voltage or current wave and multiplied by 100% is presented as total harmonic distortion (THD). THD frequently use as the measurement index of measuring harmonic distortion. Equation 2.3 and Equation 2.4 shows the fundamental of THD in voltage and current form.

$$THD\ in\ voltage = \frac{\sqrt{(V_2^2 + V_3^2 + V_4^2 + \cdots + V_n^2}}{V_1}\ x\ 100\% \tag{2.3}$$

$$THD\ in\ current = \frac{\sqrt{(I_2^2 + I_3^2 + I_4^2 + \cdots + I_n^2}}{I_1}\ x\ 100\% \tag{2.4}$$

2.2.2 Harmonic Source on Power System Distribution

Harmonic distortion is caused by non-linear loads that connected to the power system. Hence, everything that has non-linear characteristic will cause harmonic distortion in power system. Non-linear loads also can be determined through waveform which is loads that draw non-sinusoidal current from a sinusoidal voltage source. However, not all harmonic can cause serious problem and there are many kinds of harmonic producing loads available which it can be argued. Most loads that have some degree of non-linearity, but their effect on the distribution system is safe it can be neglected. The strongest sources of non-linear loads that produce harmonic distortion are transformers, arc furnaces, variable frequency drives and equipment like computers and copy machines [6].

2.2.3 Effect of Harmonic Distortion on Power Distribution

Harmonic occurs when loads cause the current to non-sinusoidal with the voltage during each half cycle. This condition will contribute to unwanted effect on power system components and Power Quality. These effects depend on the type of the load and power sources. The most sensitive type of equipment is comprises electronic devices that have been design assuming a pure sinusoidal fundamental frequency voltage or current waveforms [5]. Otherwise, the least sensitive equipment is any kind of equipment that main role is as heating element as in an oven or arc furnace. Figure 2.4 shows the electric furnace in steel industri.

Figure 2.4: The electric furnace in steel industrial

The effect of harmonic can be divided into; two short-term effects and long term effects. For the short term effects, it related with failure, malfunction or inoperative of equipment and associated power losses. It is happen when the equipment is exposed to the high voltage or current harmonic. In the other hand, long term effects mainly affected thermal nature such as transformer, motors and capacitor bank [5]. However, these problems are not usually visible to the power distribution service providers or customers until the equipment is stop functioning. Moreover, high order of harmonic also will reduce the lifespan of equipment and it is costly for replacements or repairs.

2.2.4 Harmonic Standard

IEEE Standard 519-1992, “IEEE recommended Practice and Requirements for Harmonic Control in Electrical Power System”. This standard is an ordinary standard which apply to every types of static power converters used in industrial power systems. It briefly explains the total harmonic distortion of current drawn must be below 5% and harmonic for single component must not exceed than 3% [2]. IEEE 519-1992 will ensure that multiple customers are always producing the less amount of harmonic voltage. However, this standard is not covering the effect of radio frequency interference.

2.3 Harmonic Mitigation Method

In power system, filtering is very important to protect the consumer from an inadequate supply voltage quality. Therefore, the nonlinear loads generate harmonic current which distort the voltage waveform. There are two type of harmonics elimination which is Active Power Filter (APF) and Passive Power Filter (PPF).

2.3.1 Passive Power Filter (PPF)

A Passive Power Filter (PPF) is a simple filter that operates without using any amplifier element such as transistors and operational amplifiers. Passive filter is a filter that has no active component thus; it does not need additional power supply for its own operation. In addition, in the previous study state those passive filters not only filter current components but are also source of reactive power that can be used for compensation [7]. PPF is divided into four categories which are low-pass filter, high-pass filter, band-pass filter and tuned filter which the circuit configuration is shown in Figure 2.5. Those passive filters are used to mitigate power quality problems in six-pulsed AC to DC converter with

R-L load [8]. Besides, PPF are well operating at very high frequencies since they are not restricted by the bandwidth limitations of op amps. In application, passive power filter are capable in larger current or voltage levels than can be handled by active device [9]. Moreover, if comparing with circuit that using active elements, passive filter generate just a little noise [7]. However, passive filter have some disadvantages in certain applications which is cannot provide signal gain since they use no active elements and only capable in eliminate high harmonic order of current and voltage.

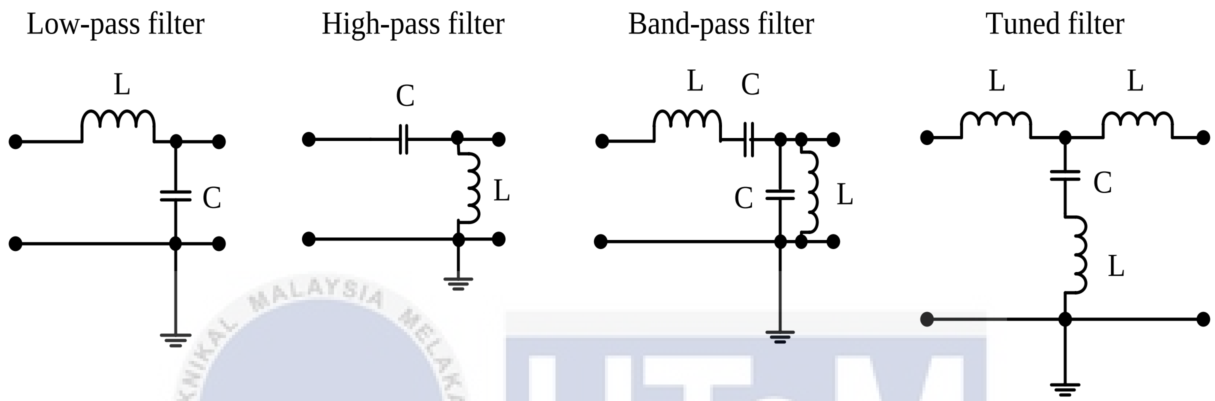


Figure 2.5: Common types of passive filter configuration and its frequency response

2.3.2 Active Power Filter (APF)

Active power filter is a type of electronic filter that use active component such as amplifier in filtering harmonics. The concept of APF is to generate a current waveform that can mitigate current harmonics in the system. In the previous research, using Passive Power Filter (PPF) do not give a satisfy solution in low order compensation [10]. Thus, APF become a viable method in improving power quality which adjusted itself to mitigate power line harmonics [11]. Moreover, APF have others capabilities which are can eliminate voltage and current harmonics, compensating the voltage flickering, compensating reactive power and regulating terminal voltage [9]. APF has two type topologies which are Voltage Source APF (VSAPF) and Current Source APF (CSAPF) [13]. In subtopic 2.4, the topologies of APF were further explained. In addition, there are three types APF which are shunt APF, series APF, and hybrid APF [12]. Each type of the APF was further explained in subtopic 2.5.

2.4 Topologies of Active Power Filter

The type of APF topologies is divided into two types which are Voltage Source APF (VSAPF) and Current Source APF (CSAPF).

2.4.1 Voltage Source APF (VSAPF)

APF popular topology is VSAPF which use an electrolytic capacitor as the DC link. However, electrolytic capacitor has an own disadvantage which is limited lifetime and this contribute to the disadvantage of VSAPF [10]. Besides, VSAPF also same like CSAPF which can be implementing in low power system, high power system, three phase three pole or three phase four poles. Figure 2.6 shows the circuit configuration of VSAPF.

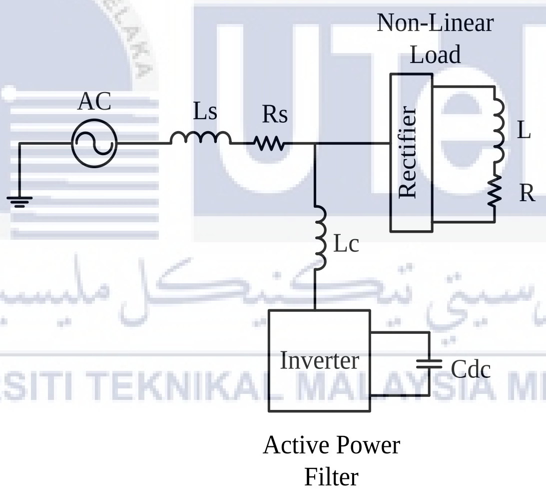


Figure 2.6: Circuit Configuration of VSAPF

2.4.2 Current Source APF (CSAPF)

Generally, CSAPF can be implementing in low power system, high power system, three phase three pole or three phase four poles. CSAPF has advantage itself which is good in controlling current, simple protection, and highly recommended in term of reliability compared to the VSAPF [11]. PWM is the current control methods that usually use in order to control CSAPF. Figure 2.7 shows the typical single-phase CSAPF. There is capacitor that connected to the inductance which functioning as the switching protection and LC low pass filter for overvoltage situation as well as minimize frequency from the PWM currents [11]. Furthermore, inductance L_{DC} acts as a storage element which store DC current that flow through it.

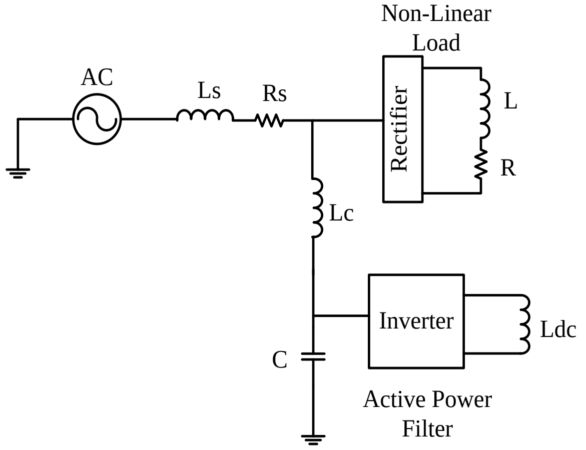


Figure 2.7: Circuit Configuration of CSAPF

2.5 Type of Active Power Filter

Active power Filter (APF) is the advisable solution in order to cancel mitigate compensate harmonic. There are three type of APF which is Shunt active power filter, Series active power filter and Hybrid active power filter. The subversion types of APF shown in Figure 2.8.

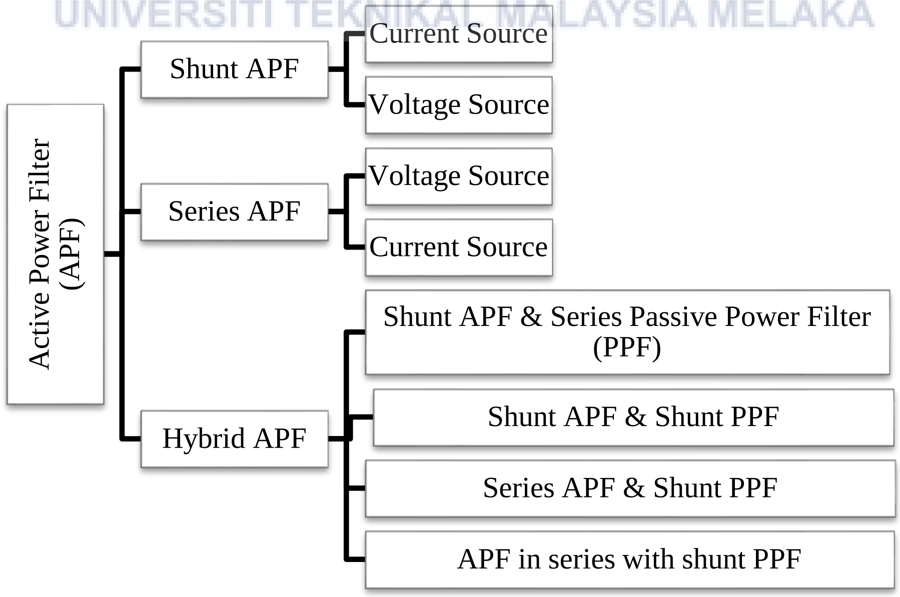


Figure 2.8: Types of APF

2.5.1 Shunt Active Filter

Shunt APF is most known connection and widely used in active filtering applications. The SAPF is connected in parallel with the line of source and non-linear load [12]. SAPF consists of a voltage or current source configurations. The voltage source inverter (VSI) is the most type used today due to its well-known topology and straight forward installation procedure [13]. By referring Figure 2.9 it show that by using the relationship in Equation 2.5 APF is connected in parallel to obtain the sinusoidal source current (i_s).

$$i_s = i_L - i_F \quad (2.5)$$

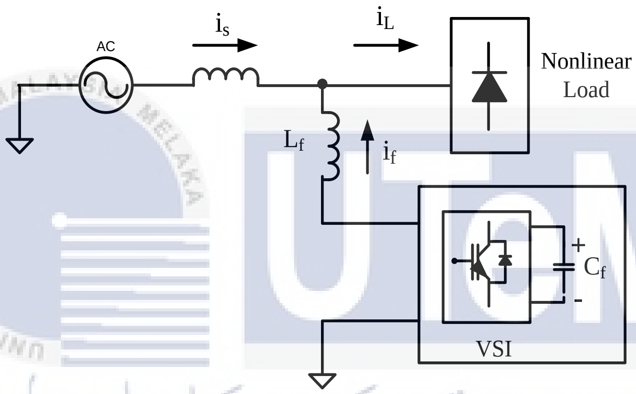


Figure 2.9: Block diagram of the shunt APF

2.5.2 Series Active Filter

Series APF is connected in series with the distribution line with a support of transformer. Same like shunt APF, series APF also used VSI as the controlled source and it shows that both of the connection uses the similar principle configuration. However, as the interface series APF applied transformer whereas shunt APF applied transformer in the connection. By referring Figure 2.10 it shows the block diagram of the series APF and the injection of harmonic, (v_f) across the interfacing transformer which function to cancel the voltage harmonic of the load. The voltage of APF (V_{AF}), voltage of load (V_L), supply voltage (V_S) can be described by applying Kirchhoff's voltage law in Equation 2.6.

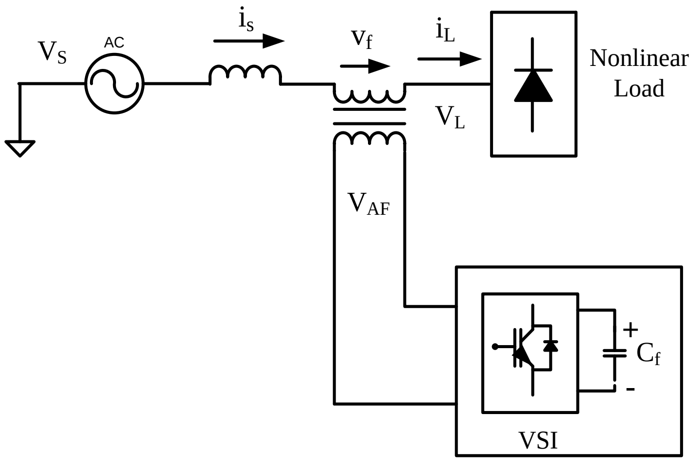


Figure 2.10: Block diagram of the series APF

$$-V_s - V_{AF} + V_L = 0 \tag{2.6}$$

2.5.3 Hybrid Active Power Filter

The hybrid power filters are combination of both APF and PPF [14]. The target of hybrid configuration is to improve the filter reliability by combining the APF performance with the PPF [15]. APF and PPF have their own advantage. In hybrid filter configuration, by improving the compensation characteristics of the PPF a reduction in the rating of APF can be achieved [16]. The circuit combination and arrangement of the hybrid configuration can be in many ways. For example; Shunt APF and Series APF, Shunt APF and Shunt PPF, APF in series with Shunt PPF, and Series APF with Shunt PPF. The combination of both PPF and APF is to provide the better performance and cost effective solution. HAPF aimed to act as a "harmonic isolator" and present zero impedance to the external circuit at the fundamental frequency and a high resistance to source or load harmonics [4].

2.6 Control Technique of Active Power Filter

There are two major control techniques of APF namely time domain and the frequency domain methods.

2.6.1 Frequency Domain

Frequency domain compensation can handle single node problems and can also be extended to minimize harmonic distortion throughout the network [17]. Fast Fourier Transform (FFT) is a foundation that is constructed for frequency domain techniques. FFT is a standard way to converts a signal in the time domain to the frequency domain or spectrum. FFT concept that was applied is by eliminating the fundamental component of harmonic spectrum for voltage and current. Hence, FFT become a powerful tool for analysing harmonic in power system [18]. Variable of Fourier transform is the increase in highest harmonic to be eliminated, the increase in number of calculations which results in a large response time [19]. Besides, based on previous study, if the signal passed through the circuit that has lower gain than f_1, the unwanted signal will be removed and the useful one is remain. The theory is illustrated as in Figure 2.11 [9].

