



UNIVERSITI TEKNIKAL MALAYSIA MELAKA

**DESIGN OF SINGLE PHASE H-BRIDGE MULTILEVEL
INVERTER BY USING MICROCONTROLLER**

This report submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Engineering Technology Bachelor's Degree of Electrical Engineering Technology (Industrial Power) with Honours

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UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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TAJUK: **DESIGN OF SINGLE PHASE H-BRIDGE MULTILEVEL INVERTER BY USING MICROCONTROLLER**

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APPROVAL

This report is submitted to the Faculty of Engineering Technology of UTeM as a partial fulfillment of the requirements for the degree of Bachelor of Engineering Technology Bachelor's Degree of Electrical Engineering Technology (Industrial Power) with Honours. The member of the supervisory is as follow:



ABSTRACT

The demand of producing electrical power by using renewable energy is increasing from day to day. Regarding to this matter, modern power electronic technology becomes important as it involves in generation of power electric in renewable energy and also the integration of renewable energy to the electricity grid. An inverter is needed for the distributed power generation in order to convert a DC power to AC power. As the need of producing higher power for the industrial section, the new breed of power converter, a multilevel inverter is emerged. The multilevel inverter began with the three-level cascaded H-bridge multilevel inverter. Then, it comes up with the other topologies. The most popular topologies are diode-clamped, flying capacitor and also cascaded multilevel inverters. This project report involves the single phase H-bridge multilevel inverter. This type of multilevel inverter has many applications nowadays. In renewable energy power generating system, this type of multilevel is suitable to be applied to the photovoltaic system as it satisfies the requirements of solar system. The idea of performing a multilevel inverter over the conventional inverter is to synthesize the stair-case voltage waveform by reducing the harmonics. It is developed by using MOSFET and have a separate DC sources for every each of the full bridge.

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ABSTRAK

Permintaan bagi penghasilan kuasa elektrik dengan menggunakan tenaga boleh diperbaharu semakin meningkat dari hari ke hari. Berturutan dengan perkara ini, teknologi elektronik kuasa moden menjadi penting kerana ianya terlibat dalam penjana kuasa elektrik tenaga boleh diperbaharu dan juga integrasi tenaga boleh diperbaharu ke grid elektrik. Penyongsang diperlukan untuk penjana kuasa teragih untuk menukar kuasa DC (arus terus) kepada kuasa AC (arus ulang-alik). Sebagai keperluan menghasilkan kuasa yang lebih tinggi dalam sektor industri, bentuk baru bagi sistem kuasa penukar, iaitu penyongsang bertingkat muncul. Penyongsang pelbagai peringkat bermula dengan tiga peringkat penyongsang penerus titi bertingkat. Kemudian, tercetus pula topologi yang lain. Antara topologi yang paling popular adalah diod-terkapit, kapasitor-terkapit dan juga penerus titi penyongsang pelbagai peringkat. Laporan projek ini melibatkan satu fasa penerus titi penyongsang bertingkat. Jenis inverter bertingkat ini mempunyai banyak aplikasi pada masa kini. Dalam sistem penjana kuasa tenaga boleh baharu, penyongsang bertingkat amat sesuai untuk digunakan untuk sistem photovoltaic kerana ia memenuhi keperluan sistem solar. Idea melaksanakan penyongsang bertingkat lebih baik berbanding penyongsang konvensional kerana ia mampu untuk mengurangkan harmonik. Ia dibina dengan menggunakan MOSFET dan mempunyai sumber DC (arus terus) berasingan bagi setiap setiap penerus titi.

DEDICATIONS

To my beloved parents



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Firstly, I would like to thank god for giving me the opportunities to learn and gain new knowledges and also experiences throughout my final year project. I tend to finish this report followed as I planned.

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LIST OF ABBREVIATIONS, SYMBOLS AND NOMENCLATURE

AC	-	Alternating Current
DC	-	Direct Current
FPGA	-	Field-programmable gate array
IGBT	-	Insulated Gate Bipolar Transistor
MOSFET	-	Metal Oxide Semiconductor Field Effect Transistor
PCB	-	Printed Circuit Board
PWM	-	Pulse-Width Modulation
TRIAC	-	Three terminal semiconductor device for controlling current
SMPS	-	Switch Mode Power Supply

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CHAPTER 1

INTRODUCTION

1.0 Introduction

Nowadays, fossil fuels are the foremost energetic contributor to the global economy. However, it can cause environmental issues such as global warming, air pollution and many more. Therefore, the demand of generating more electrical power from renewable energy is increasing as it is a green technology, which can help in solving the environmental issues. Figure 1.0 below shows the renewable energy goals, according to the Sustainable Energy Development Authority Malaysia (SEDA).

