THE IMPLEMENTATION OF SINUSOIDAL PWM ON SINGLE PHASE 5-LEVEL CASCADED H-BRIDGE MULTILEVEL INVERTER

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ABSTRACT

In the new millennium era of technology, modern industrial devices are mostly based on electronic devices that are very sensitive to harmonics. The needs for a free-harmonics and high rating power source is extremely increased in the past few years to meet the requirement from the industries. An inverter which converts DC power to AC power is one of the power electronic devices that have been in the researchers' radar for further improvement to generate a clean power source. An inverter can be broadly classified into single level inverter and multilevel inverter. A multilevel inverter as compared to a single level inverter has advantages like minimum harmonics distortion and higher power output. An implementation of cascaded h-bridge topology and a sinusoidal pulse-width modulation, synthesize a higher quality output power especially with multilevel configuration.

ABSTRAK

Dalam era teknologi alaf baru, peralatan industri moden kebanyakannya adalah berasaskan kepada peranti elektronik yang mana amat sensetif kepada harmonik. Keperluan kepada bekalan kuasa yang bebas harmonik serta mempunyai kadar kuasa tinggi meningkat secara mendadak semenjak beberapa tahun kebelakangan ini untuk memenuhi permintaan yang tinggi daripada penggiat industri. Pengubah yang berfungsi menukar kuasa arus terus kepada kuasa ulang alik merupakan salah satu peralatan yang telah menjadi tumpuan para penyelidik untuk tujuan menaik taraf keyupayaannya serta untuk tujuan penjaanan kuasa elektrik yang berkualiti. Pengubah secara asasnya boleh diklasifikasikan kepada dua, iaitu pengubah satu peringkat dan pengubah pelbagai peringkat. Pegubah pelbagai peringakt mempunyai pelbagai kelebihan jika dibandingkan dengan pengubah satu peringkat. Contohnya, gangguan harmonik yang rendah serta kuasa keluaran yang lebih tinggi. Dengan menggunakan kaedah topologi *Cascaded H-bridge* dan *sinusoidal pulse-width modulation*, konfigurasi pengubah pelbagai peringkat dapat menghasilkan kuasa keluaran yang lebih berkualiti.

CONTENTS

LIST OF TABLE

LIST OF FIGURES

LIST OF ABBREVIATIONS & SYMBOLS

MLI	-	Multilevel Inverter
CHB	-	Cascaded H-Bridge
PWM	-	Pulse Width Modulation
SPWM	-	Sinusoidal Pulse Width Modulation
NPC	-	Neutral Point Clamp
IC	-	Integrated Circuit
EV	-	Electric Vehicle
FACT	-	Flexible AC Transmission System
STSTCOM	-	Static Compensator
DVR	-	Dynamic Voltage Resonator
V	-	Voltage
A	-	Ampere
BAT	-	Battery
MIN	-	Minimum
TYP	-	Typical
MAX	-	Maximum
K	-	Kilo
Hz	-	Hertz
pF	-	Piko Farad
kW	-	Kilo Watt
RC	-	Radio Control
ms	-	Mili second
THD	-	Total Harmonic Distortion
EMI	-	Electromagnetic Interference
PWh	-	PetaWatt Hour
DSP	-	Digital Signal Processing

AC	-	Alternating Current
DC	-	Direct Current
VSI	-	Voltage Source Inverter
CSI	-	Current Source Inverter
HVDC	-	High Voltage Direct Current
UPS	-	Uninterruptable Power Supplies
NPC	-	Neutral Point Clamp
FC	-	Flying Capacitor
MOB	-	Multi-output Boost
SVM	-	Space Vector Modulation
THIPWM	-	Third Harmonic Injection Pulse Width Modulation
FPGA	-	Field Programmable Grid Array

LIST OF APPENDICS

CHAPTER 1

INTRODUCTION

1.0 Chapter Overview

The following chapter serves several purposes. Section 1.1 provides a brief discussion of the research project presented in this thesis. General idea of multilevel inverter is presented in section 1.2. Section 1.3 discusses some of the application of multilevel inverter in real situation. Merit and demerits of multilevel are briefly discussed in section 1.4. A comparison of multilevel fundamental switching over PWM switching is discussed in section 1.5. In section 1.6, problem statements of the research is presented and followed by objectives of research and its scope of work in section 1.7 and 1.8 respectively. Thesis outline and chapter summary are concluded in section 1.9.

1.1 The Work

In this research, a multilevel inverter with an equal direct current (DC) sources is studied and developed. The common switching method is used to control the power transistor.

The implementation of Pulse Width Modulation (PWM) method as a control technique was modeled and simulated in five levels and two levels scheme to see the different properties of harmonics and power output of the inverters in an ideal environment. The resultant form the simulation is then compared with an actual hardware and experiment setup.

Using the idea of mathematical operation of sinusoidal signal and triangle signals, the algorithm is developed to get switching pulses for the inverters. This algorithm is considered as a core element in the development of the inverter model and the experimental hardware.

1.2 Multilevel Converter

Three main multilevel converter topologies which have been mostly applied in engineering application are known as the cascaded h-bridge converter with separated dc sources, the diode clamp and the flying capacitor and

Here, it seems important to discuss the different between the terms 'multilevel converters' and 'multilevel inverter'. The word 'multilevel converter' refers to the converter itself. The implication of the term reflects that the power can flow in one of two directions. Power which flow from the ac side to the dc side of the multilevel converter is operated in rectification mode. Vice-versa, the power also can flow from the dc side to the ac side of the converter. This mode is called as inverting mode of operation. The 'multilevel inverter' term basically is a 'multilevel converter' that uses the inverting mode of operation.

The multilevel inverter is meant to generate a preferred ac voltage waveform from dc voltages. Figure 1.0 shows an example of ac voltage waveform generated from several dc voltages.