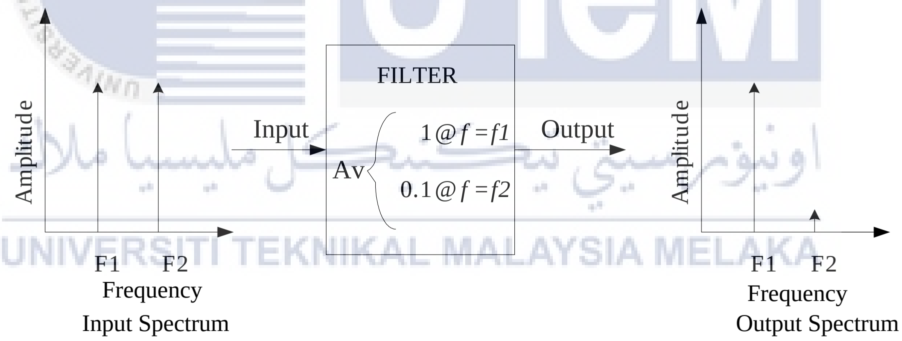


Figure 2.11: Reduction of harmonic via frequency domain

2.6.2 Time Domain

Time domain harmonic analysis is a voltage or current that expresses as a function of time. This control technique approaches are based on instantaneous estimation with voltage or current signal as reference signal to prevent it from distorted or harmonic polluted. Time domain is available for single-phase and three-phase system except synchronous-detection theorem and synchronous-reference-frame theorem that can only apply for three-phase systems [19]. Time domain control technique consists of five techniques in mitigation harmonic which is high-pass or low pass filtering method, instantaneous reactive power theory algorithm, synchronous reference frame theorem algorithm, sine multiplication theorem algorithm, and PI controller.

Based on the previous study, it is difficult to perform time-domain simulation for large systems since there are usually limited to the part of the system near to interrupted load. Hence, this is the main reasons of frequency domain methods more widely used for mitigation harmonic [19].

2.7 Multilevel Inverter

The multilevel inverter has been presented since 1975 as alternative in producing high power and medium voltage for particular demand [20]. The main purpose of MLI is to synthesize a near sinusoidal voltage from several levels of DC voltages [15]. As the number of levels increases it will provides a staircase wave that approaches a desired waveform hence the harmonic distortion of the output wave decreased [20]. Multilevel inverter comes with three types which are Diode Clamped MLI, Flying Capacitors MLI and Cascaded H-Bridge MLI.

2.7.1 Diode Clamped Multilevel Inverter

Diode clamped topology also known as neutral point which uses clamping diode and dc capacitors with multiple voltage levels through different phases to generate AC voltage waveform. By referring to Figure 2.11there are two series-connected bulk capacitors and the middle point between two capacitors can be represent as the neutral point. This topology use diode as the clamping device to clamp the DC bus voltage. Hence, diode is use to limit the power devices voltage stress. Regarding to the previous study, in order to improve the output voltage to become closer to sinusoidal waveform, the number of voltage level also must be increase [20]. The inverters have a three-level, four-level, or five-level topology. Figure 2.12 shows the Diode clamped in three levels topology.

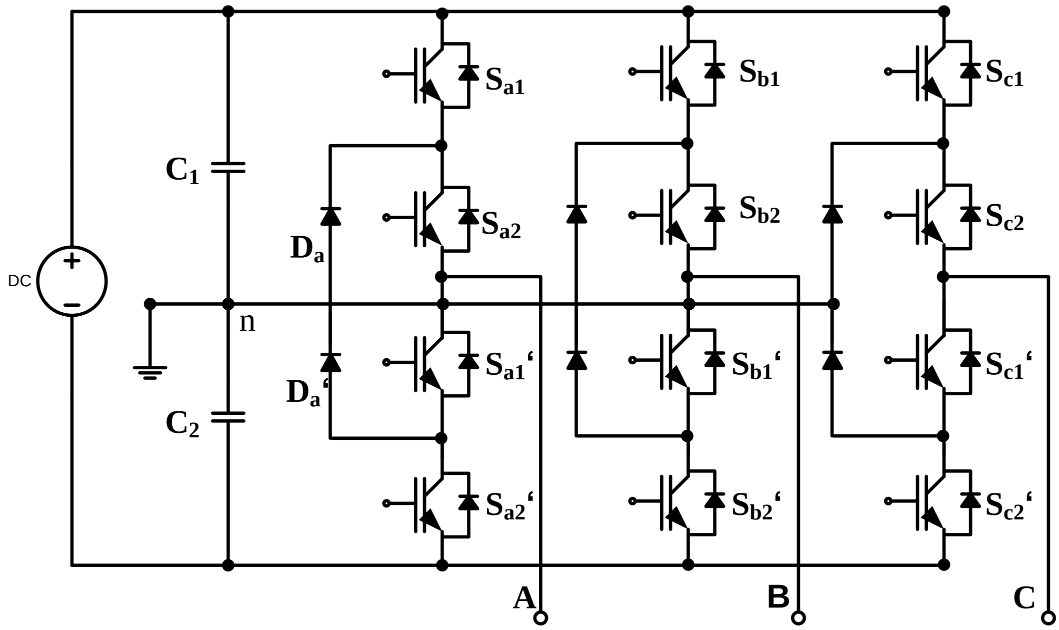


Figure 2.12: Three-level Diode Clamped topology [20]

2.7.2 Flying Capacitor Multilevel Inverter

Flying capacitor topology is also known as capacitor clamped topology. The design of this inverter is same with the diode-clamped inverter but diode clamping using clamping diode while the inverter uses capacitor in their place [20]. Flying capacitor is connected in series with capacitor clamped switching cells and each capacitor consist different voltage from the next capacitor. The changing of voltage between two adjoining legs present the size of the voltage steps in the output waveform. The advantage of this inverter is it preventing the filter demand and controlling the active and reactive power flow besides phase that overlap [20]. However, the cost of this inverter is high due to the large number of bulky capacitor and industrial does not interest use of this topology [21]. Three-level Flying Capacitor topology is shown in Figure 2.13.

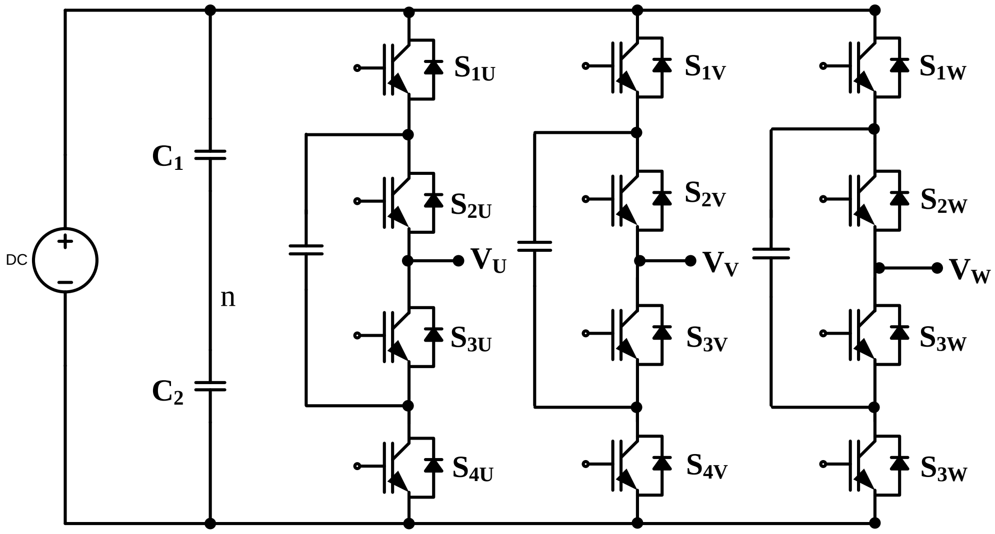


Figure 2.13: Three-level Flying Capacitor Topology [20]

2.7.3 Cascaded H-Bridge Multilevel Inverter

Cascaded H-Bridge MLI is in series configuration [21]. The concept of H-Bridge MLI is to apply capacitors and switches and it need less number of components in each level. If compared to Diode Clamped MLI and Flying Capacitor MLI, Cascaded H-Bridge has less number of components. H-Bridge uses a separate DC source and the DC source might be from batteries or fuel cells [21]. The DC source is isolate with each other since the output terminals of H-bridges are connected in series. The application of Cascaded H-Bridge MLI is motor drives, APF and electric vehicle drives. Since APF is main role in this project, Cascaded H-Bridge is applied. Figure 2.14 shows the circuit configuration of single phase Cascaded H-Bridge MLI.

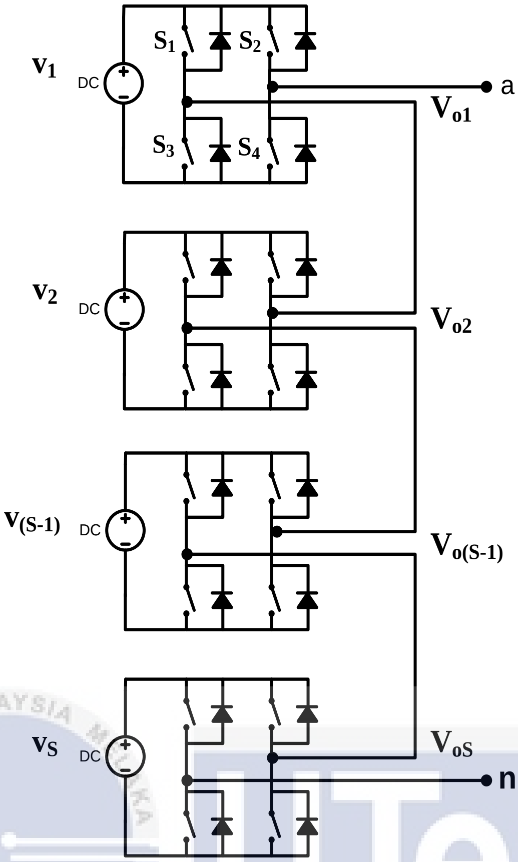


Figure 2.14: Single phase Cascaded H-Bridge MLI

2.8 Summary of Literature Review

Based on the literature review, reduction of harmonic using APF based on FFT was choose as current study because FFT is the simplest technique to mitigate harmonic if compare to others [11]. This is because FFT technique just mitigate harmonic by inversing the reference signal of harmonic thus, the harmonic will be cancelled. If compared to the p-q theory, it used a lot of equation in order to mitigate harmonic whereas, FFT technique just used inverse method of THD. Since the technique is simple, therefore the circuit will not be bulky in size.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter reviews the methodology used in this project. It covers up all the method that used to design and analyze the reduction of harmonic using single phase shunt active power filter. Besides, this chapter also briefly explain about Fast Fourier Transform Method. The detail explanations have been presented in this chapter with supported block diagrams.

3.2 Research Methodology

Research methodology consists of flowchart, milestone and Gantt chart to ensure this project completed on time. This subtopic is going to assist the explanation of the process and procedures in managing this project.

3.2.1 Flowchart

This flow of this project is presented in flowchart. Figure 3.1 shows the flow of this project in order to ensure it is completed on time. The first step of this project is collecting all the information and data that related to this project. Literature reviews have been done and more emphasis in Active Power Filter based on Fast Fourier Transform. The information based on literature reviews that have been done, the simulation of single phase information based on literature reviews that have been done, the simulation of single phase MLI connected to the non-linear is conducted. For the next step, the performance of MLI was analysed using different control switching technique which are trinary, unipolar, and bipolar switching scheme. The simulation is simulated with three different kind of non-linear loads. The load variable is conducted with R-load, RL-load, RC-load and Rectifier. In this project, the MATLAB/Simulink was applied to model and analyse the result of single phase MLI. Then, the implementation of the MLI and single phase shunt APF was conducted in MATLAB/Simulink and the analysis is carried out in term THD. Finally, all the result and discussion of the data have been complied and presented in this report.

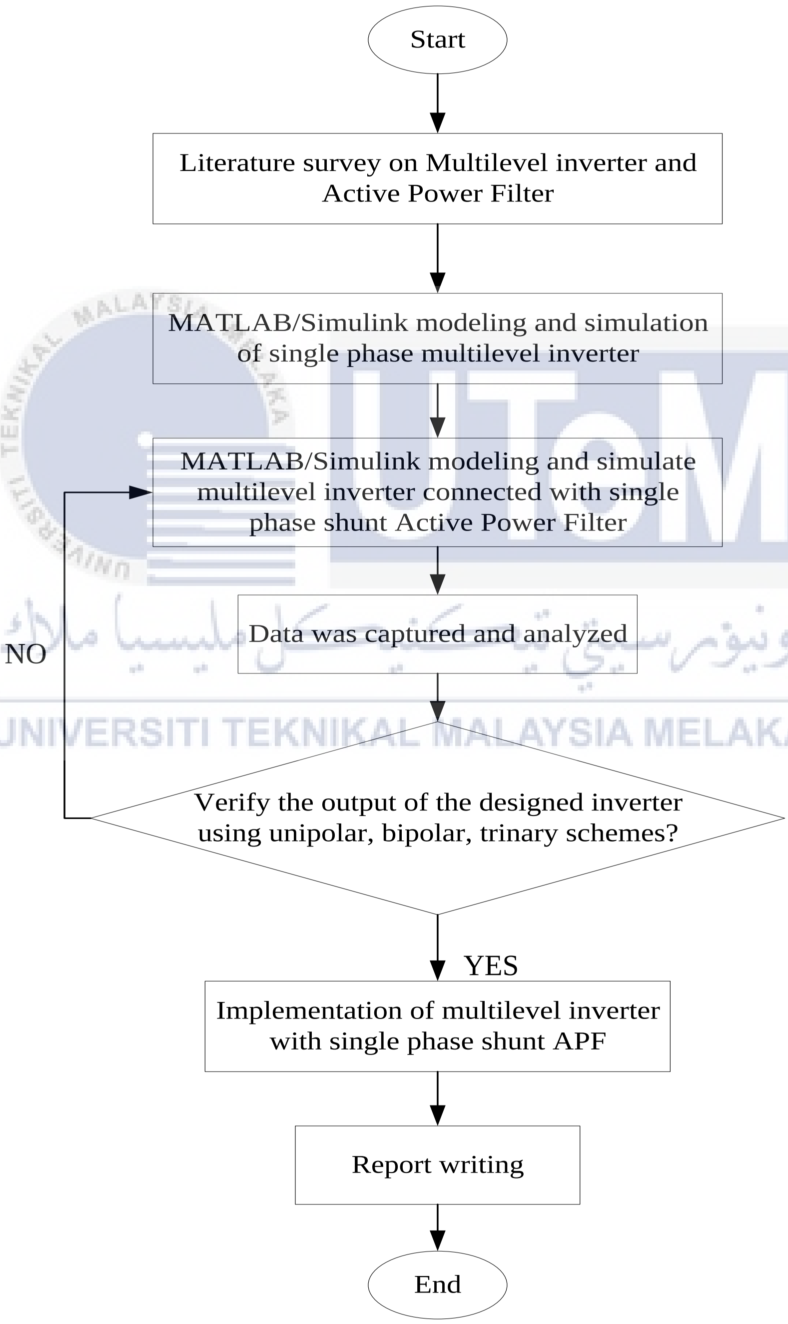


Figure 3.1: Flowchart of research methodology

3.2.2 Milestone

Below is the milestone set for this research. There are six milestone have been recorded for this project to ensure this project run methodically.

Milestone 1: Research on Multilevel Inverter and Active Power Filter

Milestone 2: Modelling and simulate the single phase CHB-MLI using unipolar, bipolar and trinary switching scheme and analyse the performance of single phase CHB-MLI

Milestone 3: Modeling and simulate multilevel inverter connected with single phase shunt Active Power Filter.

Milestone 4: Validate the data obtained from the simulation

Milestone 5: Implementation of multilevel inverter with single phase shunt APF

Milestone 6: Report writing

3.2.3 Gantt Chart

Table 3.1 shows the gantt chart of the research on the APF using FFT. The main purpose of this gantt chart is to ensure this project or research goes well and complete on time. This project has been started on September 2015 and end on May 2016. According to this chart, for the first month have been focusing on the research of MLI and APF. All the research is compiled in Chapter 2 which is literature review. For the next two month, it is focusing on the modelling and simulate the PWM cascaded multilevel inverter with connected to the non-linear load and the harmonic is determined. The MATLAB/Simulink programme is constructed to design the system. The simulation is focusing on the harmonic in each non-linear loads and the performance of shunt APF is recorded to mitigate the harmonic.