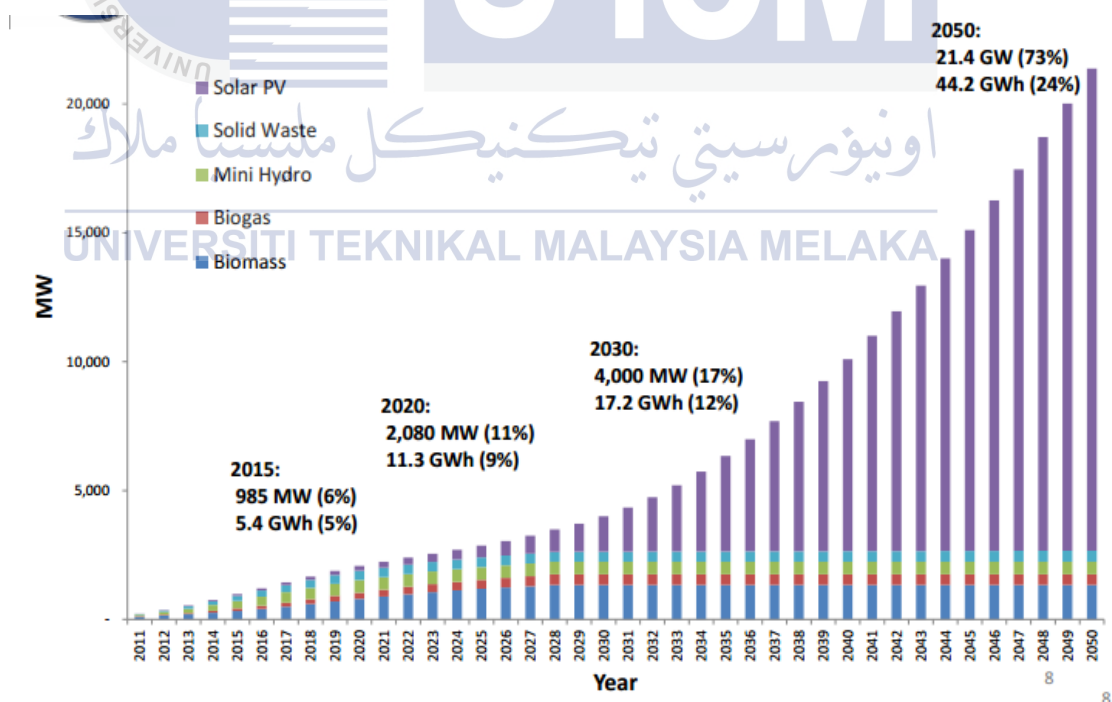


FIGURE 1.0 : The Renewable Energy Goals in Malaysia

Figure 1.1 below shows the increment of global installed renewable power capacity.