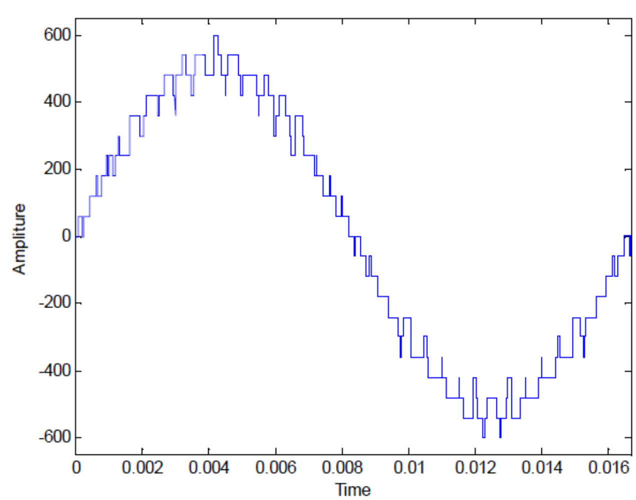

Figure 1.0: Multilevel Inverter Output Waveform
Using 5 Equal DC sources

In above figure, five 120 V dc source produce a pulse waveform with a peak-to-peak voltage of 1200V. Here, the multilevel inverter produces a fair approximation to a sinusoidal waveform. This approximation will get better and better once the amount of dc sources increase. Ideally, once the number of dc sources reach infinity, the pulse waveform will become a pure desired sinusoidal.

Considering a switching scheme, there are many techniques has been develop to be implemented on a multilevel inverter. For example, Sinusoidal PWM, Space Vector PWM, and Selective Harmonic Elimination PWM.

One of the merits of using multilevel inverter is the better total harmonic distortion over the well-known conventional two level inverters. This can be proven by undergo a simulation and experimental exercise.

1.3 Multilevel Inverter Applications

Multilevel inverters has gained much interest in the medium voltage and high power applications because of their various benefits such as lower common mode voltage, lower voltage stress on power switch, lower dv/dt ratio to supply lower harmonics content in output voltage and current [5]. Figure 1.1 shows the overview of the driven application of multilevel inverter.

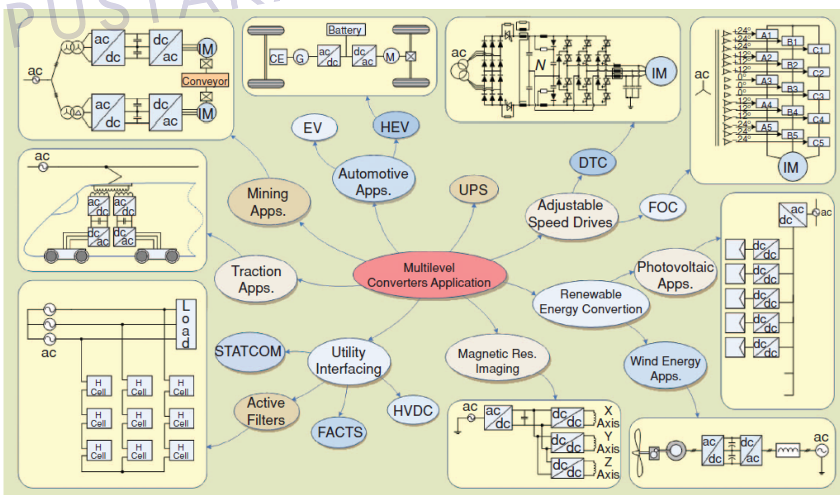

Figure1.1: Multilevel Inverter driven application overview

In power systems area, the distribution control and management are known as a real problem of the electrical grid. The introduction of Flexible AC Transmission System (FACT) has become a solution to the issue. It enhanced controllability and the capability of power transfer in the network. There are several technologies which considered as FACT such as AFs, static compensators (STATCOM), dynamic voltage restorers (DVRs), unified power flow controller (UPFCs), and unified power quality conditioners. These devices are currently gaining importance and there are many multilevel converter applications for these types of systems have been anticipated and developed. For example, a Cascaded H-bridge-based STSTCOM, a Neutral Point Clamp-based AF, and a seven-level Flying Capacitor H-bridge AF proposed for a marine population power system as shown in Figure 1.2(a)-(c), respectively.

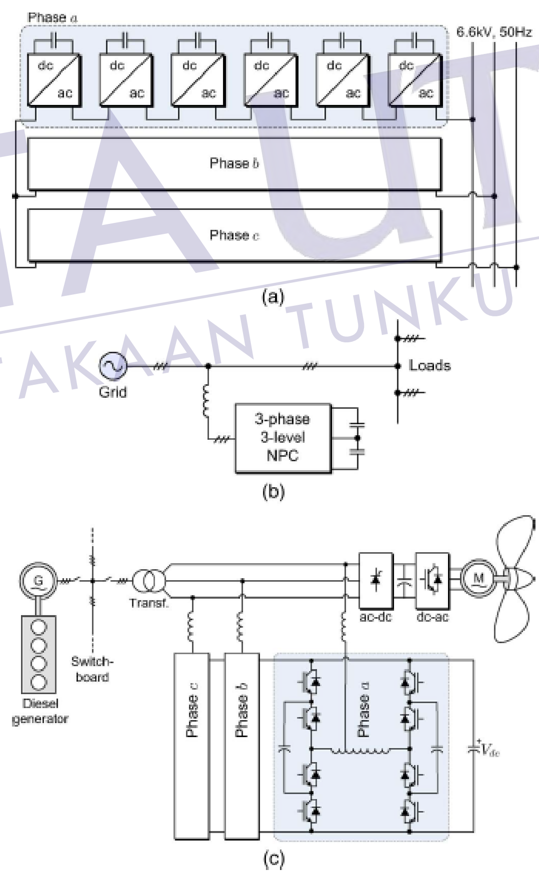

Figure 1.2: (a) Thirteen-level Cascaded H-bridge-based 6.6kV 1-MVA transformer STSTCOM. (b) 3-Level Neutral Point Clamp based AF. (c) 7-level Flying Capacitor H-bridge AF.