Table 3.1: Gantt chart of Research Methodology

Milestone	Task	Month/Year								
		2015				2016				
		9	10	11	12	1	2	3	4	5
1	Literature review on MLI and APF									
2	Modelling and simulation of the PWM cascaded MLI connected to non-linear loads.									
3	Verify the result from the simulation of MLI inverter connected to the non-linear loads without APF									
4	Implementation of MLI connected to non-linear loads with single phase shunt APF									
5	Verify the result from the simulation of MLI connected to the non-linear loads with APF									
6	Report writing									

3.3 Single Phase Shunt Active Filter

The concept of APF is to develop a current waveform that can be mitigating the current harmonic waveform of power system. In this project, the APF is connected parallel to the MLI and the non-linear loads. Besides, this project use PWM voltage source inverters to connect parallel to the APF and they are acting as a current controlled voltage source. The mitigation for current harmonic in the non-linear load is by injecting shunt APF equal with opposite harmonic compensating current which shifted by 180 degree phase. After the injecting of shunt APF, the result of harmonic in the line is cancelled out and at the same time it will eliminate and reduce effect of the harmonic. Basically, to generate the reference signal in shunt APF the help of control technique is needed then the result of non-linear loads and shunt APF waveform is compared with the source current in order to eliminate the harmonic. This concept has been express in the Equation 3.4.

$$I_s = I_L - I_{AF} \tag{3.4}$$

Where: I_s = Source current, I_L = Load current, and I_{AF} = Active Filter Current

3.3.1 Fast Fourier Transform (FFT) Technique

FFT technique is an ordinary way to process the voltage or current signals. FFT is a powerful tool for harmonic analysis in APF [11]. FFT applied concept is it will mitigate the harmonic spectrum for voltage or current by inverse the reference signal of harmonic hence the harmonic will be cancel OFF. This control technique of shunt active filter acts as a harmonic current source, injecting into the line harmonic with the same amplitude and opposite phase [11]. In order to determine the highest frequency of harmonic spectrum that need to be compensated, the sampling frequency of voltage or current waveform must be calculated. In FFT there are discrete Fourier transform and continuous Fourier transform. In this project it is focusing on continuous function Fourier transform. Equation 3.5 and Equation 3.6 show the continuous function in time domain and frequency domain function.

$$\mathrm{F(f)} = \int_{-\infty}^{\infty} f(t).e^{-j2\pi ft}\, dt \tag{3.5}$$

$$f(t) = \int_{-\infty}^{\infty} F(f).\ e^{j2\pi ft}\, df \tag{3.6}$$

The concept of FFT above is applied and derived based on concept of APF. The system configuration is shown in Figure 3.2. By referring the Figure 3.2, MLI is the ideal voltage and produce pure sinusoidal signal. However, the waveform of MLI is distorted causing of influence in shape of non-linear loads current. APF is designed to generate firing pulse in order to mitigate the harmonic develop by non-linear loads. Since there are high frequency and unstable system due to direct feedback of loads current signal, low pass filter ($L_f - C_f$) is added on active filter feeder. Low pass filter was functioning to reduce the high frequency ripple feedback of the filter current and indirectly stabilized the system.

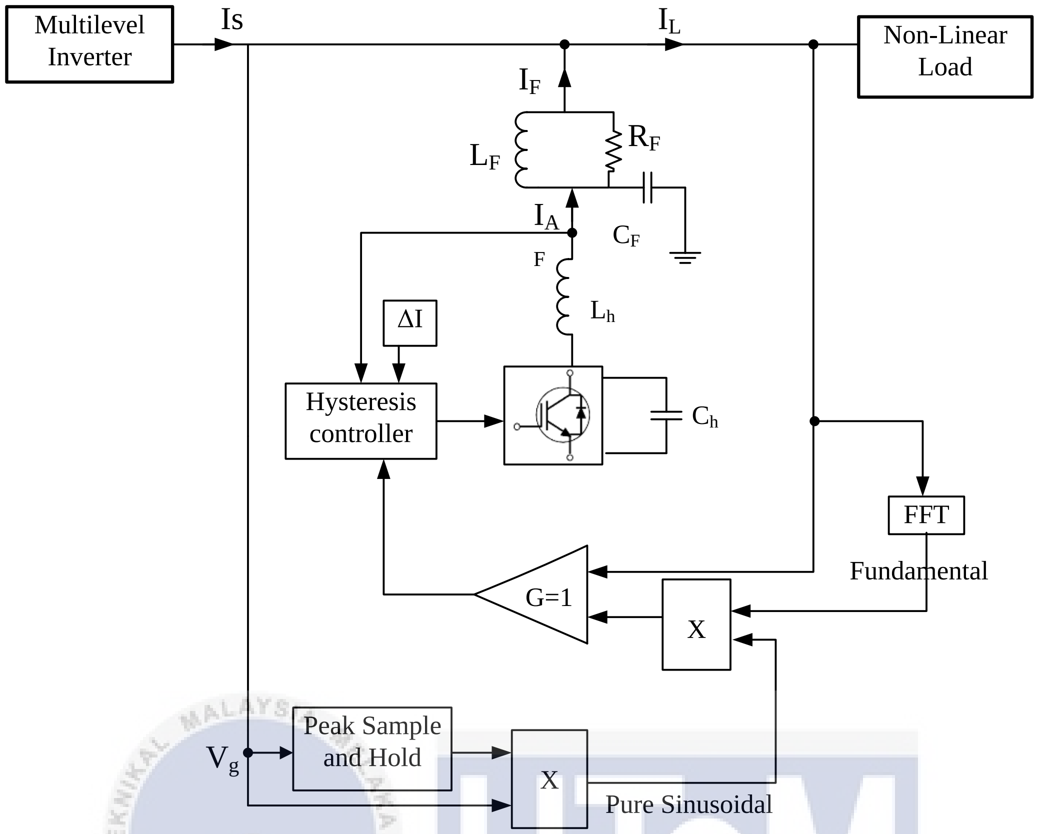


Figure 3.2: System configuration of Single Phase Active Power Filter

3.3.1.1 Hysteresis Controller

The hysteresis controller as in Figure 3.3 is a controller that develops pulse triggering signal for the IGBT's. There are three input of hysteresis control which is hysteresis gap ($\Delta I/2$), reference signal and H-bridge AC-current (I_{AF}). Input of hysteresis gap is necessary to generate upper-envelope and lower envelope of reference signal. Next, in hysteresis controller consist of upper comparator and lower comparator. That comparator will set or reset output of R-S flip-flop and it depending on instantaneous value of H-bridge AC-current (I_{AF}). The output of flip-flop will trigger followed the positive group and negative group of IGBTs.

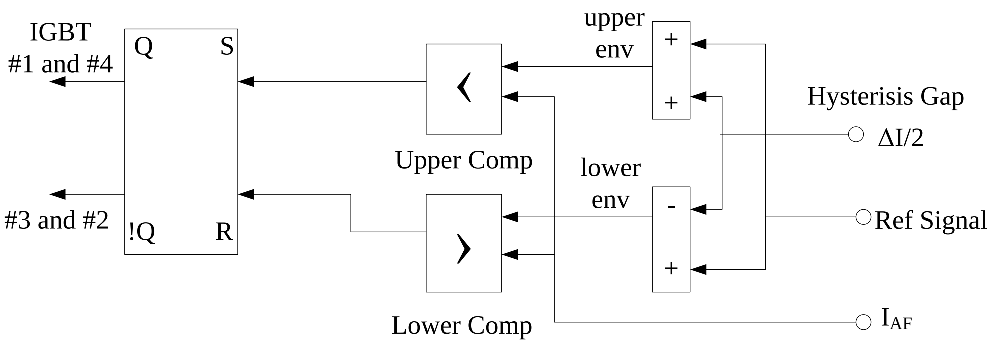


Figure 3.3: Block diagram of hysteresis controller

3.3.1.2 Main Inductance and Chopping Frequency

The small inductance L_h is better to catch up on the modification of reference signal. If the size of inductance is big, it would avoid APF from detecting the reference signal. The combination of small current ripple (ΔI = twice of hysteresis gap) with small value of inductance will produce a very high switching frequency. In this project, switching frequency of APF is in range as in Equation 3.7.

$$\frac{V_d - \sqrt{2}V_{MLI}}{2L_h\Delta I} < f_s < \frac{V_d}{2L_h\Delta I} \qquad (3.7)$$

Where:
V_d = DC link voltage or voltage across C_h
ΔI = Filter current ripple, it is maintained constant by hysteresis controller

Since there is main inductance L_f, APF not only act as an inverter but also functioning as a boost-converter. The boost-converter will boost the MLI voltage and store electrical charges in DC link capacitor $C_{h.}$ If the capacitor is big enough in size for accumulate electrical charge, the DC power source is not required anymore. The Equation 3.8 is used for APF that do not perform DC source to estimate instantaneous chopping frequency.

$$f_{s(t)} \approx \frac{V_{d(t)} - \mid V_{MLI} \mid}{2L_h\Delta I} \qquad (3.8)$$

3.4 Control Switching Technique Used for Multilevel Inverter

There are three type switching scheme was applied in this project which are trinary seven level, bipolar and unipolar. The simulation was repeated with this three type switching scheme.

3.4.1 Trinary seven level DC Source Control Switching

The Cascaded H-Bridge Multilevel Inverter (CHB-MLI) was implemented with trinary seven level DC source control switching. The switching scheme was developed follow the characteristic from the Table 3.2 for one sinusoidal wave.

Table 3.2: Switching of seven level trinary DC source

Switching	Pulse generator											
S_1	0	1	0	0	0	1	0	0	1	0	1	0
S_2	1	1	0	1	0	1	1	0	1	1	1	0
S_3	0	0	1	0	1	0	0	1	0	0	0	1
S_4	1	0	1	1	1	0	1	1	0	1	0	1
S_5	0	0	1	1	1	0	0	0	0	0	0	0
S_6	1	1	1	1	1	1	1	1	0	0	0	1
S_7	0	0	0	0	0	0	0	0	1	1	1	0
S_8	1	1	0	0	0	1	1	1	1	1	1	1

The block diagram of trinary switching schemes was conducted as shown in Figure 3.4 and Figure 3.5 shown bipolar CHB-MLI switching scheme block diagram.

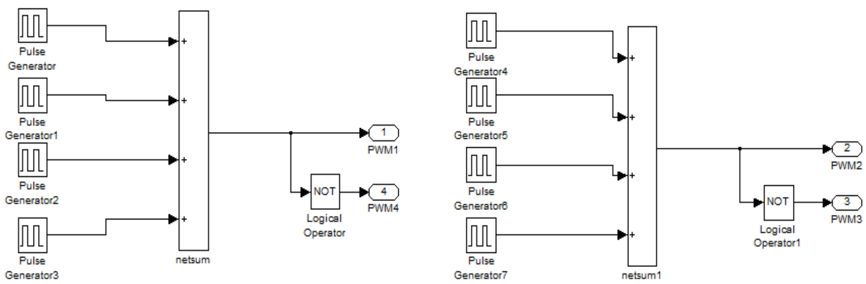


Figure 3.4: The Trinary Switching in PWM1

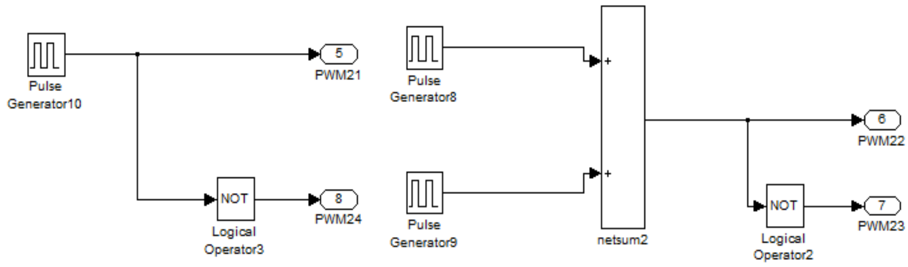


Figure 3.5: The Trinary Switching in PWM2

3.4.2 PWM with Bipolar Switching

The Cascaded H-Bridge Multilevel Inverter (CHB-MLI) was implemented with two-triangle wave carrier Bipolar Switching. Figure 3.6 and Figure 3.7 shows the switching wave and compensator signal respectively.

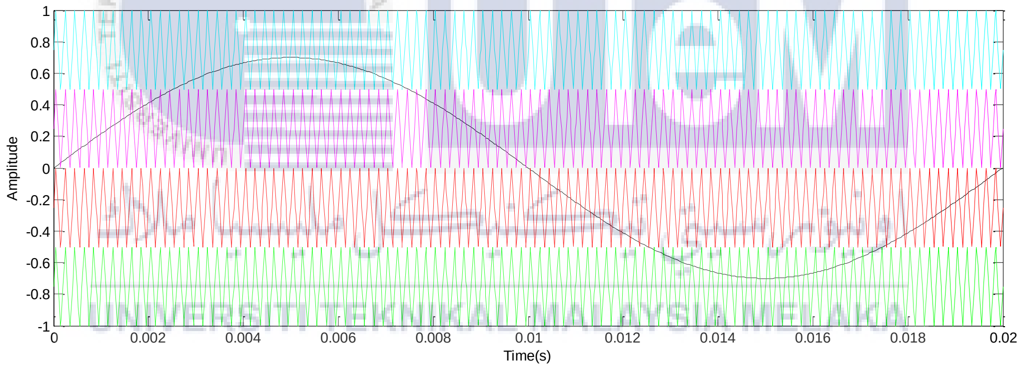


Figure 3.6: Bipolar Switching wave

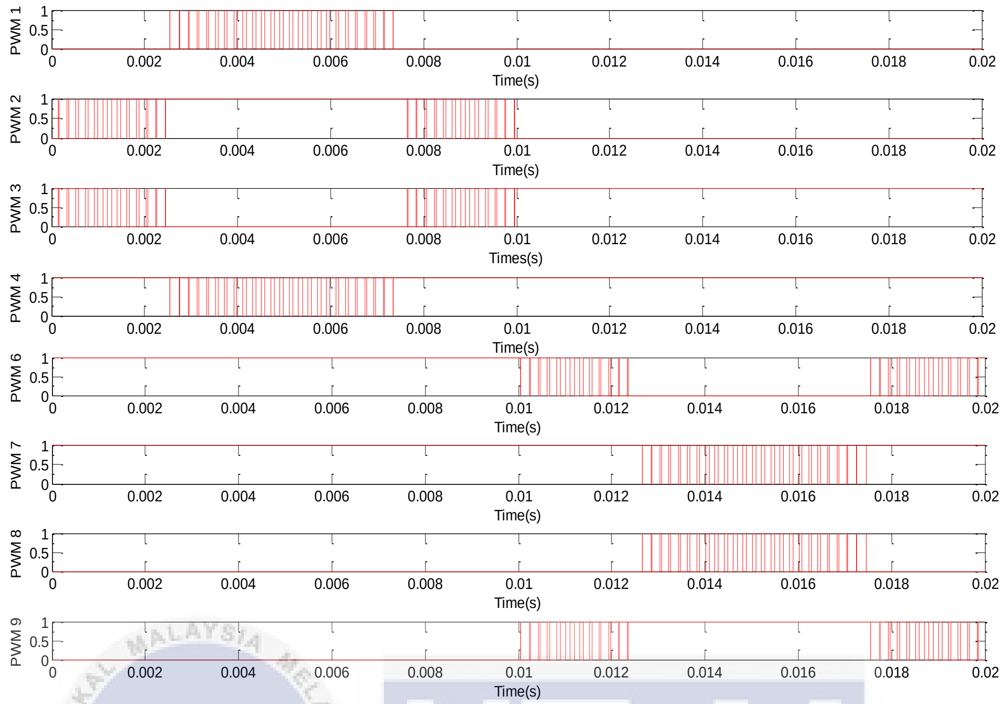


Figure 3.7: Bipolar PWM compensator signal for two-carrier

The simulation of bipolar switching is simulating with each load such as R, RL, RC and rectifier. The parameter of the loads was determined by using try and error method. The parameter is as in Table 3.3.

Table 3.3: Parameter of load

Type of loads	Value
R	5Ω
L	2H
C	1μF

The block diagram of bipolar switching schemes is conducted as in Figure 3.8 to analyse the performance of the bipolar CHB-MLI. The CHB-MLI was simulated with two-carriers.

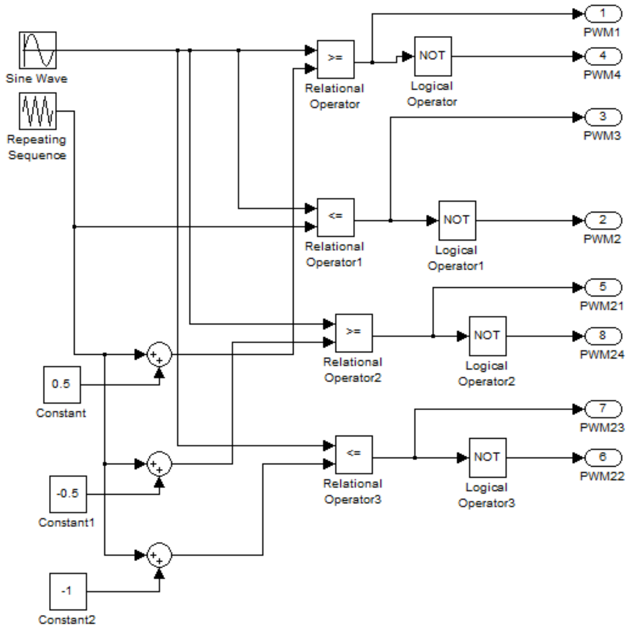


Figure 3.8: Block diagram of Bipolar Switching in PWM

3.4.3 Unipolar Switching

The Cascaded H-Bridge Multilevel Inverter (CHB-MLI) was implemented with two-triangle wave carrier Unipolar Switching. Figure 3.9 and Figure 3.10 shows the switching waveform and compensator signal respectively.