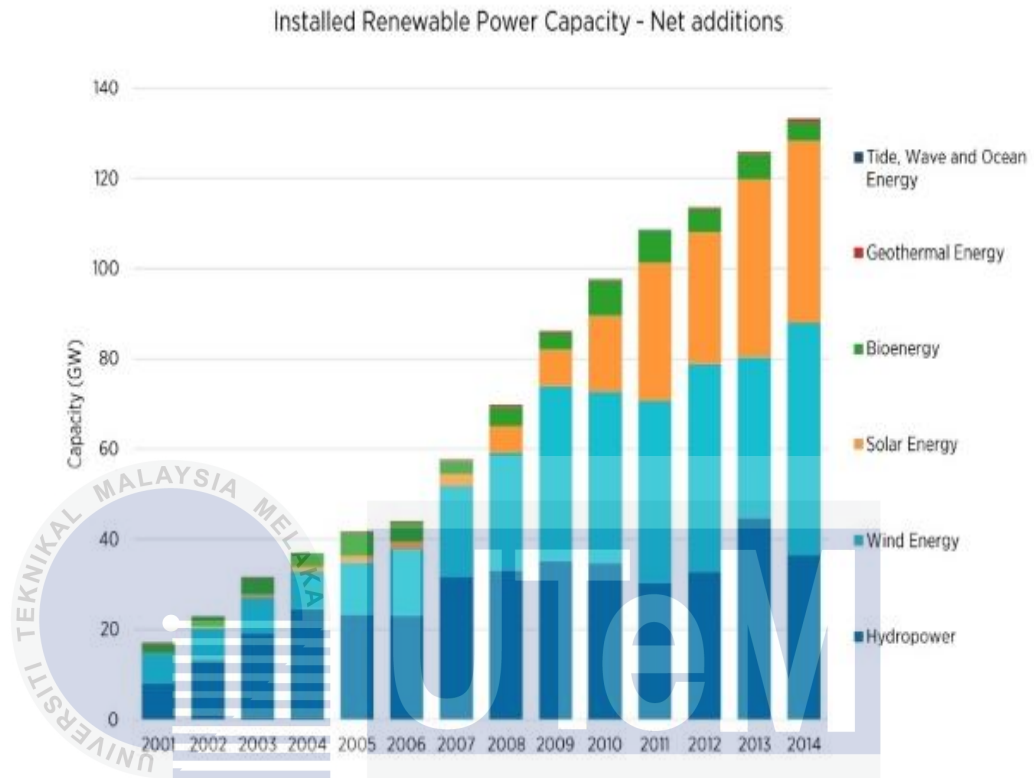


FIGURE 1.1 : Installed Renewable Power Capacity

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Renewable energy is a form of energy that can be gained from natural resources. There are several types of renewable energy technologies which are Bioenergy, geothermal energy, hydropower, ocean energy, wind energy and solar energy (KaliAMOorthy et al. 2015). Solar energy is one of the most attractive research fields. This is because it can contribute to clean power generation (Villanueva et al. 2009). Photovoltaic (PV) system requires no fuel, no pollution, no noise and also less maintenance. Most of the growth of this system is in grid-connected system. More than 78% of the global market in 2010 comes from the grid-connected applications (Xiao et al. 2011). This system is introduced for the increment of the energy injected into the grid by the methods of decreasing the switching frequency and supplying high reliability (Villanueva et al. 2009). The usage of H-bridge multilevel inverter in this system helps in reducing the device voltage stress, increasing the efficiency and

decreasing the output filters. An inverter is an electronic device that converts direct current (DC) to alternating current (AC). It is assumed that the term of “inverter” was coined by David Prince (L.Owen 1996). This is due to the article that has been published by Prince in 1925 entitled “The Inverter” in GE Review. The article contains the important elements which are required for the modern inverters. Nowadays, there are several types of inverters available such as multilevel inverter. A multilevel inverter is a powerful electronic device which is capable of providing a desired alternating voltage level at the output using multiple lower level DC voltages as an input. It includes the array of power semiconductors and capacitor voltage sources, the output which generates stepped waveform voltages (Subramanian & Rasheed 2013). The concept of this converter has been introduced since 1975 (Ahuja et al. 2013). There are three topologies of multilevel inverter have evolved which are diode clamped multilevel inverter, flying capacitor clamped multilevel inverter and cascaded H-bridge multilevel inverter (Bhargava & Shrivastava 2012). A cascaded H-bridge multilevel inverter satisfy the requirements of PV systems since solar cells can be assembled in a number of separate generators with the additional advantage of the ability to eliminate the DC/DC booster, significant reduction of the power drops caused by sun darkening and the increment of efficiency and reliability. Therefore, the usage of cascaded H-bridge multilevel inverter is important for photovoltaic system.

1.1 Problem Statement

Inverters are less efficient, high cost and high switching losses. Mostly a two-level inverter is used in order to convert DC voltage to AC voltage. Although it is effective to be used to create AC, but it has a few disadvantages too. This type of inverter creates harmonic distortions in the output voltage. Besides, it also has high dv/dt stresses. It can create problem regarding those applications require low distortion in the output voltage.

A medium voltage grid also facing a difficulty in connecting one power semiconductor switches directly. Therefore, the multilevel power converter is introduced for high power and medium voltage situations.