Environmental concerns are increasing recently. People are now talking about carbon emission to the air by internal combustion engine vehicles. This lead to the massive research and development to a new eco-friendly vehicle like electric vehicles (EV) and hybrid type vehicles. Although they are experiencing great development recently, however, multilevel inverters/converters have not played a key-role in this area due to the fact that they are out of the range of high-power. However, due to its capability in having a superior power quality, better efficiency, and significantly benefit from independent dc source such as batteries have motivate numerous researchers to propose some interesting concept toward multilevel inverter applications in EVs and hybrid vehicles in automotive applications.

As far as the green technologies and renewable energy are concerned, the use of multilevel inverter/converter is greatly appreciated. For example in photovoltaic grid-connected systems as a power interface where currently they are a lot of large photovoltaic-based power plants over 1000 kW are running. It makes the photovoltaic grid-connected systems are one of the most emerging renewable energy source in recently. Figure 1.3 (a) and (b) presents a Cascaded H-bridge based and a Neutral Point Clamp-based multilevel photovoltaic structure, correspondingly.

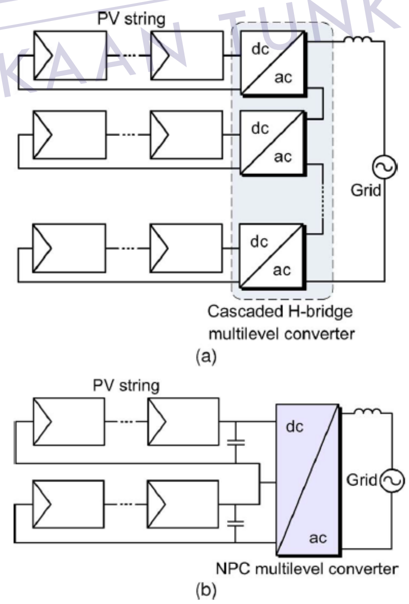

Figure1.3: (a) Cascaded H-bridge based. (b) Neutral Point Clamp Based Multilevel Converter For Photovoltaic Grid-Connected System.

1.4 Merit and Demerit of Multilevel Inverter

Obviously, in recent years multilevel inverter has gained an attention from many areas due to its advantages over the conventional inverters. The ability of the multilevel inverter to utilize a large number of dc sources is one of the merits that it holds. This makes multilevel inverters able to generate high voltages and thus high power ratings. Due to this, the use of bulky and expensive transformers to produces high voltages with conventional 12, 24 and 48-pulse inverter can be abandoned.

Another advantage of multilevel inverter is that it has a reduced Total Harmonic Distortion (THD) with low switching frequencies. Furthermore, due to its lower voltage steps, the value of EMI is lesser and because of its capability to utilize multiple levels on the dc bus, the multilevel inverters able to trim down the voltage stress on each power devices. Additionally, multilevel inverters have higher efficiency because the devices can be switched at low frequency.

Nevertheless, there is still a pitfalls on everything created in this world including multilevel inverter. One of the demerits of multilevel inverters is the isolated power supplies required for each one of the multiconverter. Furthermore, number of components is increased in multilevel inverter compared to traditional inverters. The idea of having larger number of components also means the probability of a device failure will increase.

1.5 The Switching

There are many ways and techniques have been developed to control multilevel inverter switching, from the very basic fundamental switching up to the most advance space vector pulse width modulation switching scheme. But, the most famous and applied by industries out there is the PWM switching control scheme. PWM switching control scheme comes with advantages over the traditional multilevel fundamental switching scheme.

One benefit of PWM methods employing much higher switching frequencies concerns harmonics. The harmonics filtering exercise is much easier and cheaper due to the fact that the undesirable harmonics occur at much higher switching frequencies. Also, the produced harmonics might be above the bandwidth of some actual system. This means that there is no power dissipation caused by the harmonics. On the contrary, multilevel fundamental switching scheme creates harmonics at lower switching frequencies and this increased the complexity of the filtering activity.

1.6 Problem Statement

Ever since the industrial revolution in 1800, the demand for energy is increased dramatically, especially in developing countries in-line with the economy growth. Modern industrial machineries, electric vehicles, home appliances and public healthcare contribute to the high demand of energy. The recent policies situation in World Energy Outlook 2012 (WEO 12) revealed that "several fundamental trends persist: energy demand and CO2 emission rise even higher; energy market dynamics are increasingly determine by emerging economies; fossil fuels remain the dominant source; and providing universal energy access to the world's poor countries continues to be an elusive goal".

WEO 12 highlights that electricity generation increases form 21.5 PWh in 2010 to 36.6 PWh in 2035, with average price increase of 15% in real terms. As the nuclear capacity projection reduced for 2035, the renewable are likely to become the world's second largest source of power generation by 2015 with electricity generation share increase from 20% in 2010 to 31% by 2035. This is true as the researches are aggressively looking into other environmental friendly source even before the Japan nuclear incident in 2011. A renewable energy technology has become a prime agenda which mainly focusing on wind, solar and energy efficiency technologies in order to reduce increasing demands.

As far as the solar power is concerned, there is still a lot of work has to be done to bring the technology become a major player in electricity generation. Not only the efficiency of the PV cell, but also related instruments required by the system as the highest PV efficiency now is just around 40%. This will justify how important the other instrument to be at best efficiency to achieve optimum energy from the sun.

One of the important components in the system is the inverter which converts the DC energy stored in the battery banks to AC energy which will then used by consumer or connected to power grid. As the current trend required cleaner power source, higher output power, less losses and almost free harmonics, people are looking forward for better inverter. Thus, a conventional single level inverter is no more relevant to cope with the current trend. Nowadays, industries, researches are focusing to come out with inverter that can overcome the above mentioned issues. As a result a multilevel inverter is created and first published by Nabae in 1980s.

1.7 The Objectives

There are three objective have been set for this work to be achieved at the end of the activities.

- To simulate the modelled Cascaded H-Bridge Multilevel Inverter (CHB-MLI) performance with the implementation of Sinusoidal PWM control technique
- To implement DSP based Sinusoidal PWM controller on develop CHB-MLI hardware.
- To analyse the multilevel inverter performance in term of THD, output voltage level between multilevel inverter and conventional h-bridge inverter.