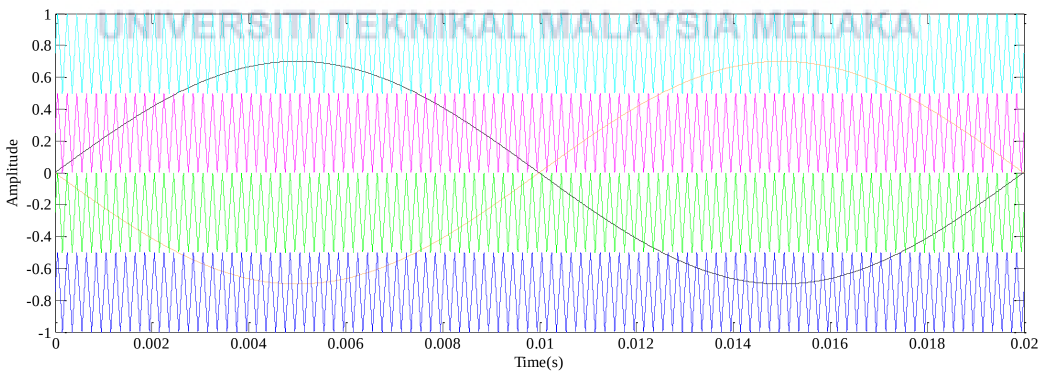


Figure 3.9: Unipolar Switching wave

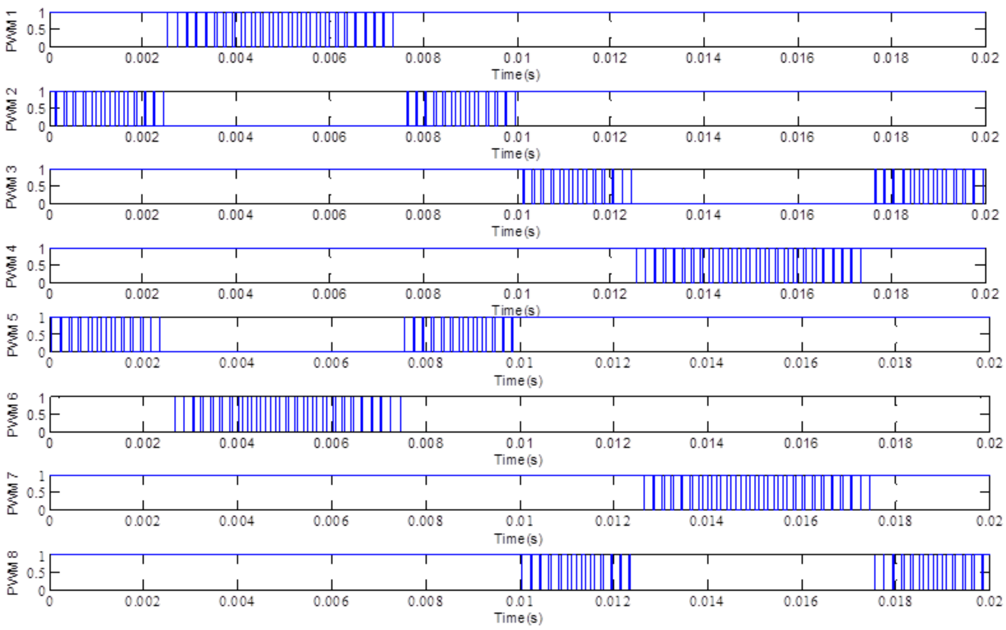


Figure 3.10: Unipolar compensator signal for two-carrier

The simulation of unipolar switching scheme is simulating with loads such as R, RL, RC and rectifier. The parameter of the loads was determined by using try and error method. The parameter is as in Table 3.3.

Table 3.4: Parameter of load

Type of load	Value
R load	5Ω
L load	2H
C load	1μF

The block diagram of bipolar switching schemes is conducted as in Figure 3.11 to analyse the performance of the unipolar CHB-MLI. The CHB-MLI was simulated with two-carriers.

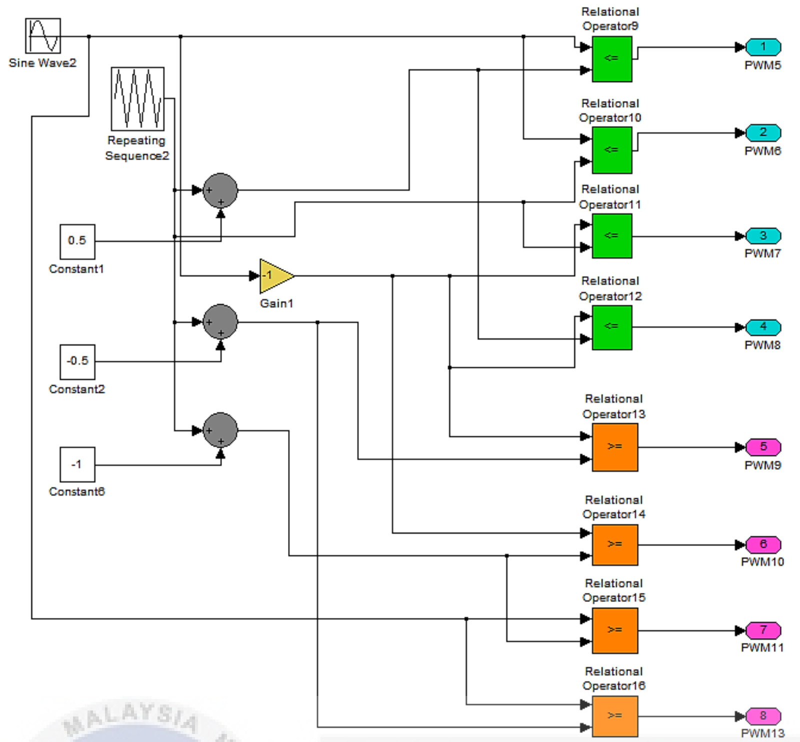


Figure 3.11: MATLAB Simulink model of two-carrier unipolar cascaded multilevel inverter

3.5 Analysis of MLI Connected to the Non-Linear Load without APF

The performance of MLI switching scheme connected to the non-linear load before injecting APF was analyze in this subtopic. There are three switching scheme which are trinary seven levels, bipolar and unipolar that connected to the RL-load with rectifier. The entire switching scheme was connected to the three type of non-linear load which are R-load with rectifier, RL-load with rectifier, and RC-load with rectifier. However, in this subtopic only demonstrate unipolar, bipolar, trinary seven level MLI connected to the RL-load with rectifier. A single phase CHB-MLI is connected to 100 Ω and 0.8 H RL-load and rectifier. The value of RL-load was determined by using try and error method. Figure 3.12 shows MATLAB/Simulink model of MLI connected to the non-linear load.

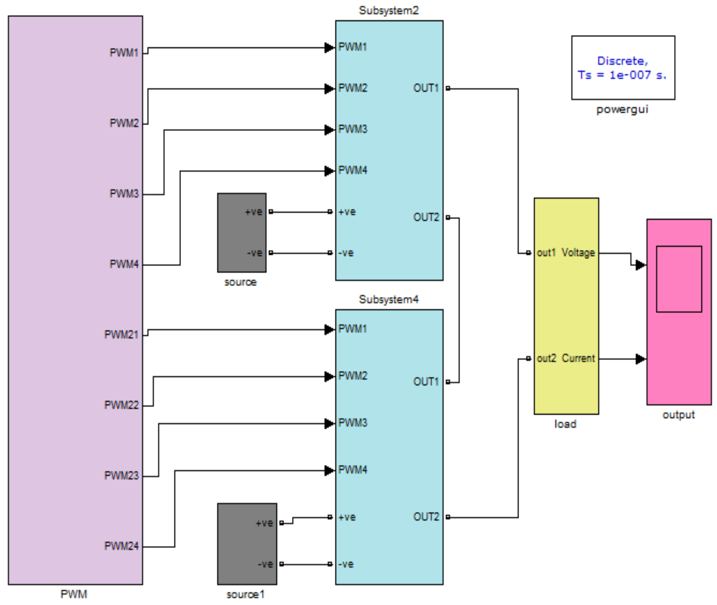


Figure 3.12: MATLAB/Simulink model of MLI connected to the non-linear load

3.5.1 Simulation of Trinary Seven Levels Switching Connected to the Non-Linear Load without Shunt APF

The output waveform of load current and load voltage are shown in Figure 3.13. THD current and voltage for RL- load and rectifier is shown in Figure 3.14. Result shows the voltage THD is 21.63% and current THD 31.61%.

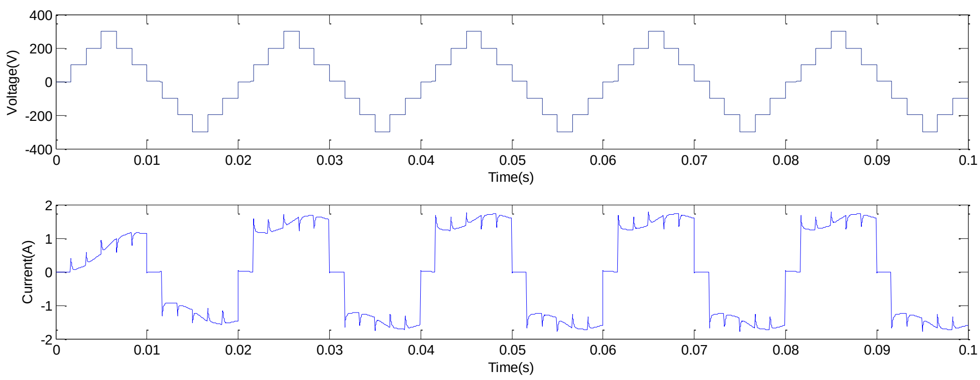
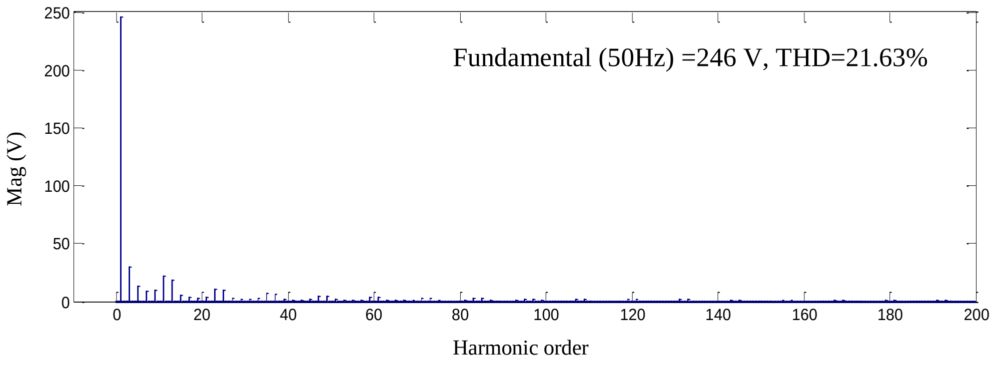
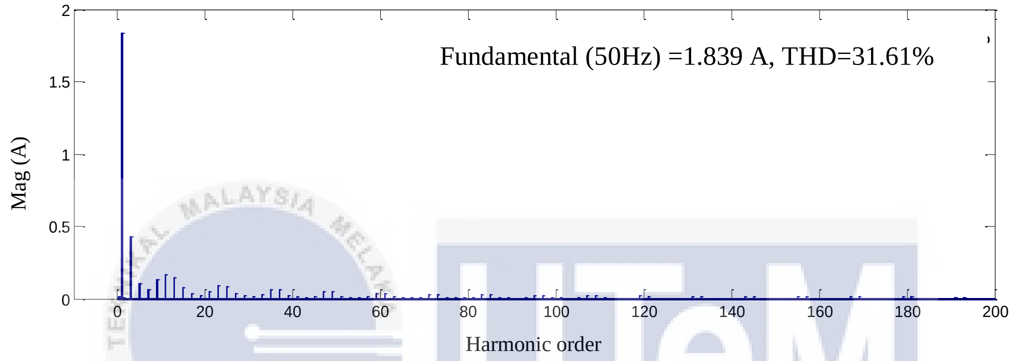


Figure 3.13: Single Phase Seven Level Trinary DC Source MLI with RL-load and Rectifier



(a)



(b)

Figure 3.14: (a) THD Voltage for Single Phase Trinary Seven Levels MLI, (b) THD Current for Single Phase Trinary Seven Levels MLI

3.5.2 Simulation of PWM with Bipolar Switching Connected to the Non-Linear Load without Shunt APF

The output waveform of load current and load voltage that connected to the load are shown in Figure 3.15. THD current and voltage for RL- load and rectifier is shown in Figure 3.16 and it shows the voltage THD is 41.87% and current THD is 47.63%.

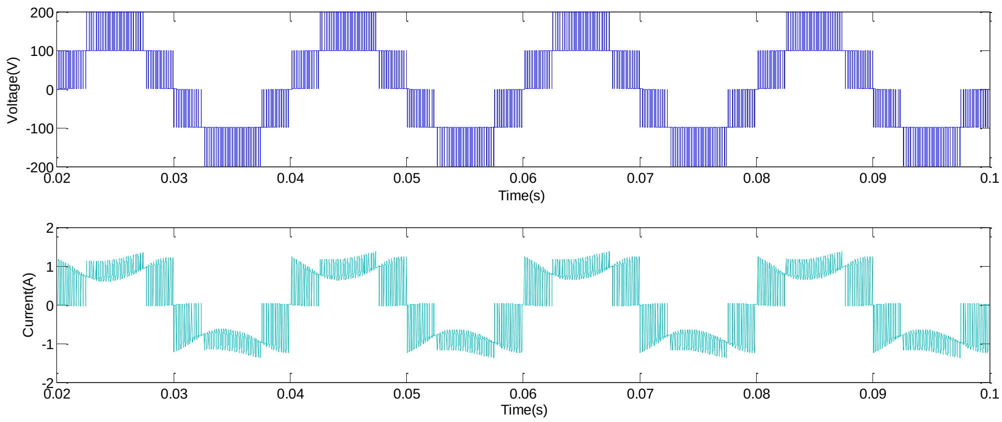
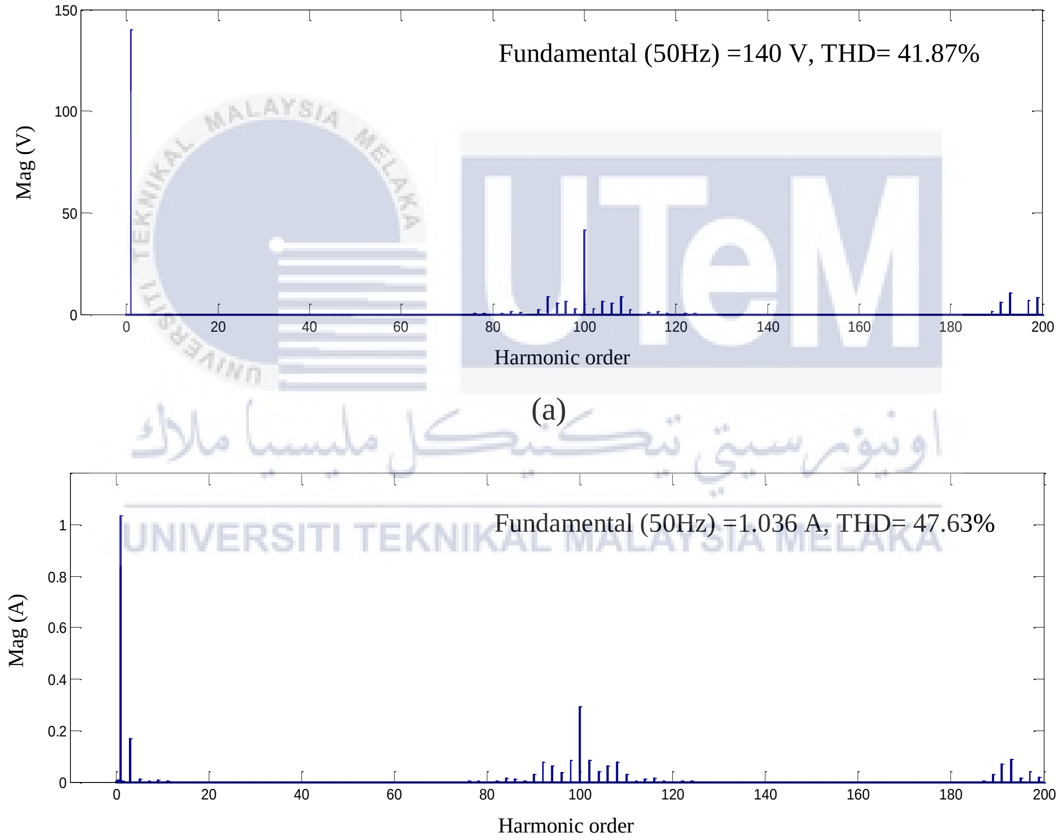


Figure 3.15: Single Phase Bipolar Waveform for RL-Load and Rectifier



(a)

(b)

Figure 3.16: (a) THD Voltage for Single Phase Bipolar MLI, (b) THD Current for Single Phase Bipolar MLI

3.5. 3 Simulation of PWM with Unipolar Switching Connected to the Non-Linear Load without Shunt APF

The output waveform of load current and load voltage are shown in Figure 3.17. THD current and voltage for RL- load with rectifier is shown in Figure 3.18 and the result shows voltage THD is 21.35% and current THD is 39.60%.