The flying capacitor multilevel inverter is difficult to be realized since each of the capacitor need to be charged with different voltages as the voltage level increases. Besides, diode clamped multilevel inverter having the issue of expanding the multilevel because of the voltage unbalancing, the increase in the number of clamping diodes and the difficulty of disposition between the DC link capacitors and the devices when the voltage increases.

1.2 Objectives of Research

The objective of this research is mainly focus on:

- a) To design the single phase h-bridge multilevel inverter
- b) To simulate the design of single phase h-bridge multilevel inverter
- c) To replicate and test the single phase h-bridge multilevel inverter

1.3 Scope of Research

The scope of this research is limited to the following aspects so that the research could be focused to achieve the stated objectives. This project scopes are as below:

- a) To design the single phase h-bridge multilevel inverter for small power usage by using microcontroller
- b) To simulate the design of single phase h-bridge multilevel inverter by using MATLAB
- c) To replicate and test the single phase h-bridge multilevel inverter for designated input and output



CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

This chapter will discuss the theory related to this project. It contains some research principles and the topologies introduced. Moreover, this part also consists of circuit designs for different topologies of multilevel inverter. The power electronic converter can be classified into six types which are diode, rectifier, AC to DC converter, DC to DC converter, AC to AC converter, DC to AC converter, and static switches. The inverter is a type of DC to AC converter.

2.1 Power electronic conversion device

The technology of the power electronic conversion devices is developing nowadays. Due to the development, the power electronics becomes more applicable. There are many categories of power electronic conversion devices. The most famous type of convertors are AC to DC converters, DC to DC converters, AC to AC converters, and DC to AC converters.

2.1.1 AC to DC converter

This type of converter circuit converts AC voltage into DC voltage. A rectifier converts AC to DC by adjusting the voltage and current. As the firing angle of the thyristors is varied, the DC output voltage is able to be controlled. The AC input voltage can be either in single or three phase formed.

AC to DC: RECTIFIER

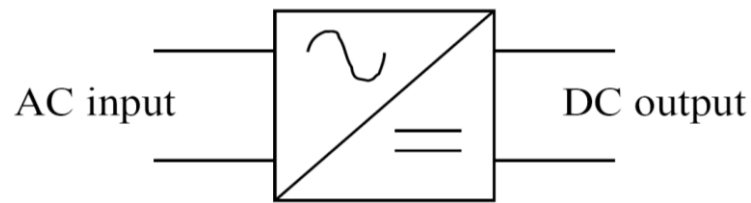


Figure 2.1 : AC to DC converter

2.1.2 DC to DC converter

This type of converter circuit converts a fixed DC input voltage into variable DC voltage or oppositely. As the duty cycle is varied, the DC output voltage is able to be controlled. The linear regulators and switching choppers is applying this concept of conversion.

DC to DC: CHOPPER

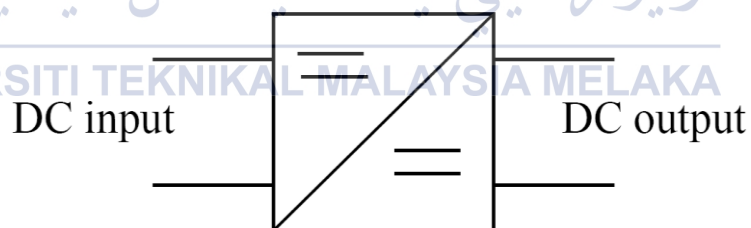


Figure 2.2 : DC to DC converter

2.1.3 AC to AC converter

This type of converter circuit converts a fixed AC input voltage into variable AC output voltage. As the firing angle of TRIAC (three terminal semiconductor device for controlling current) is varied, the AC output voltage is

able to be controlled. It is known as AC voltage regulator. Its AC frequency, phase, magnitude, and power converters are particularly with an intermediary DC link.