1.8 Project Scope

The work is focusing on the development of a single phase five-level multilevel inverter only. The developed multilevel inverter is based on the Cascaded H-bridge Multilevel Inverter (CHB-MLI) topology and the switching is controlled by the implementation of sinusoidal pulse width modulation scheme (SPWM). In-term of analysis, the works are limited to the comparison of total harmonic distortion between conventional inverter and multilevel inverter and its output voltage.

1.9 Thesis outline

In chapter 1, several topics were discussed. The brief summary of the work to be presented in this thesis was first described. The introductory of basic knowledge of multilevel converter was discussed. Also, the typical applications of multilevel inverter were also given. The discussion came along with the merits and demerits of using multilevel inverter as well as the switching method. Furthermore, problem statement, project scope and its objective were also discussed in this chapter.

Chapter 2, discussions were focus on the inverter, multilevel inverter and also the selected topology used in the project, the Cascaded H-bridge Multilevel Inverter. This chapter also discussed in depth on sinusoidal pulse width modulation technique. Previous work by other researchers also discussed here.

Methodologies that have been carried out to run this research were revealed in Chapter 3. Four milestones were discussed.

To further discuss on modelling and simulation works, Chapter 4 provides information of the works done. Induction on SimPowerSystem, S-function and related blocks used in the modelling and simulation were discussed in this chapter.

Chapter 5 will discuss more on hardware development. The circuitries, components and related items were presented here.

Results and analysis from the research were discussed in Chapter 6. The discussions were mainly focused on voltage and current rms produced by the multilevel inverter. Moreover, total harmonic distortion values come out from the inverters were also compared and analysed.

Chapter 7 were basically concluded all the works and results obtained from the research. Some suggestions for future improvement were also included in this chapter.

CHAPTER 2

LITERATURE REVIEW

2.0 Chapter Overview

In this chapter, several topics on core theories behind the research will be discussed. Section 2.1 provides information on the inverter and the Cascaded H-bridge multilevel inverter which has been used in the research. Later, a control technique sinusoidal pulse width modulation is discussed in section 2.2 in more details. In section 2.3, researches that have been done previously by others which closely related to this research are revealed and discussed.

2.1 The Inverter and Multilevel Inverter

2.1.1 The Inverter

A device that converts DC power into AC power at desired output voltage and frequency is called an Inverter. Phase controlled converters when operated in the inverter mode are called line commutated inverters. But line commutated inverters require at the output terminals an existing AC supply which is used for their commutation. This means that line commutated inverters cannot function as isolated AC voltage sources or as variable frequency generators with DC power at the input. Therefore, voltage level, frequency and waveform on the AC side of the line commutated inverters cannot be changed. On the other hand, force commutated inverters provide an independent AC output voltage of adjustable voltage and adjustable frequency and have therefore much wider application. Based on their operation the inverters can be broadly classified into

- Voltage Source Inverters(VSI)
- Current Source Inverters(CSI)

A **voltage source inverter** is one where the independently controlled ac output is a voltage waveform. A **current source inverter** is one where the independently controlled ac output is a current waveform. Some industrial applications of inverters are for adjustable- speed ac drives, induction heating, stand by air-craft power supplies, UPS uninterruptible power supplies) for computers, HVDC transmission lines etc. An inverter changes DC voltage from batteries or solar panels, into standard household AC voltage so that it can be used by common tools and appliances. Essentially, it does the opposite of what a battery charger or "converter" does. DC is usable for some small appliances, lights, and pumps, but not much else. Some DC appliances are available, but with the exception of lights, fans and pumps there is not a wide selection. Most other 12 volt items we have seen are expensive and/or poorly made compared to their AC cousins. The most common battery voltage inputs for inverters are 12, 24, and 48 volts DC - a few models also available in other voltages. There is also a special line of inverters called a **utility intertie** or grid tie, which does not usually use batteries - the solar panels or wind generator feeds directly into the inverter and the inverter output is tied to the grid power. The power produced is either sold back to the power company or (more commonly) offsets a portion of the power used. These inverters usually require a fairly high input voltage - 48 volts or more. Some, like the Sunny Boy, go up to 600 volts DC input.

2.1.2 The Multilevel Inverter

Among available inverter in today market, multilevel inverter comes with great advantages. This is also true if a comparison done to a well-known two-level inverter [2]. Basically these advantages are focused on improvements in the output signal quality and a nominal power increase in the inverters. The term multilevel inverter was first introduced back in 1981 by Nabae [3]. By increasing the numbers of levels in the inverter, the output voltages have more steps generating a staircase waveform, which has a reduced harmonics distortion [4]. Figure 2.0 shows the comparison of the quality between a single-phase two-level inverter is compared to three- and nine-level voltage multilevel waveform.

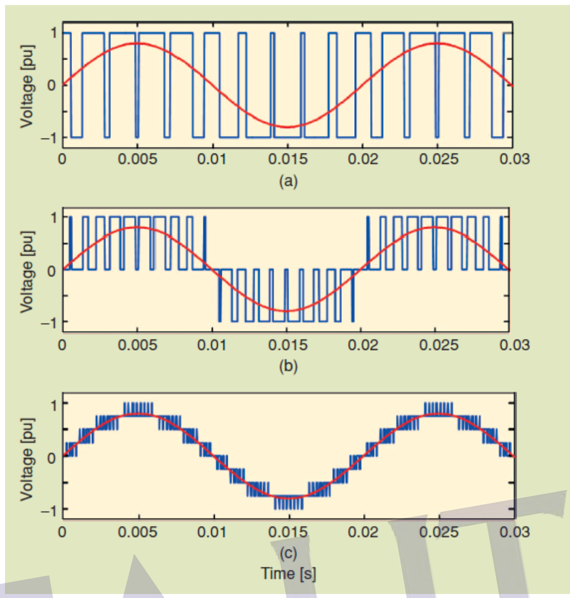

Figure 2.0: Comparison of output phase voltage waveforms:
(a) two-level inverter, (b) three-level, (c) nine-level.
(Source: [4])

Multilevel inverters has gained much attention in the application areas of medium voltage and high power owing to their various advantages such as lower common mode voltage, lower voltage stress on power switch, lower dv/dt ratio to supply lower harmonics content in output voltage and current [5]. Figure 2.1 shows the overview of the driven application of multilevel inverter.