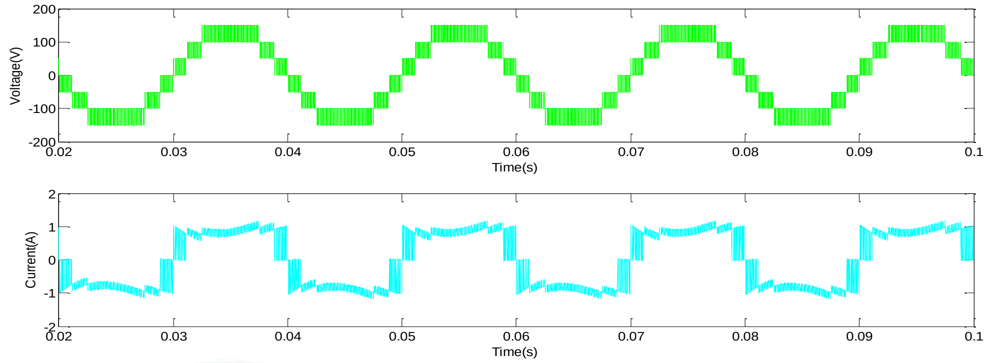
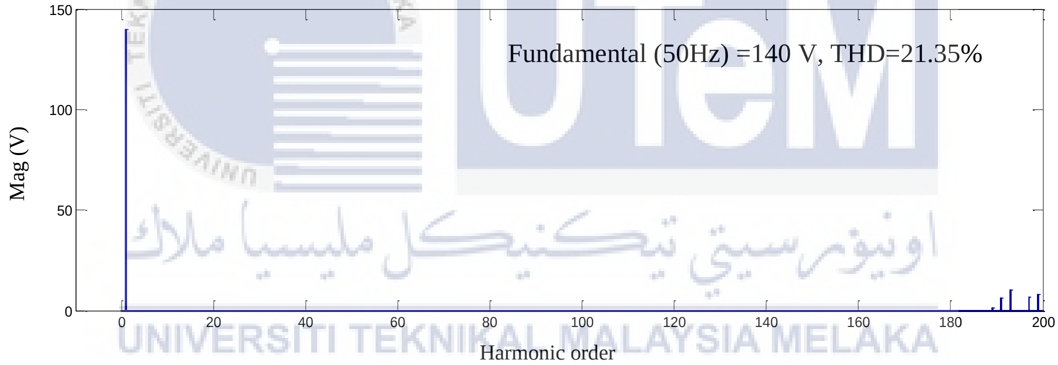
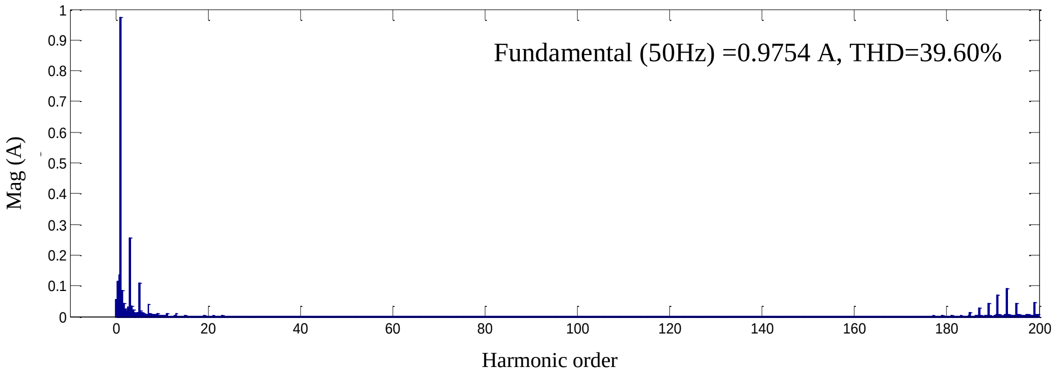


Figure 3.17: Single Phase Unipolar Waveform for RL-Load and Rectifier



(a)



(b)

Figure 3.18: (a) THD Voltage for Single Phase Unipolar MLI, (b) THD Current for Single Phase Unipolar MLI

Table 3.5: The THD Result for Bipolar Switching and Unipolar Switching

Load	Trinary		Bipolar		Unipolar	
	THD_i	THD_v	THD_i	THD_v	THDi	THD_v
RL with rectifier	31.61%	21.63%	47.63%	41.87%	39.60%	21.35%

From the Table 3.5, it shows that THD of current and voltage is over the limit of IEEE-519 harmonic standard which is must below than 5% [2]. Thus, APF was injected to the circuit in order to mitigate harmonic.

3.6 MLI Connected to the Non-linear Load with Injecting of APF Based on FFT

In order to overcome the problems of high value of current THD, APF based on FFT was connected in parallel with the inverter and non-linear loads. The experimental with new control method of single phase APF is developed as shown in Figure 3.19.

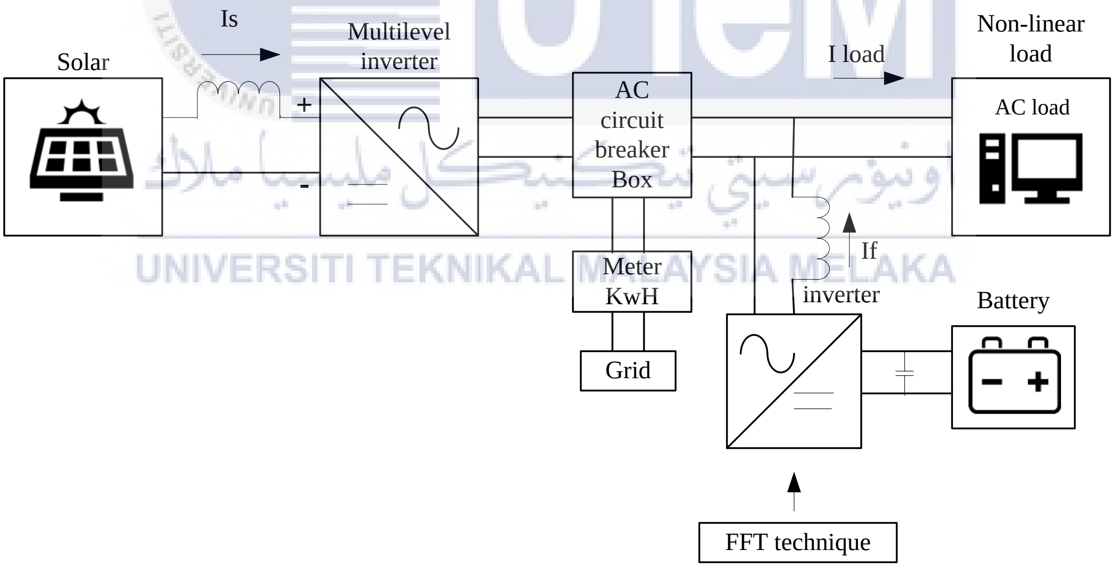


Figure 3.19: Block diagram of shunt APF based on Fast Fourier Series for PWM cascaded multilevel inverter for solar application

The main power circuit consists of $V_{DC\ 1}$ and V_{DC2} with value 100V and 300V respectively. Both of the V_{DC} was connected to the three type of switching scheme MLI such as trinary seven level, bipolar and unipolar switching. Each of the control switching is implemented and the performance of the MLI was verified. Then, the inverter was connected to the non-linear loads. The simulation was repeated with three different kinds of loads which are R-load with rectifier, RL-load with rectifier and RC-load with rectifier. The APF based on FFT was connected parallel to the inverter and non-linear loads. FFT technique was functional as a controller to control the APF in mitigation of harmonic. Shunt APF was injected to this circuit for mitigation of current harmonics caused by the high THD produce from non-linear loads. Figure 3.20 shows the MATLAB/Simulink model of Single Phase Shunt APF Based on FFT for PWM Cascaded Multilevel Inverter.

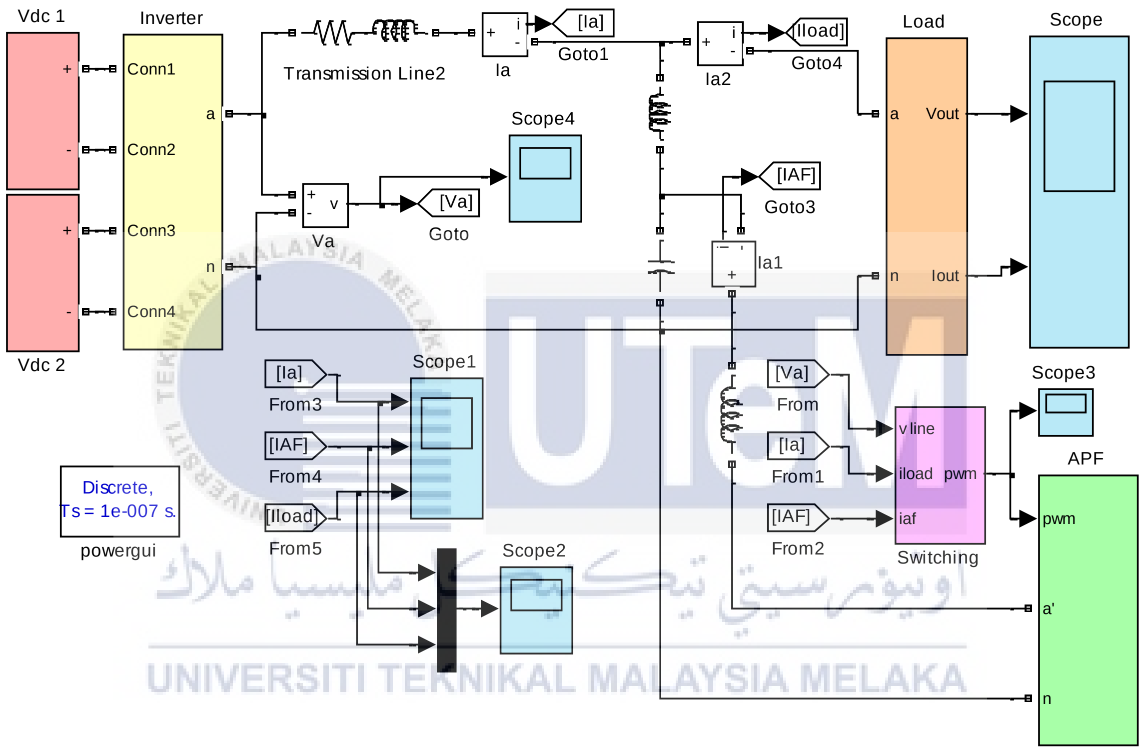


Figure 3.20: MATLAB/Simulink model of Single Phase Shunt APF Based on FFT for PWM Cascaded Multilevel Inverter

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

This chapter discuss the performance of single phase shunt active power filter based on Fast Fourier Transform method for PWM cascaded multilevel inverter. The simulation block was conducted in order to analyze the performance of a single phase shunt Active Power Filter based on Fast Fourier Transform method. Besides, this chapter is focusing the result of the THD line current and THD load current with different type of non-linear loads.

4.2 Simulation Result

This subtopic present the simulation result of the single phase shunt APF based on FFT method for PWM cascaded multilevel inverter with three different non-linear loads which are R-load with rectifier, RL-load with rectifier, and RC-load with rectifier. All the value of R, L, and C loads was determined by using try and error method. Each load is connected to MLI by using trinary seven levels, bipolar, and unipolar switching schemes. The APF was connected parallel to the MLI and non-linear loads.

4.2.1 Simulation of Trinary Seven Level DC Source MLI with Active Power Filter

In this subtopic was demonstrated the simulation result of single phase CHB-MLI with trinary seven level switching scheme and non-linear load after the injecting of APF in the system. The inverter is connected with the various type of load such as R, RL, RC loads and rectifier. The DC voltage source supplies are 100 V and 50 Hz.

4.2.1.1 Simulation with R- load and Rectifier

A single phase CHB-MLI with trinary seven level switching schemes is connected to R load and rectifier with value R is 5 Ω. Figure 4.1 shows the waveform of line current, active filter current and load current. THD line and load current for R load is shown in Figure 4.2 and the result shows line current have small value of THD which is 2.93% after injecting active filter in the circuit even though load current have high percentage of THD with 31.70%.

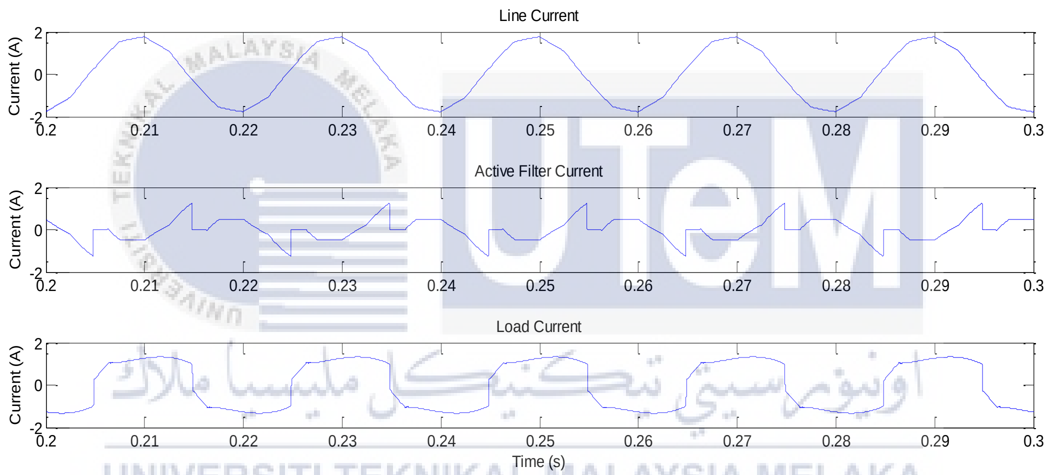
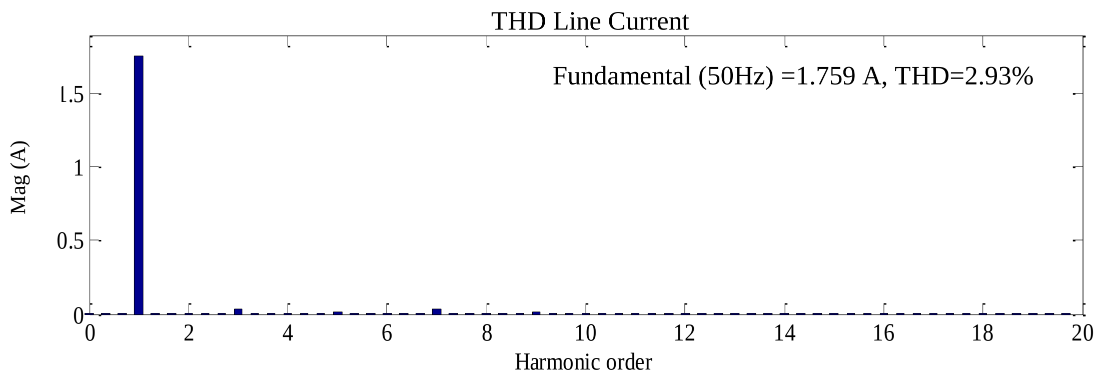
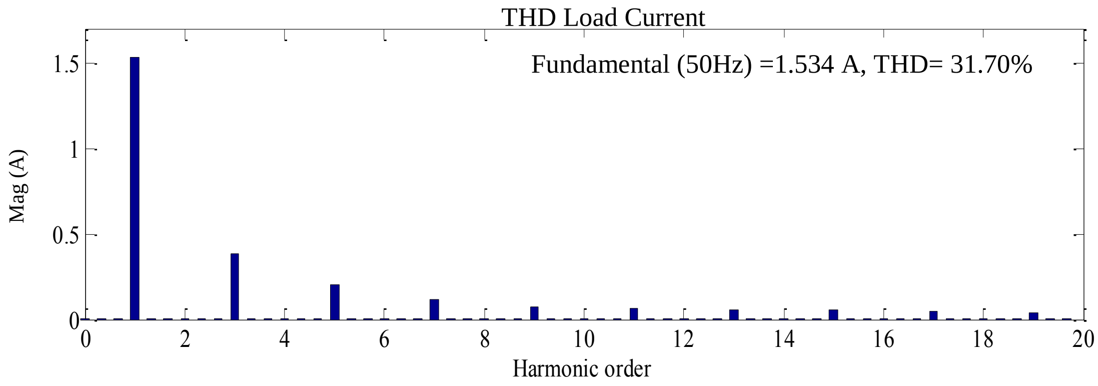


Figure 4.1: Single Phase Seven Level Trinary DC Source MLI for R-load and rectifier with shunt APF



(a)



(b)

Figure 4.2: (a) THD Line Current for Seven Level Trinary DC Source MLI (R-load and Rectifier), (b) THD Load Current for Seven Level Trinary DC Source MLI (R-load and Rectifier)

4.2.1.2 Simulation with RL- Load and Rectifier

A single phase CHB-MLI is connected to RL- load and rectifier with value 5 Ω and L=0.8 H. The output waveform of line current, load current and active filter current are shown in Figure 4.3. THD line and load current for RL- load with rectifier is shown in Figure 4.4 and it shows the line current THD is 4.75% and load current THD is 41.05%. The line current was still within the IEEE harmonic standard.