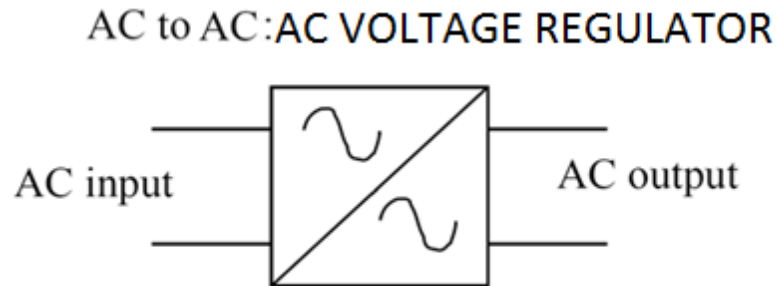


Figure 2.3 : AC to AC converter

2.1.4 DC to AC converter

Inverters are able to produce AC output voltage from DC input voltage. It can produce the AC of controllable magnitude and frequency.

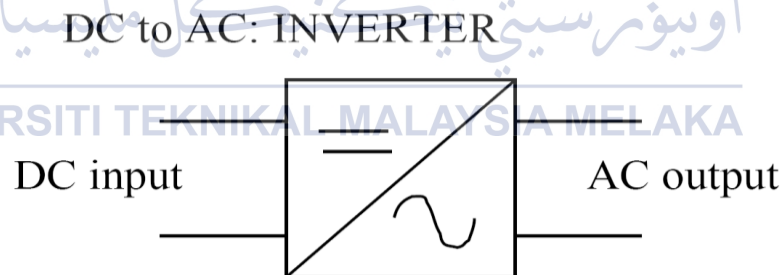


Figure 2.4 : DC to AC converter

2.2 Inverter

The inverter is an electronic device that converts DC power to AC power at desired output voltage and frequency (Hosseini et al. 2013). Inverter can be categorized into two types which are Voltage Source Inverter (VSI) and Current

Source Inverters (CSI). VSI is an inverter which its voltage waveform is the independently controlled AC output. The CSI is having a current waveform at the independently controlled AC output. Due to its connections of semiconductor devices, inverters can be classified into three categories. The categories are the bridge inverters, series inverters, and parallel inverters (Monhanty & Sahoo 2010).

2.3 Multilevel Inverter

Multilevel inverter is developed as the alternative of high power and medium voltage cases. In order to achieve higher power, semiconductor switches with low voltage DC sources is used (Khomfoi & Tolbert 1975). This type of converter has several advantages compared to the two-level converter. It can produce the output voltages with very low distortion and reduced the dv/dt stresses. As a result, the electromagnetic compatibility (EMC) problems can be handled. Apart from that, the small common-mode (CM) voltage can be formed. This converter also able to draw the input current with low distortion. Besides, it can be functioned at both fundamental switching frequency and high switching frequency PWM. Due to the development of this converter, few modulation and control strategies is introduced such as multilevel sinusoidal pulse width modulation (PWM), multilevel selective harmonic elimination, and space-vector modulation (SVM) (Rodríguez et al. 2002). There are several topologies have been proposed for this converter which are diode-clamped (neutral-clamped), capacitor-clamped (flying capacitors), and cascaded H-bridge with separate DC source.

2.3.1 Diode-clamped

Diode-clamped multilevel inverter or also known as Neutral-Point Clamped inverter was introduced in 1981 by Nabae, Takahashi, and Akagi. It got its name, Neutral-Point Clamped inverter because its mid-voltage level for three-level inverter was defined as the “neutral point” (Sejpal 2013). It is

preferable to use this type of multilevel inverter in the applications of limitations in space allowance and also in weight reducing since it would be bulky if capacitors are used for clamping. Figure 2.5 shows a three-level Diode-clamped multilevel inverter (Monhanty & Sahoo 2010).