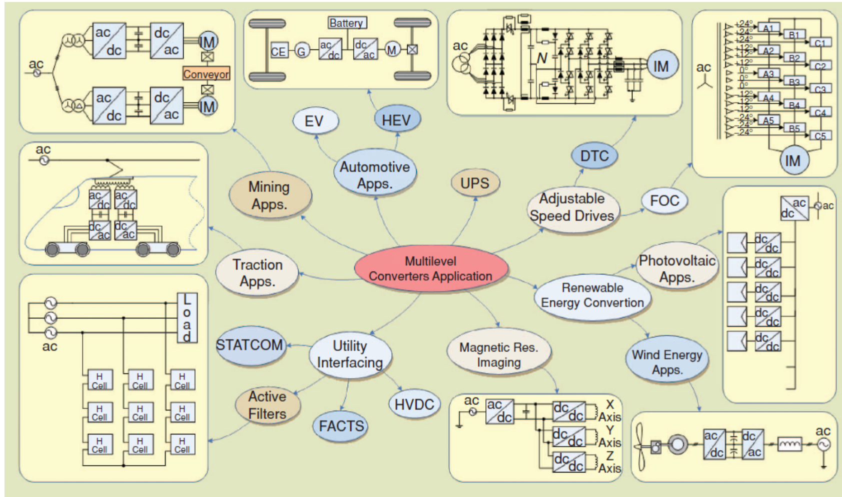

Figure 2.1: Multilevel inverter driven application overview (source: [4])

Three major multilevel inverter structures which have been mostly applied in industrial application have been emphasized as the diode clamp, the flying capacitor and cascaded h-bridge inverter with separated DC sources. Based on these three common topologies, a hybrid and asymmetric hybrid has been developed. Figure 2.2 shows common multilevel inverters topologies.

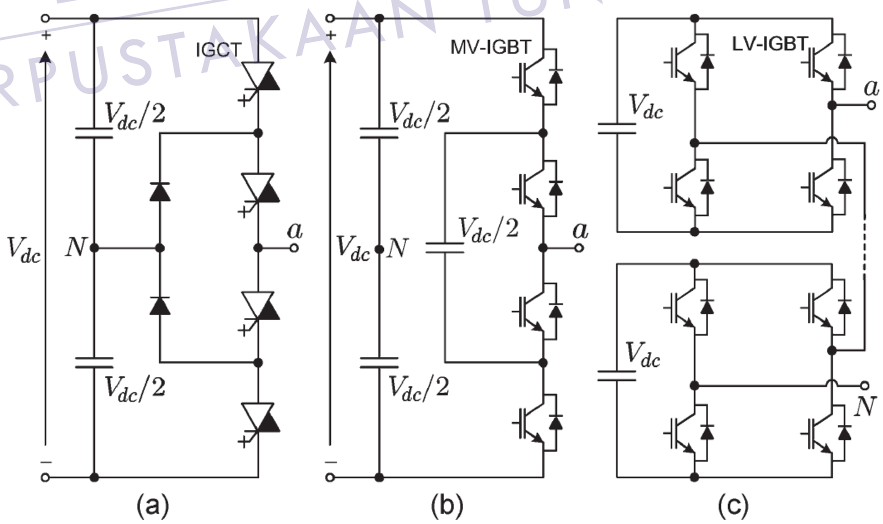

Figure 2.2: Multilevel inverter topologies: (a) three-level NPC-MLI, (b) three-level FC-MLI, (c) five-level CHB-MLI(source: [6])

Among the three topologies, Neutral Point Clamp (NPC) inverters and cascaded inverters are the most popular. NPC inverters used in high-power area are mainly three-level inverters [7]. Comparing with two-level inverters, NPC three-level inverters have economic advantages. But it is not easy to control the unbalance dc-link capacitor voltage problem. It would be a limitation to applications beyond four-level NPC inverters for reason of reliability and complexity considering the balance of capacitors voltage and much number of clamping diodes. An alternative multilevel inverter topology with less power devices requirement compared to previously mentioned topologies is known as cascaded H-bridge multilevel inverter (CHB-MLI) and the topology is based on the series connection of H-bridges with separate DC sources. Since the output terminals of the H-bridges are connected in series, the DC sources must be isolated from each other. This topology is a good choice for more than five-level output waveform. Cascaded inverters have structurally no problem of dc-link voltage unbalancing but require many separated dc sources in motor drive applications. Nevertheless, CHB has a least component requires for a given number of levels [5],[7].

2.1.3 Cascaded H-bridge Multilevel Inverter

As the name suggest, a cascaded H-bridge inverter is constructed by a series of h-bridge inverter in cascade configuration. Basically, a three-phase inverter has a same structure as single H-bridge inverter which use unipolar PWM. This type of topology is relatively a new configuration after the NPC and FC structure [27]. The topology proposed a concept with a uses of separate dc source connected for each H-bridge to generate an ac voltage waveform. The final ac output waveform is produced by cascading the individual H-bridge output waveform.

Figure 2.3 illustrates an m-level cascaded H-bridge inverter. Three different output waveforms will be generated for each inverter level with an appropriate control scheme for the switches: $+V_{dc}$, 0 and $-V_{dc}$. With S1 and S2 turned on, +Vdc will be produced, while –Vdc can be realize with by switched on S2 and S3. The 0 output voltage will be generated by switching on all S1, S2, S3 and S4 switches. The sum of different individual h-bridge inverter outputs connected in series synthesized the final ac output voltage of the multilevel inverter. An equation of m=2s+1 determine the number of voltage levels m in a cascaded H-bridge inverters where s is the number of independent dc source connected to the individual H-bridge inverter. For instance, an 11 level cascaded h-bridge inverter with independent dc source is illustrated in Figure 2.4. The final output for a single phase van is a sum of va1, va2, va3, va4 and va5.