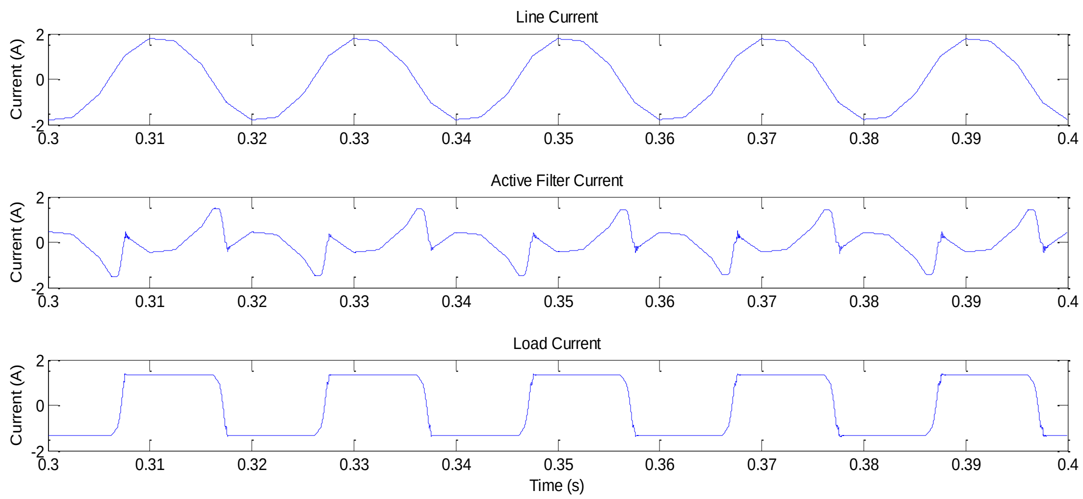
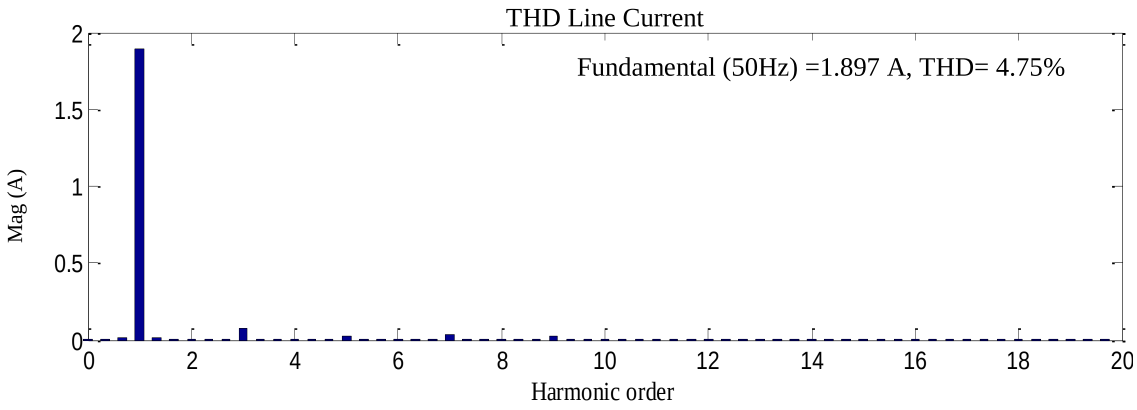
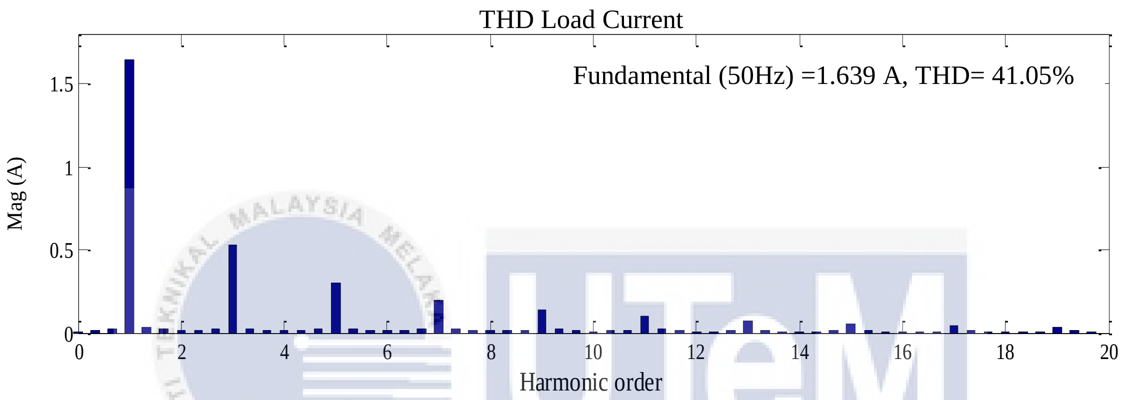


Figure 4.3: Single Phase Seven Level Trinary DC Source MLI for RL-load and rectifier with shunt APF



(a)



(b)

Figure 4.4: (a) THD for Line Current Seven Level Trinary DC Source MLI (RL-load), (b) THD for Load Current Seven Level Trinary DC Source MLI (RL-load)

4.2.1.3 Simulation with RC- Load and Rectifier

A single phase CHB-MLI is connected to RC- load and rectifier with value 5 Ω and C=1μF. The output waveform of line current, load current and active filter current are shown in Figure 4.3. THD line and load current for RL- load with rectifier is shown in Figure 4.4 and it shows the line current THD is 4.81% and load current THD is 70.78%. The line current was still within the IEEE harmonic standard.

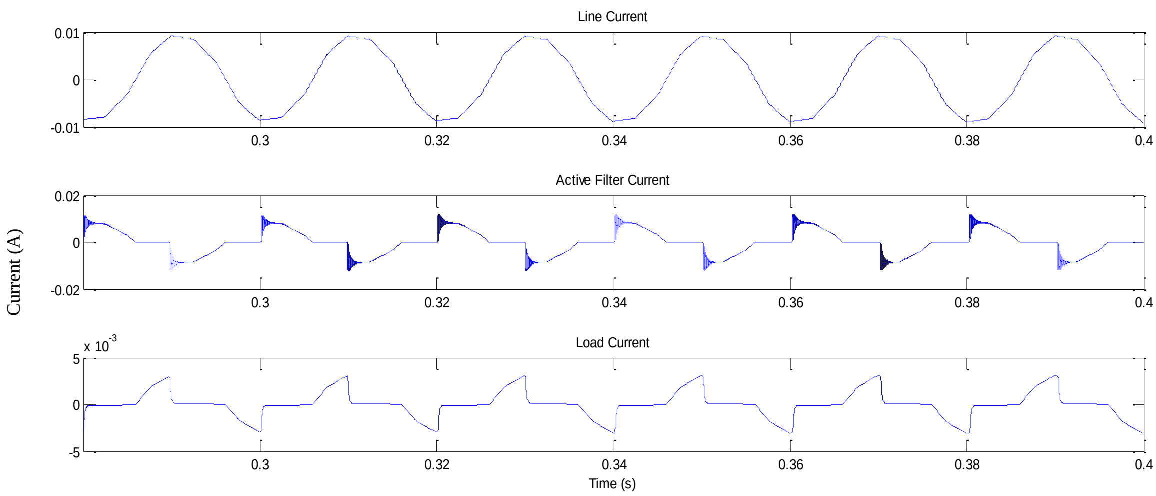
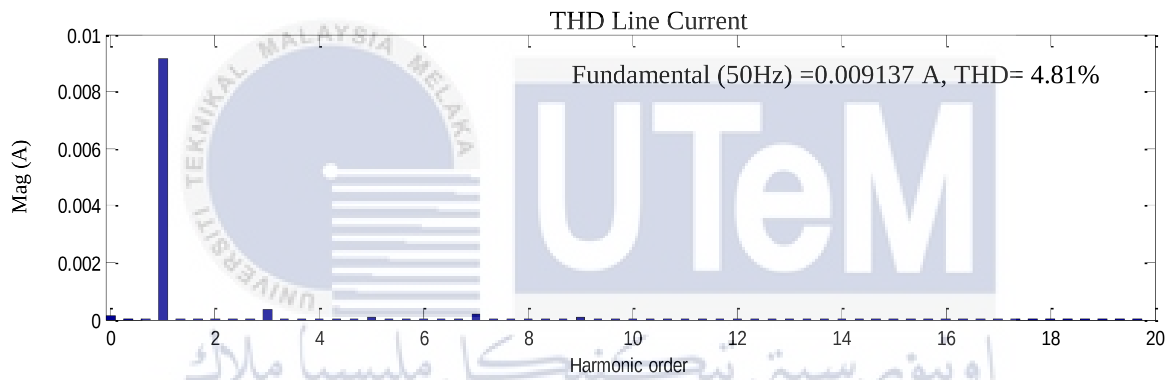
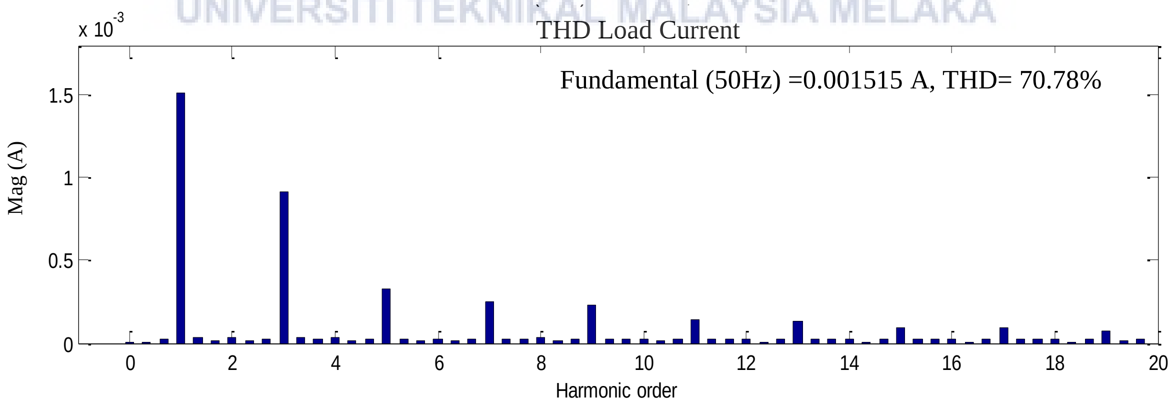


Figure 4.5: Single Phase Seven Level Trinary DC Source MLI for RC-load and rectifier with shunt APF



(a)



(b)

Figure 4.6: (a) THD for Line Current Seven Level Trinary DC Source MLI (RC-load and rectifier) with APF, (b) THD for Load Current Seven Level Trinary DC Source MLI (RC-load and rectifier) with APF

4.2.2 Simulation of Bipolar MLI with Active Power Filter

This subtopic demonstrated the simulation result of single phase CHB-MLI with bipolar switching scheme and non-linear load after the injecting of APF in the system. The inverter is connected with the various type of load such as R, RL, RC loads and rectifier.

4.2.2.1 Simulation Result with R-Load and Rectifier

A single phase CHB-MLI with bipolar switching schemes is connected to R load and rectifier with value R is 5 Ω. Figure 4.7shows the waveform of line current, active filter current and load current. THD line and load current for R load is shown in Figure 4.8 The result of THD spectrum shows the line current have small value of THD which is 0.41% after injecting active filter in the circuit even though load current have high percentage of THD with 5.24%.

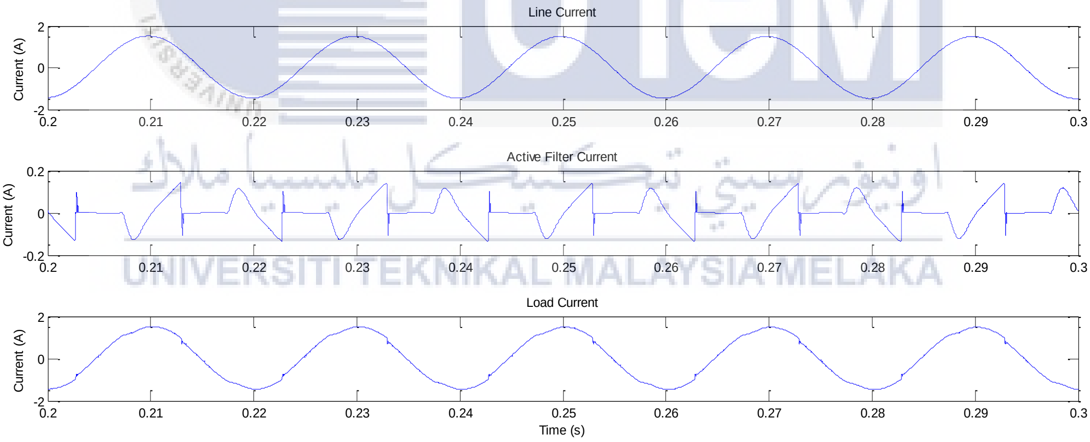
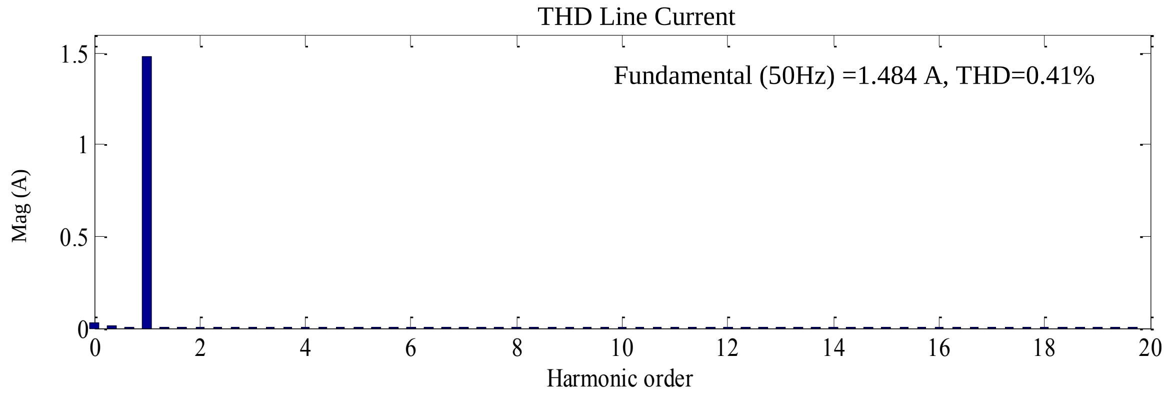
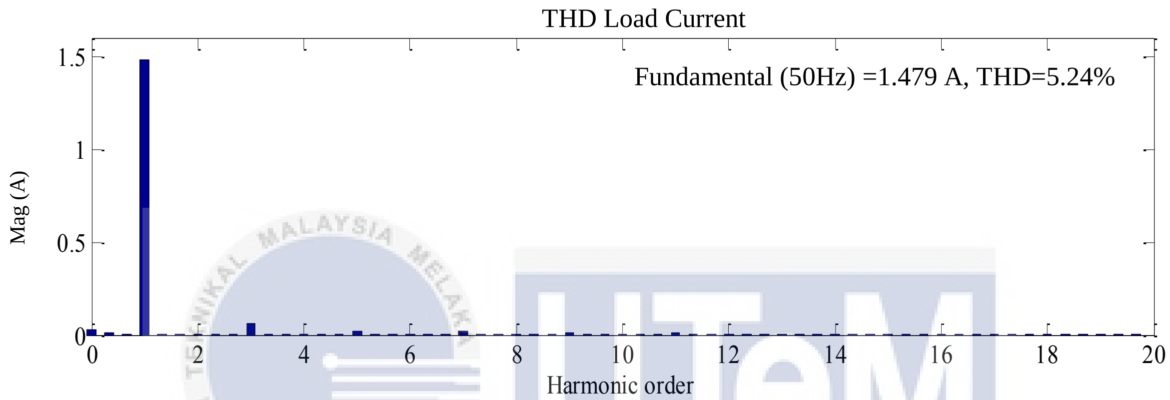


Figure 4.7: Single Phase Bipolar Waveform for R-Load and Rectifier with shunt APF



(a)



(b)

Figure 4.8: (a) THD Line Current for Bipolar Switching MLI (R-load and Rectifier), (b) THD Load Current for Bipolar Switching MLI (R-load and Rectifier)

4.2.2.2 Simulation Result with RL-Load and Rectifier

A single phase CHB-MLI is connected to RL- load and rectifier with value 5 Ω and L=4 H. The output waveform of line current, load current and active filter current are shown in Figure 4.9. THD line and load current for RL- load with rectifier is shown in Figure 4.10. The result shows the THD spectrum of line current is 0.70% and THD for load current is 41.05%. The line current has small value of THD after injecting of APF in the circuit even though load current has high percentage of THD.