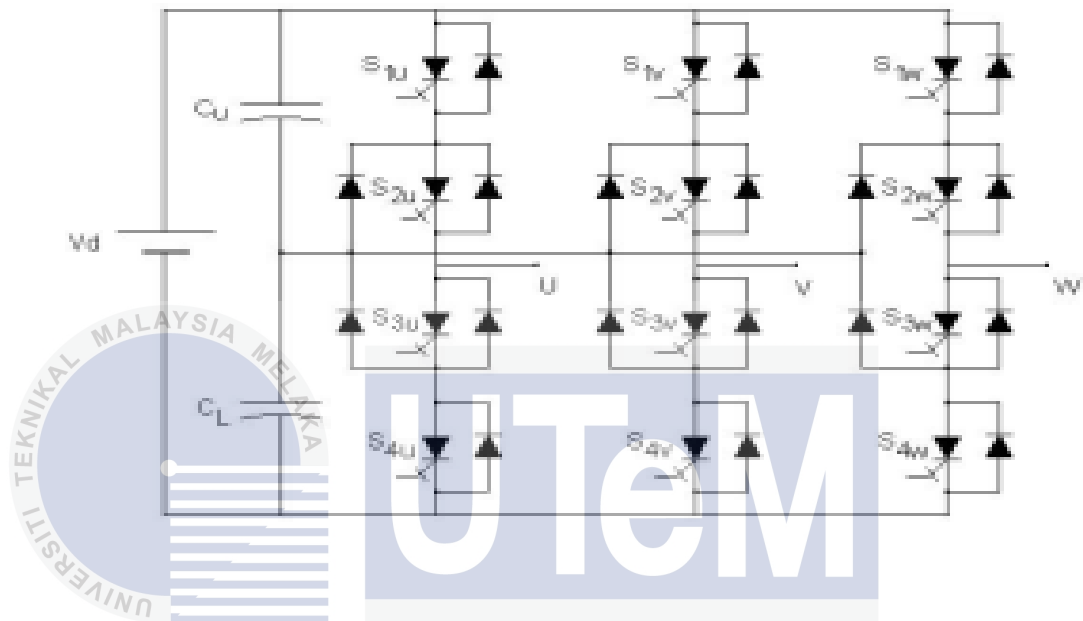


Figure 2.5 : 3-level Diode-Clamped Multilevel Inverter

There are several advantages of diode-clamped multilevel inverter (Sejpal 2013). They are:

- The sharing of a common DC source for three phases minimized the capacitance requirements
- The DC-link capacitors can be pre-charged, as a group
- Good efficiency of fundamental frequency switching

Even though diode-clamped multilevel inverter brings benefits to industry nowadays, but it also has the advantages (Sejpal 2013). The advantages are:

- The required clamping diodes increases in number as the level increases
- Controlling power flow of each converter difficulties

2.3.2 Capacitor-clamped

Capacitor-clamped multilevel inverter or also known as a Flying Capacitor multilevel inverter was introduced by Meynard and Foch in 1992. It has the same structure as that of the Diode-clamped multilevel inverter only instead of using clamping diodes, clamping capacitors are used as the replacement (Khomfoi & Tolbert 1975). This type of multilevel inverter is having a ladder structure of dc side capacitors. The voltage on each capacitor is different compared to its next capacitor. Figure 2.6 shows the capacitor-clamped multilevel inverter circuit topology (Sejpal 2013).