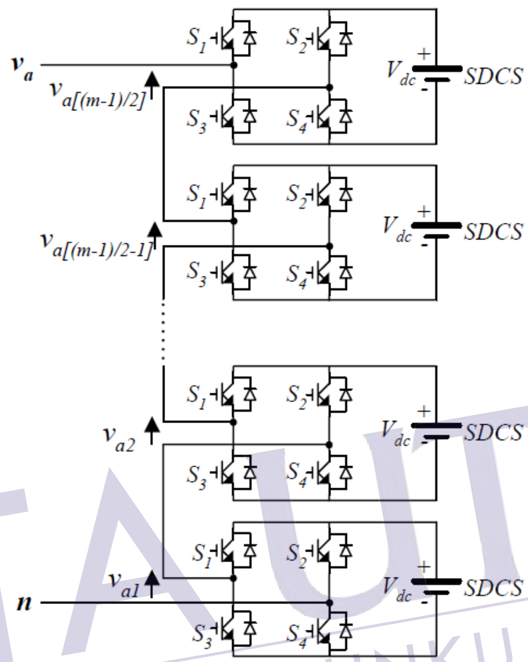

Figure 2.3: M-Level Single Phase Cascaded H-Bridge Multilevel Inverter

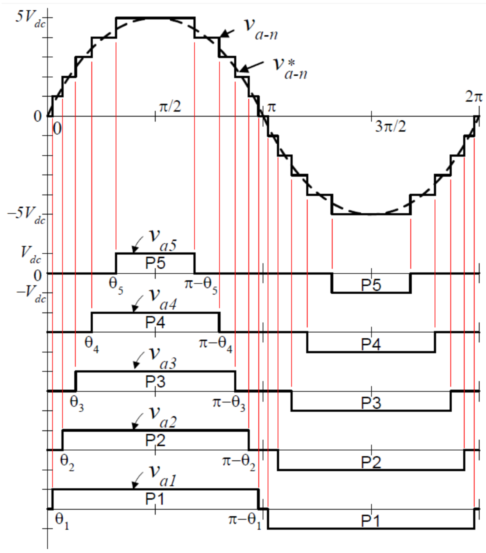

Figure 2.4: Cascaded H-Bridge Multilevel Inverter
Generalize Output Waveform

The advantages of cascaded H-bridge multilevel inverter are proven as it has been adopt in several application across an engineering field. The modularized circuit layout due to the same structure for each bridge allows the scalable structure of the inverter itself. This type of topology also required less number of components for its construction compare to NPC and FC as no extra clamping diode and voltage balancing capacitors are required. Furthermore, in-term of safety, potential to have an electric shock is lessen due the implementation of separate dc source. Nevertheless, there is still a drawback coming from this kind of inverter topology as it only restricted to certain applications wherever the independent dc source is applicable and available.

2.2 Sinusoidal Pulse Width Modulation

In order for the inverter to operates, the power electronics devices used to form the inverter need to be switched on and off for the current to flow. This switching scheme is available in several methods of signal modulations. The very popular method in industrial applications is the sinusoidal pulse width modulation (SPWM) technique.

The realization of the SPWM is done by comparing the desired sinusoidal reference signal to the high frequency triangle carrier waveform. The basic concept of SPWM is illustrates schematically in Figure 2.5 where the comparator is used for signal comparison.

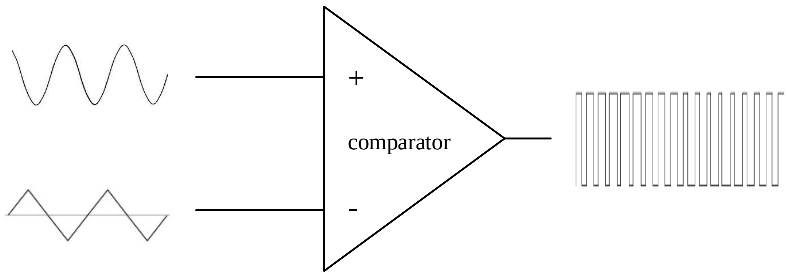

Figure 2.5: Basic Concept of Sinusoidal PWM generation

The switching moments and commutation of the modulated output beats are establish by the intersection of the carrier signal v_c and the reference signal v_r. Figure 2.6 illustrates the switching scheme of the PWM where v_r is the peak value of reference sinusoidal signals and v_c is the peak value of triangular carrier signal. This is an example of a carrier and reference signal with a subjective magnitude and frequency.

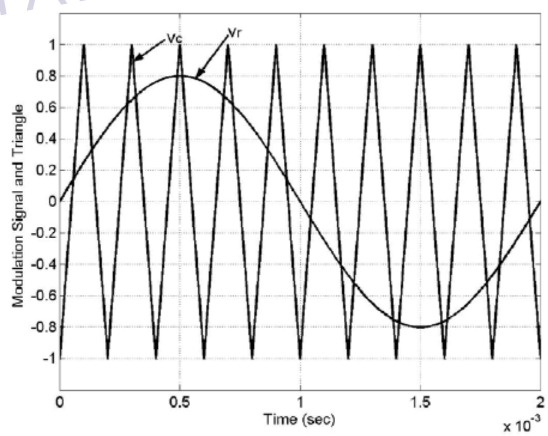

Figure 2.6: Switching Scheme of the PWM

By using Half-bridge PWM inverter as shown in Figure 2.7, the comparison between the reference signal and a triangular carrier signal done in the comparator controlled the switches S11 and S12. High output is generated at the comparator output whenever the sinusoidal reference magnitude is greater than the carrier. On the other hand, a low output is synthesized if the reference has a magnitude lowers than the carrier.