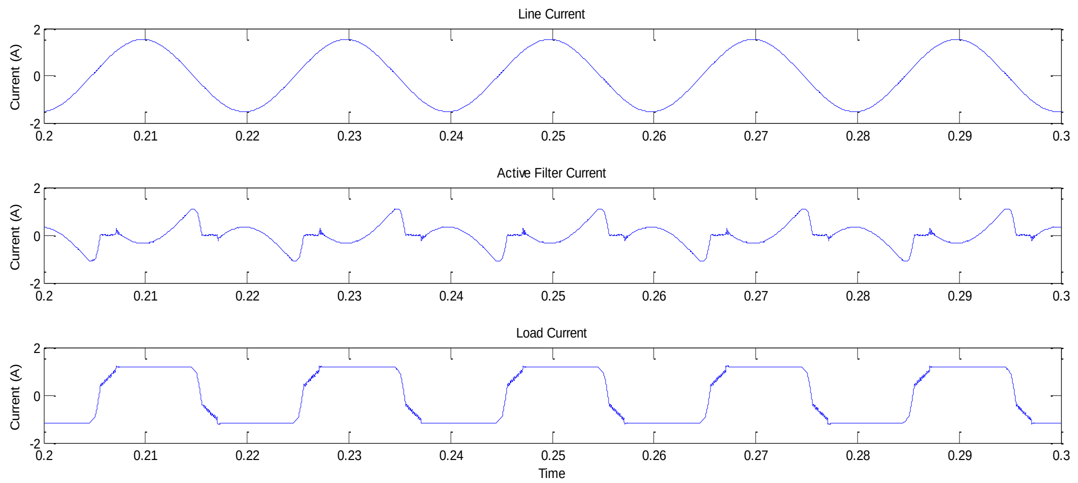
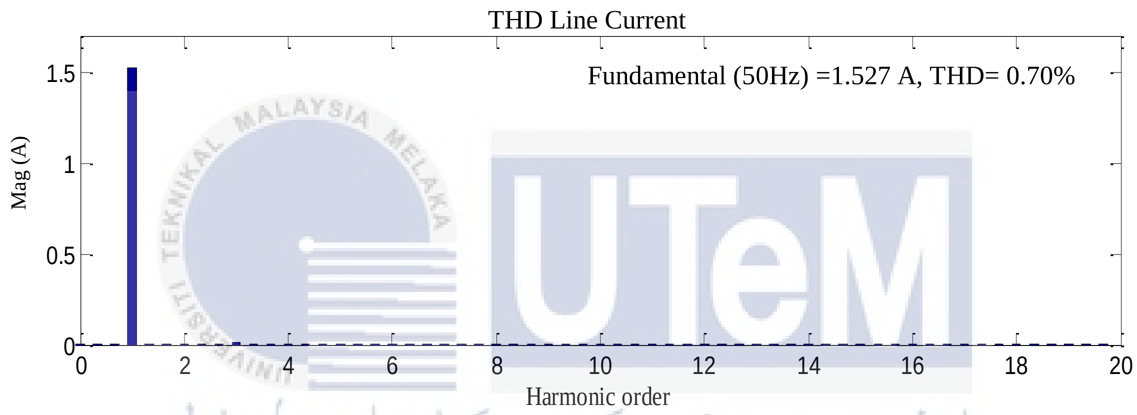
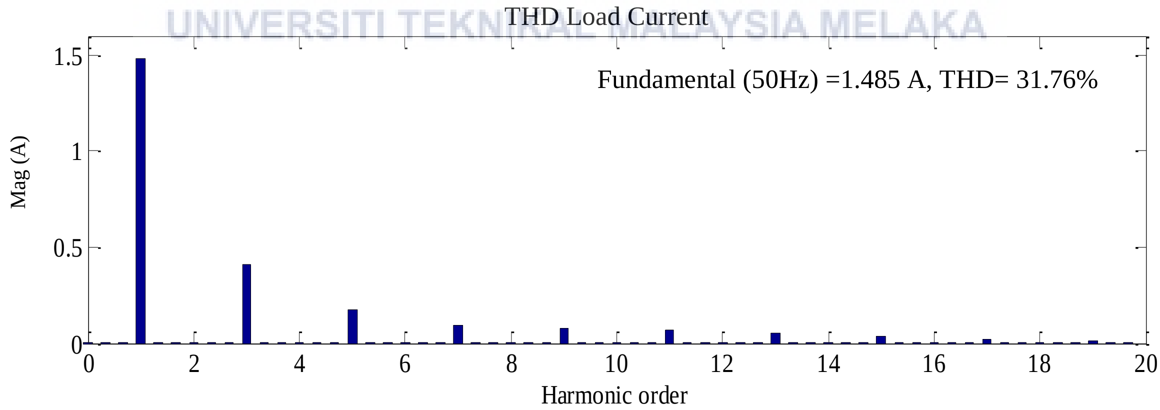


Figure 4.9: Single Phase Bipolar Waveform for RL-Load and Rectifier with shunt APF



(a)



(b)

Figure 4.10: (a) THD Line Current for Bipolar Switching MLI (RL-load and Rectifier), (b) THD Load Current for Bipolar Switching MLI (RL-load and Rectifier)

4.2.2.3 Simulation Result with RC-Load and Rectifier

A single phase CHB-MLI is connected to RC- load and rectifier with value 5 Ω and C=1μF. The output waveform of line current, load current and active filter current are shown in Figure 4.11. THD line and load current for RC- load with rectifier is shown in Figure 4.12. The result shows the THD spectrum of line current is 0.91% and THD for load current is 54.26%. The line current has small value of THD after injecting of APF in the circuit even though load current has high percentage of THD.

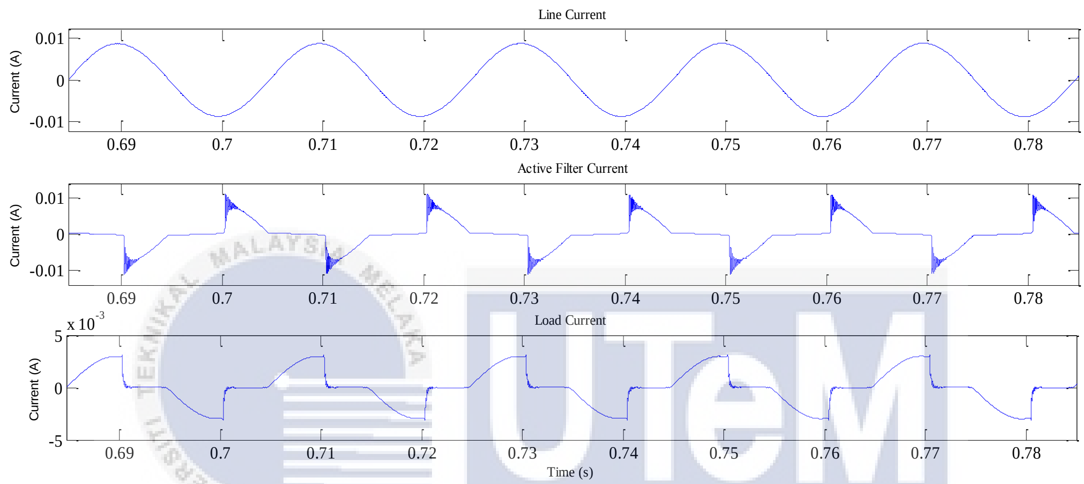
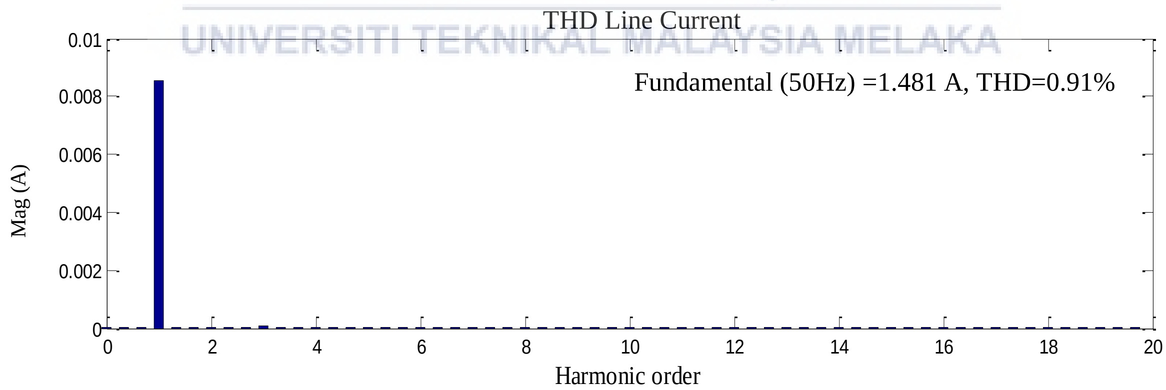
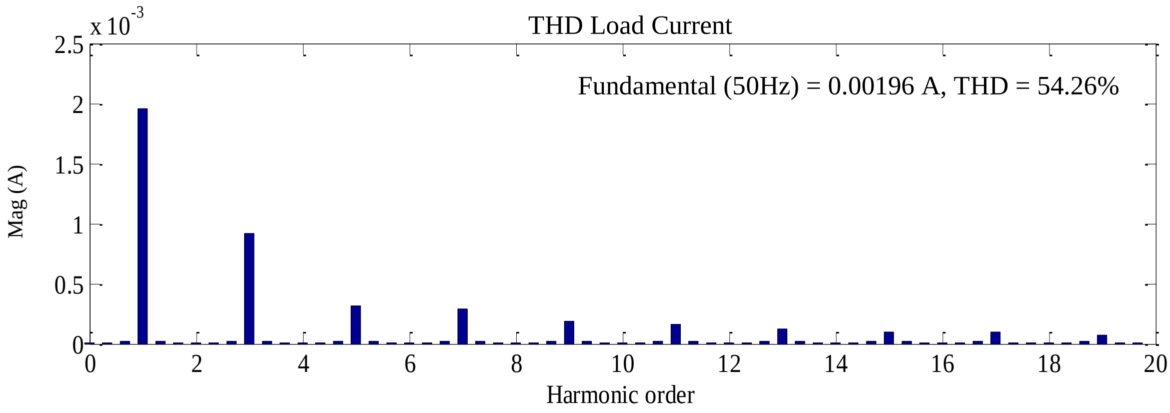


Figure 4.11: Single Phase Bipolar Waveform for RC-Load and Rectifier with shunt APF



(a)



(b)

Figure 4.12: (a) THD Line Current for Bipolar MLI (RL-load and Rectifier) with APF, (b) THD Load Current for Bipolar MLI (RL-load and Rectifier) with APF

4.2.3 Simulation of Unipolar MLI with Active Power Filter

In this subtopic was demonstrated the simulation result of single phase CHB-MLI with unipolar switching scheme and non-linear load after the injecting of APF in the system. The inverter is connected with the various type of load such as R, RL, RC loads and rectifier.

4.2.3.1 Simulation Result with R-Load and Rectifier

A single phase CHB-MLI with unipolar switching schemes is connected to R load and rectifier with value R is 5 Ω. Figure 4.13 shows the waveform of line current, active filter current and load current. THD line and load current for R load is shown in Figure 4.14. The results indicate a THD load current of 6.40% whereas, THD line current is 0.24% after injecting shunt APF in the circuit.

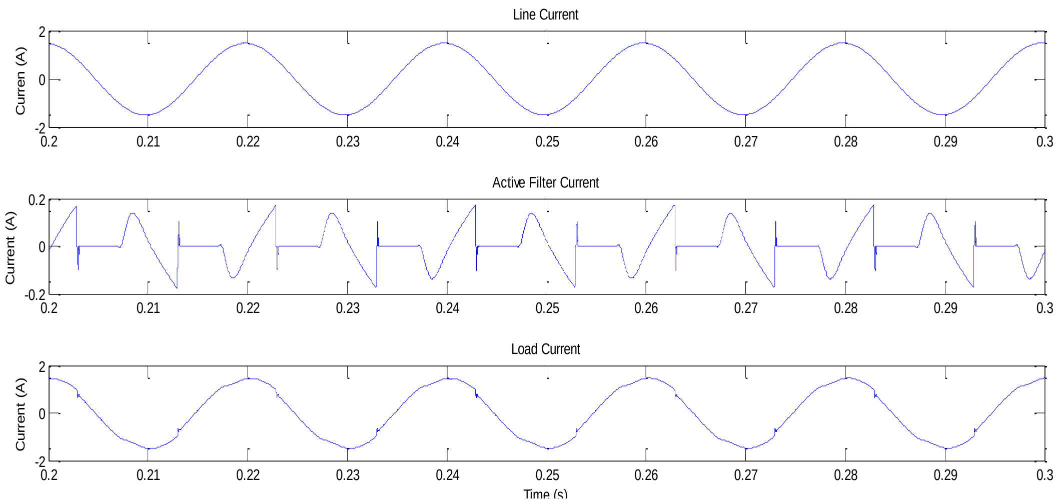
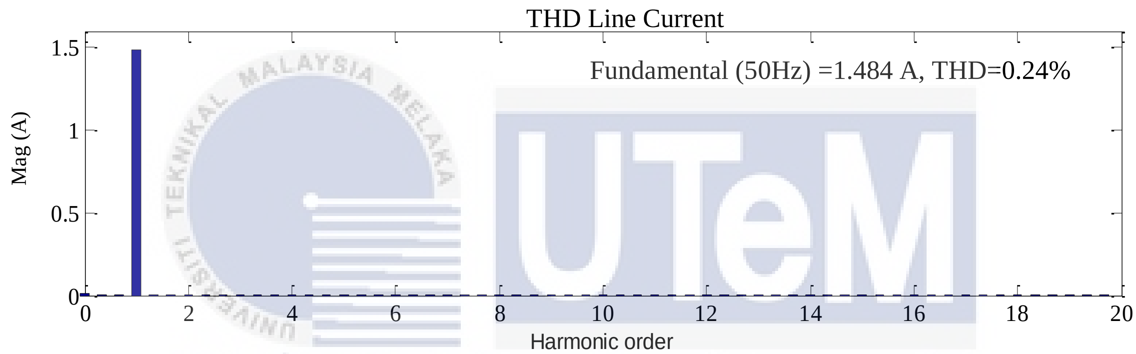
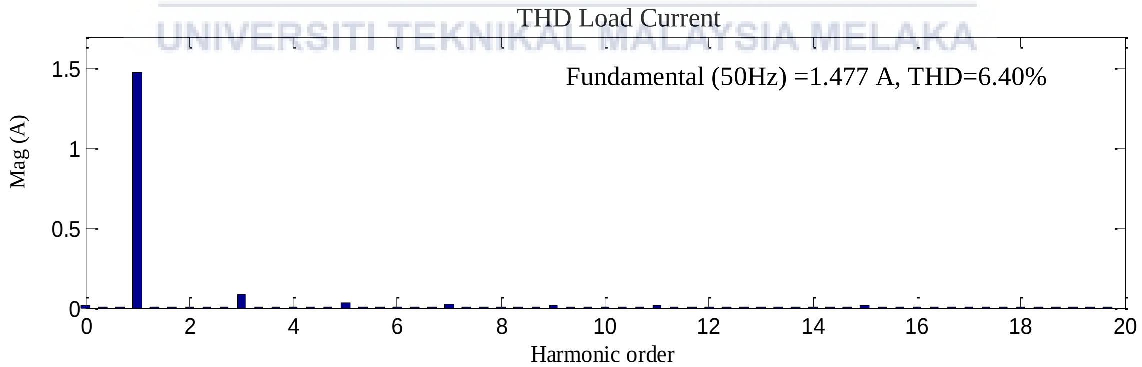


Figure 4.13: Single Phase Unipolar Waveform (R-Load and Rectifier) with shunt APF



(a)



(b)

Figure 4.14: (a) THD Line Current for Unipolar Single Phase (R-Load and Rectifier), (b) THD Load Current for Unipolar Single Phase Current (R-Load and Rectifier)

4.2.3.2 Simulation Result with RL-Load and Rectifier

A single phase CHB-MLI with unipolar switching schemes is connected to RL load and rectifier with value 5 Ω and 4 H respectively. The performance of APF was shown Figure 4.15 which consists of line current, active filter current and load current waveform. THD line and load current for R load is shown in Figure 4.16. The results indicate a THD load current of 34.05% whereas, THD line current is 0.66% with presence of shunt APF in the circuit.