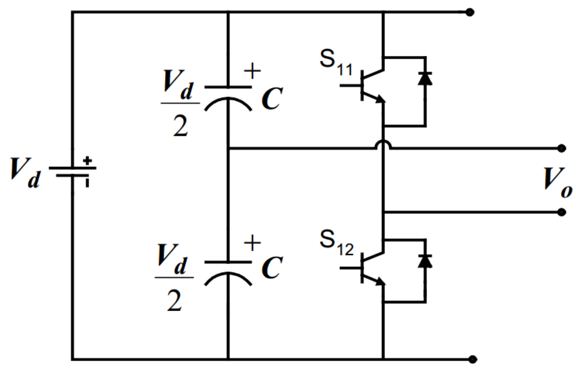

Figure 2.7: Half-Bridge Inverter

This can be described as:

$$v_r > v_c \qquad S_{11}\ is\ on, V_{out} = \frac{V_d}{2} \tag{2.0}$$

and

$$v_r < v_c \qquad S_{12}\ is\ on, V_{out} = -\frac{V_d}{2} \tag{2.1}$$

Resultant from the mathematical computation of the carrier and reference signal synthesized an output as illustrate in Figure 2.8.

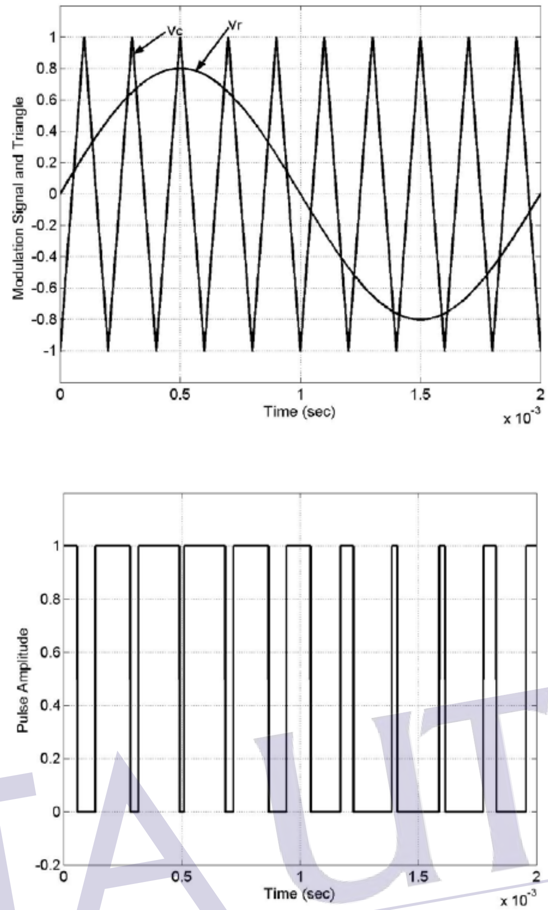

Figure 2.8: Generated PWM Signal from the Mathematical Operation of Carrier and Reference Signals

2.3 Previous Research

Multilevel Inverter is an array of power semiconductor and capacitor voltage sources that produce an output voltage with stepped waveforms. This contributes to a superior quality of waveforms that is relative to low switching frequencies as compare to two-level inverter. MLI are very useful and considered as an attractive solution for medium-voltage high power industrial drive applications [10],[4].

The era of multilevel inverter was started back in 1981 when it was first introduced by Nabae, Takahashi and Akagi. [3] proposed a natural point clamped PWM inverter adopting the new PWM technique suitable for an efficient ac drive system. Output voltage of the inverter produced lesser harmonic than that of a conventional inverter. Later, comprehensive studies have been carried out by researches to further improve what has been introduced by Nabae. The performance of multilevel inverter is very much depends on its PWM controller technique. Subsequently, several multilevel converter topologies have been developed [2, 4, 5, 9, 15].

Nowadays, there exist three commercial topologies of multilevel voltage-source inverters: Natural point clamped (NPC), flying capacitors (FC) and cascaded H-bridge (CHB). Among these topologies, cascaded multilevel inverter reaches the higher output voltage and power levels and higher reliability due to its modular topology [17]. The elementary concept of a multilevel inverter to achieve higher power is to use a series of power semiconductor switches with several lower voltage dc sources to perform the power conversion by producing staircase voltage waveform.

Cascaded multilevel inverter features a high modularity degree because each inverter can be seen as a module with similar circuit topology, control structure, and modulation [22]. Therefore in the case of a fault in one of these modules, it is possible to replace it quickly and easily. Furthermore, with an appropriated control strategy, it is possible to bypass the faulty module without stopping the load, bringing an almost continuous overall availability [23].

Due to its features and benefits, many research have been conducted using this topology as well as many analysis and synthesis have been carried out by researches to enhance the quality and performance of cascaded multilevel inverter. Recently in 2012, Suhitha.N and Ramani.K [15] had proposed a cascaded H-bridge multilevel inverter boost inverter with fundamental switching scheme for electric vehicle (EV) and hybrid EV(HEV) applications. In the research, proposed topology offers an intuitive method for minimizing the total harmonic distortion (THD) of the output voltage of the inverter.

Alireza Nami, Firuz Zare, Arindam Ghosh and Frede Blaabjerg had cascaded the diode-clamped multilevel H-bridge cell with the three-level conventional inverter in their work [24]. Idea of cascading multilevel H-bridge cells is used in [24] to propose different configurations using a seven-level symmetrical and asymmetrical diode-clamped H-bridge converter supplied with a multi-output boost (MOB) converter, cascaded with classical three-level inverters. The MOB converter can solve the capacitor voltage imbalance problem as well as boost the low output voltage of renewable energy system such as solar cells to desired value of the diode-clamp dc link voltage. From this, a nineteen output voltage levels performance was achieved, which has more voltage levels as well as lower voltage, and current THD rather than using a symmetrical diode-clamped inverter with the same configuration and equivalent number of power component.

Due to the fact that nowadays most of the modern industrial devices are based on electronic devices, they are very sensitive to disturbance and less tolerant to power quality problems. In 2011, N.Chellammal, K.N.V Prasad, S.S Dash, Y.S Anil Kumar and A.Murali Krishna had done a performance analysis of three phase cascaded H-bridge multilevel inverter for under voltage and over voltage conditions [25]. The work involved a design of closed loop control system using PI controller in order to maintain load voltage constant for under voltage and over voltage conditions. The triggering pulses to cascaded H-bridge multilevel inverter is given using multi carrier phase shift technique.