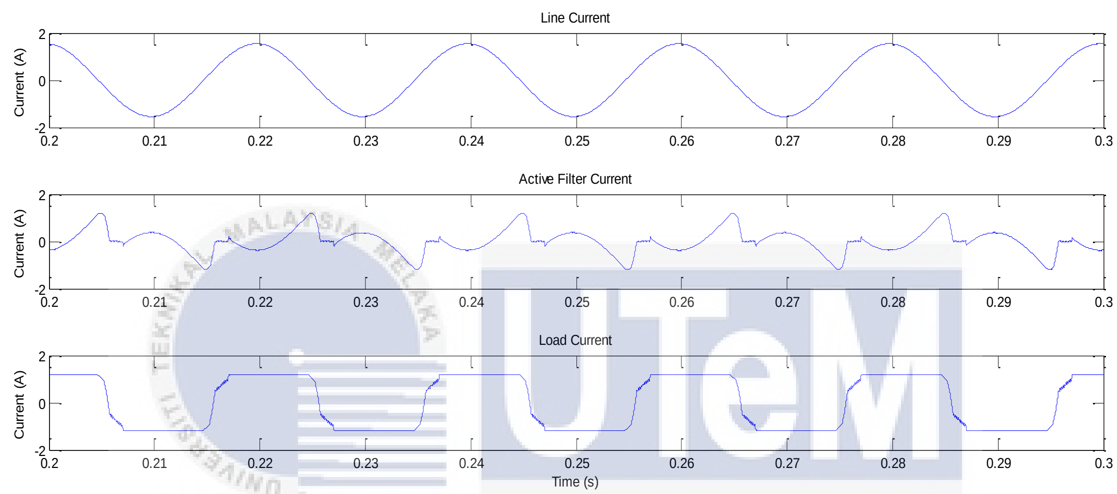
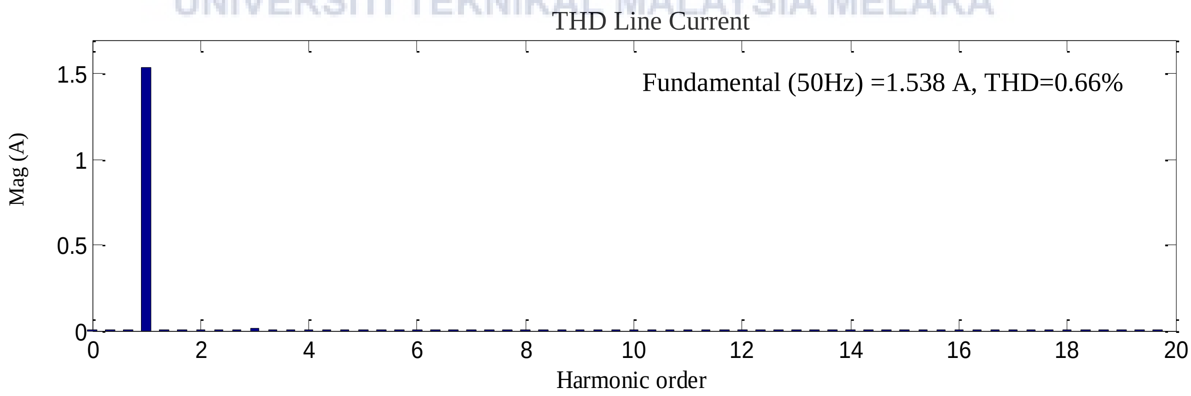
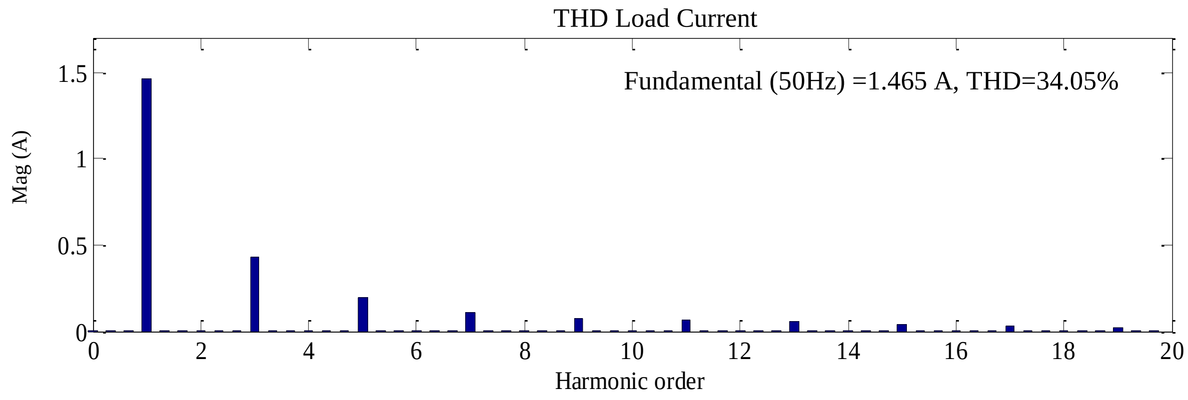


Figure 4.15: Single Phase Unipolar Waveform for RL-Load and Rectifier with shunt APF



(a)



(b)

Figure 4.16: (a) THD Line Current for Unipolar Single Phase Voltage (RL-Load and Rectifier), (b) THD Load Current for Unipolar Single Phase Current (RL-Load and Rectifier)

4.2.3.3 Simulation Result with RC-Load and Rectifier

A single phase CHB-MLI with unipolar switching schemes is connected to RC load and rectifier with value R is 5 Ω and C is 1μF. The performance of APF was shown Figure 4.17 which consists of line current, active filter current and load current waveform. THD line and load current for RC load and rectifier is shown in Figure 4.18. The results indicate a THD load current of 54.25% whereas, THD line current is 0.88% with presence of shunt APF in the circuit.

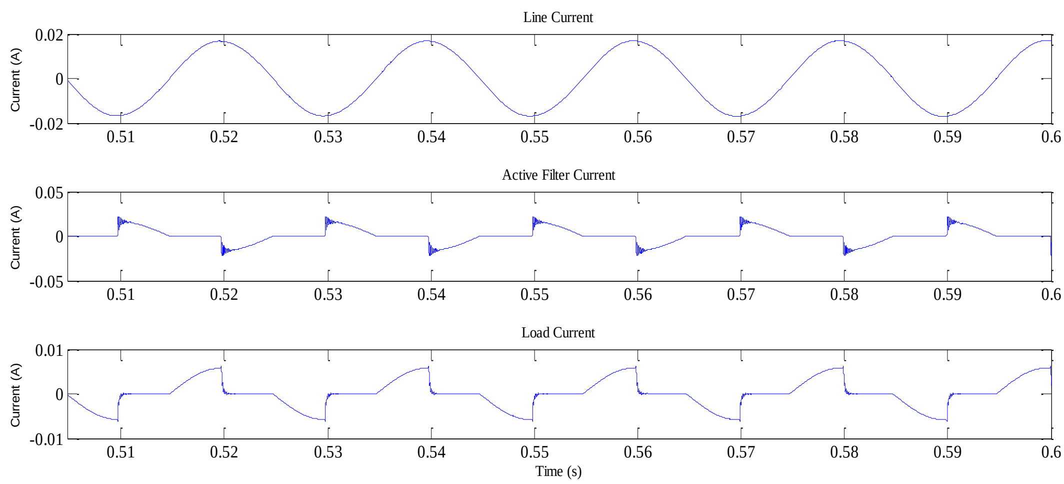
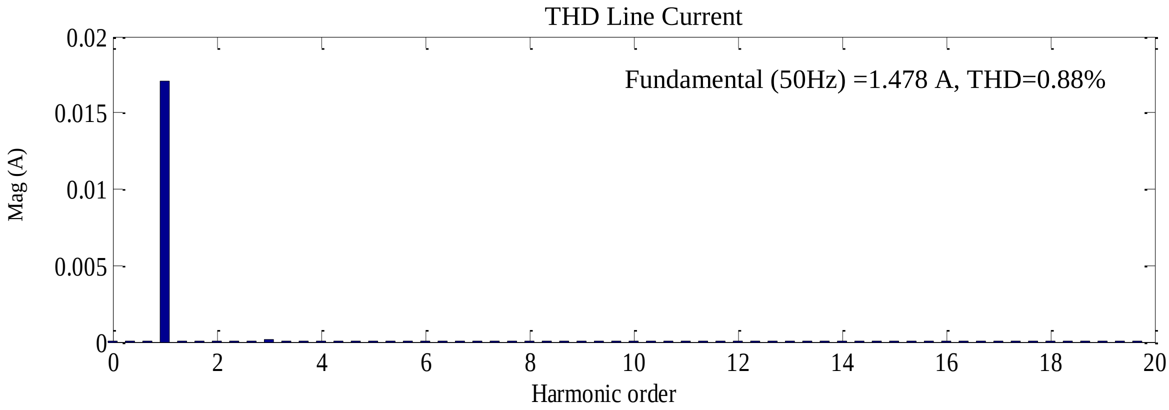
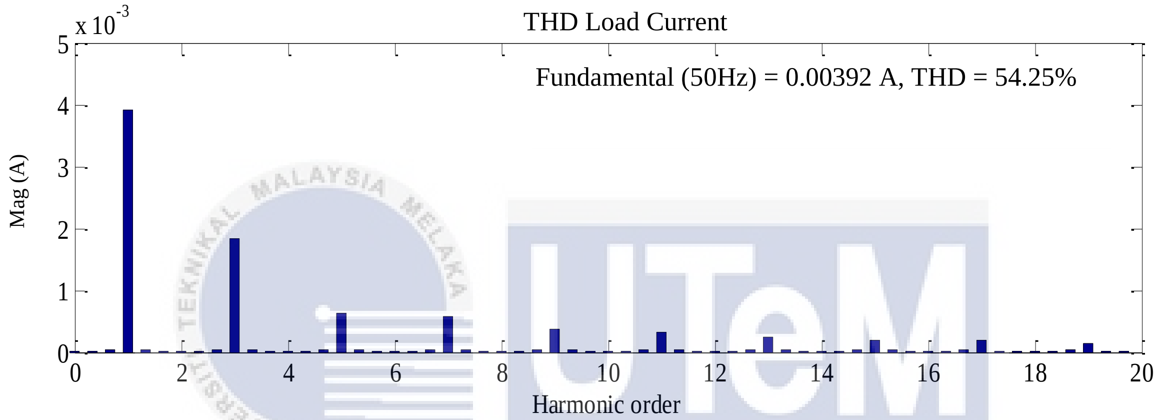


Figure 4.17: Single Phase Unipolar Waveform for RC-Load and Rectifier with shunt APF



(a)



(b)

Figure 4.18: (a) THD Line Current for Unipolar MLI (RL-load and Rectifier), (b) THD Load Current for Unipolar MLI (RL-load and Rectifier)

4.3 Summary of Result

The simulation result of THD line current and load current was recorded and summarize in Table 4.1 and Figure 4.19. In short, every non-linear load and switching schemes have different values of THD line current and load current. From Figure 4.19, it shows all the THD load current has a high percentage of THD and Bipolar RC-load rectifier has the highest percentage with 54.26% followed by Unipolar RC-load rectifier with 54.25%. This is because rectifier diode only gives the current flow pass the load during certain time which the time the voltage flow exceed the voltage stored in the capacitor and it effected the incoming voltage cycle. Even though Bipolar RC-load rectifier has the high percentage of THD load current, by injecting the APF parallel to the loads and inverter, THD line current for Bipolar RC-load rectifier just only 0.91% and it follow the requirement of IEEE harmonic standard which is must below than 5%.

Besides that, for every switching scheme in Table 4.1 shows RC with rectifier load have high percentage THD line current whereas, R with rectifier load has low percentage THD line current. Trinary seven levels THD line current for RC with rectifier has high percentage of THD line current with 4.81%. However, it still fulfils the requirement IEEE harmonic standard which is below than 5%. Conversely, unipolar THD line current for R with rectifier load has the lowest percentage of THD with 0.24% which is nearest to zero and followed by bipolar THD line current with 0.41%.

In addition, through observation of Figure 4.19 THD line current successfully reduced after injected shunt APF based on FFT in average 88% to 99% even though load current have drawn a high percentage of THD. Thus, APF based on FFT was success in mitigate the harmonic that present in the line and produced sinusoidal current waveform. In the nutshell, APF based on FFT technique is capable in mitigate harmonic that produce by non-linear loads which always been used in our daily life.

Table 4.1: THD result of line current and load current

Load	Trinary		Bipolar		Unipolar	
	THD load current	THD line current	THD load current	THD line current	THD load current	THD line current
R with rectifier	31.70%	2.93%	5.24%	0.41%	5.40%	0.24%
RL with rectifier	41.05%	4.75%	31.76%	0.70%	34.05%	0.66%
RC with rectifier	70.78%	4.81%	54.26%	0.91%	54.25%	0.88%

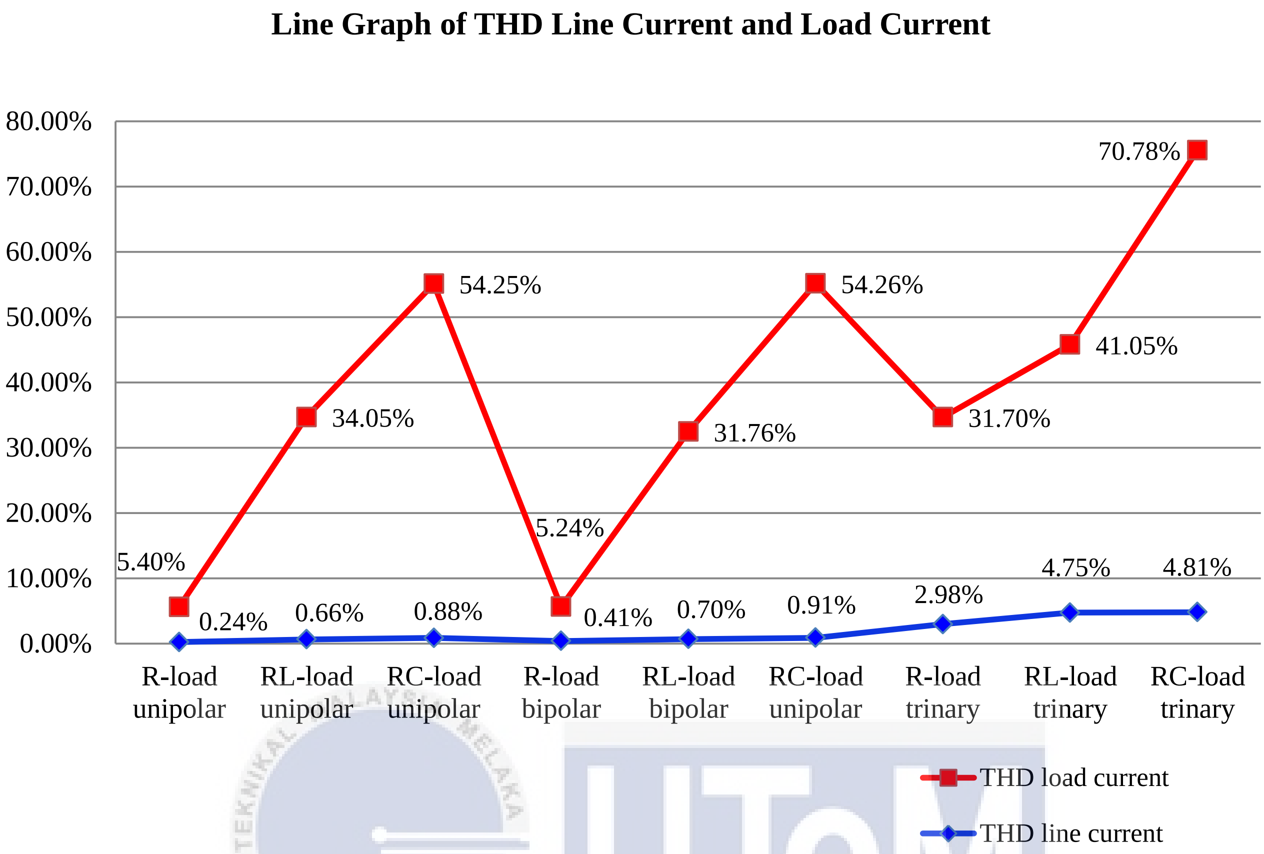


Figure 4.19: Line Graph of THD line current and load current for every switching scheme and non-linear loads.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The usage of inverter is widely used in domestic and industrial. The main role MLI is to produce better sinusoidal voltage and current in the output by applying switches in series. However, by connecting to the non-linear loads it generate current harmonic which can cause poor power quality of the system. In order to overcome the problem of harmonics, Active Power Filter (APF) based on Fast Fourier Transform (FFT) was implemented. This project was focusing in simulated and analyzed the performance APF based on FFT in mitigating harmonic that produce by non-linear loads. FFT technique was selected due to a very simple way to mitigate harmonic compared to other control technique. The performance of single phase shunt APF based on FFT method was verified. Based on simulation results that have been recorded for R and rectifier loads, the lowest THD line current is unipolar MLI with 0.24% followed by bipolar MLI with 0.41% then trinary MLI with 2.93%. For RL and rectifier load, the lowest THD line current is unipolar MLI with 0.66% followed by bipolar MLI with 0.70% then trinary MLI with 4.75%. Lastly for RC load, the lowest THD line current is unipolar MLI with 0.88% followed by bipolar MLI with 0.91% then trinary MLI with 4.81%. Therefore, it can be conclude that unipolar MLI has lowest THD line current for every load compared to the trinary seven level and bipolar switching schemes. Moreover, from the simulation result shunt APF based on FFT has been proven to mitigate harmonic below than 5% which fulfil requirement of IEEE-519 harmonic standard that directly improve the power quality in power system.

5.2 Recommendation

As for recommendation for the future research, reduction of harmonic using shunt APF based on FFT can be done by developing hardware model in the laboratory to verify the hardware results and compare it with simulation results.

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