In the researches of multilevel inverters, its corresponding PWM control strategies are one of the research hot points. Therefore several works were carried out to compare and analyze on different type or technique to control the switching of the multilevel inverters. V.Kumar Chinnaiyan, Jovitha Jerome, J.Karpagam and T.Suresh had proposed a comparison between different switching strategies for cascaded multilevel inverters, based on sinusoidal pulse width modulation (SPWM) and space vector modulation (SVM) [8]. The work is based on simulation of 5-level cascaded multilevel inverter using Matlab and Simulink® software. The research reveal that the gain of the inverter is increased when using THIPWM, but a third order harmonic is present in the phase voltage, which causes serious problems when the neutral point is grounded. What have been done by a group of researchers from Greater India also carried out by Berrezzek Farid and Omeiri Amar. In [26], they are using new types of modulation in order to increase the output voltages of the inverter for the same continuous voltage supply. The so-called new modulation technique involves SPWM, THIPWM and SVPWM. The comparison studies show reveals that SVPWM and THIPWM technique give a better performance compared to conventional SPWM method.

Based on above review a conclusion on the advantages of multilevel inverter are clear. Several researches reveal that the use of CHB-MLI has advantages over other multilevel inverter topologies and obviously better when the higher degree of levels in introduced. With the implementation of cascaded H-bridge topology and SPWM method, it is believe that a better and efficient inverter shall be produced.

CHAPTER 3

METHODOLOGY

3.0 Chapter Overview

Milestones for the project completion are discussed in this chapter. Figure 3.0 illustrates the project methodology flowchart. Regardless of the literature, the methodology involves modelling, simulation, hardware development and experimental work.

The diagram in Figure 3.0 clarifies that the methodology is mainly divided into two main tasks; the modelling and the hardware development/experimental. To make it more specific, there are divided into four milestones as per section 3.1 to section 3.4.

3.1 Milestone 1: Inverter modelling

Several topologies has been studied and based on the literature review, cascaded h-bridge has a several advantages compared to others. With Simulink® / Matlab, 5-level multilevel inverter and single level h-bridge inverter were modelled. SimPowerSystem toolbox, signal processing toolbox and s-function block are involves for the modelling.

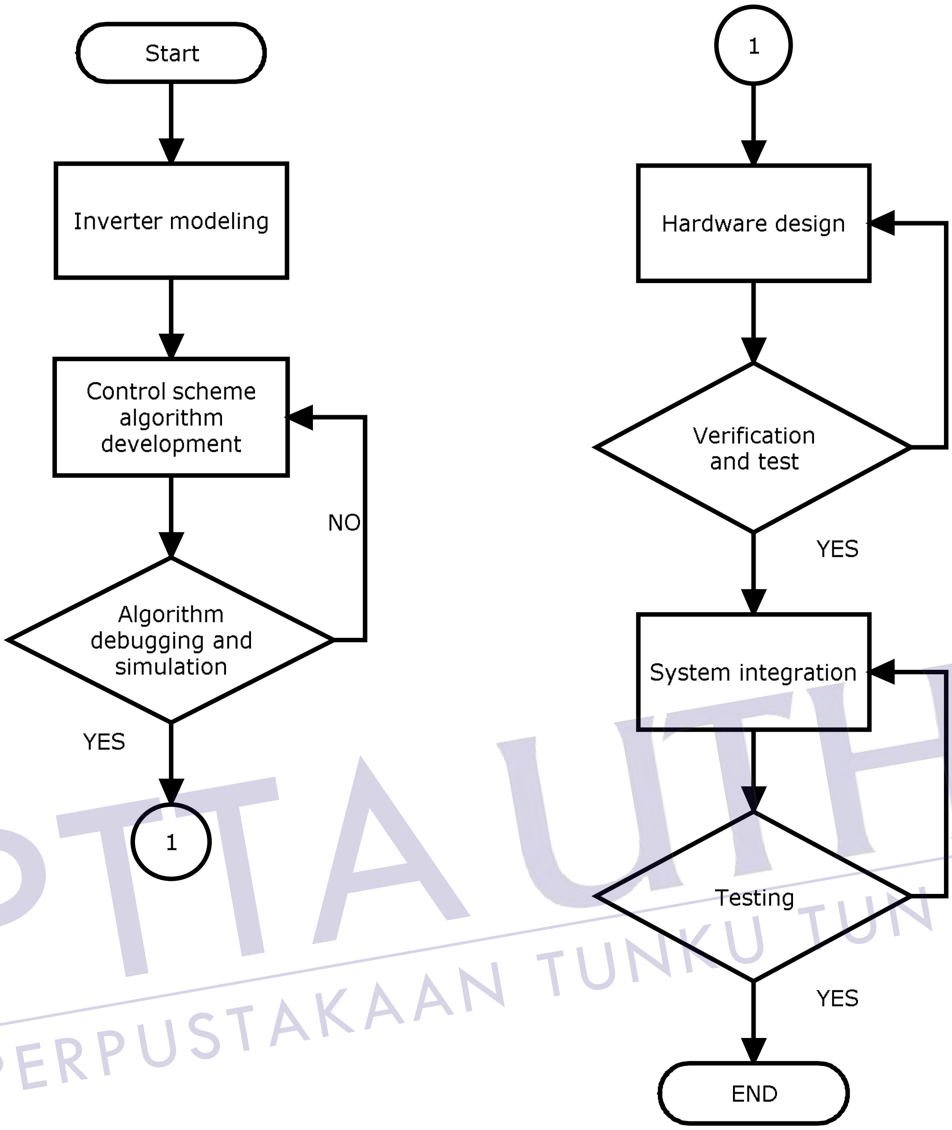

Figure 3.0: Flowchart of the Method

3.2 Milestone 2: Control Scheme and Algorithm Development

S-function block in Simulink® is used to construct the algorithm for the switching control scheme. There are two versions, one is for the modelling which is based on m-file coding, and the other one is .c based typically for target hardware DSP TMS320F28335 development board. At this stage, simulation is done on the modelled inverter with the implementation of sinusoidal PWM switching algorithm. Figure 3.1 presents the flowchart of the developed algorithm.

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