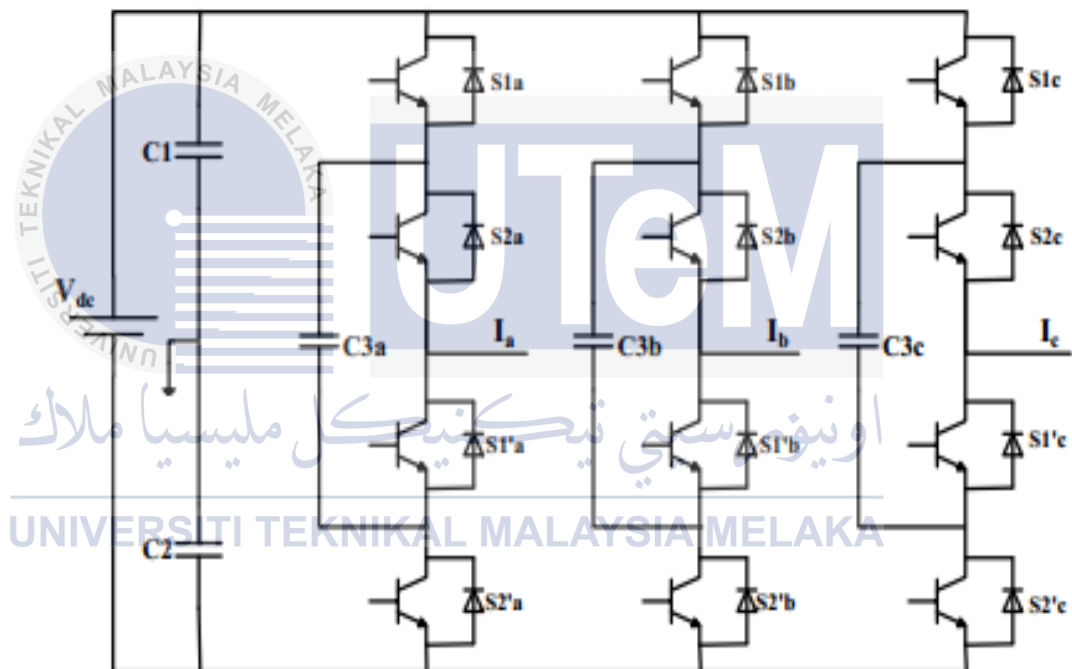


Figure 2.6 : Three-level Capacitor-Clamped Multilevel Inverter

The advantages of using flying-capacitor-based inverter are:

- Has phase redundancies to balance the inner voltage levels of the capacitors
- Controllable real and reactive power
- Able to ride through short duration outages and deep voltage sags

The drawbacks of this type of introduced topology are:

- Control difficulties occurred in order to track the voltage levels for all the capacitors. The precharging of all the capacitors to the same voltage level becomes more complex.
- Poor switching utilization and efficiency for real power transmission
- High number of capacitors make it more expensive and bulky compared to clamping diodes in the diode-clamped multilevel inverter. As the level increases, packaging becomes more difficult in inverters.

2.3.3 Cascaded H-bridge

Cascaded H-bridge multilevel inverter is the first multilevel topology proposed in 1975. Three-level is the smallest number of voltage levels for this type of multilevel inverter. Cascaded H-bridge multilevel inverter having a series of H-bridge inverter units. Each single-phase full-bridge is connected to one separate DC source (SDCS). Figure 2.7 shows a single H-bridge cell (G. M. Gebreel 2011).

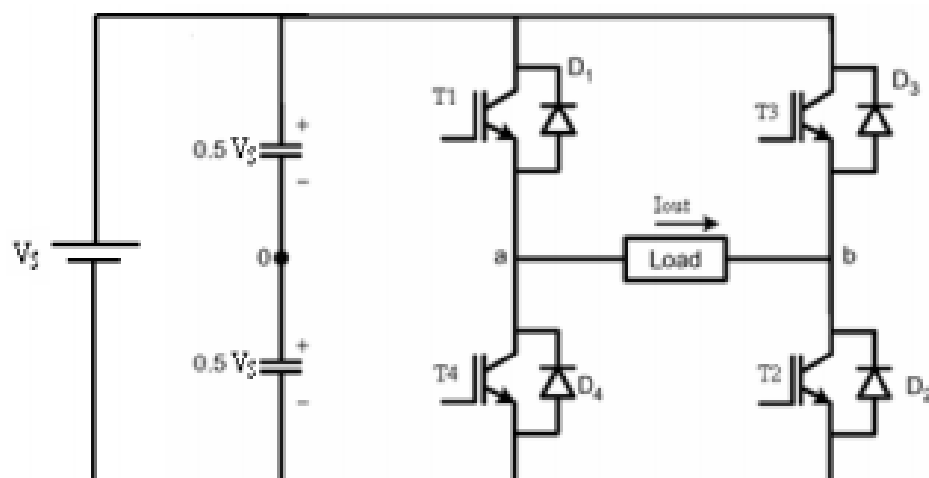


Figure 2.7 : Single H-bridge cell

Cascaded multilevel inverter does not consist of a voltage-clamping diodes or voltage-balancing capacitors as the diode-clamped and capacitor clamped topology. Hence, it is more efficient to use a cascaded multilevel inverter compared to the other two multilevel topologies. In this type of inverter, every level of inverter able to generate different voltage outputs which are $+V_{dc}$, 0, and $-V_{dc}$. The output voltage is generated by controlling the four switches S_1 , S_2 , S_3 , and S_4 . As the S_1 and S_4 is on, the output will generate $+V_{dc}$. If S_2 and S_3 are on, the generated output is $-V_{dc}$. Besides, when either S_1 and S_2 or S_3 and S_4 are on, the generated output will be '0'.

There are several advantages of using H-bridge multilevel inverter (Sejpal 2013):

- Can formed more than doubled the number of DC sources of output voltage level
- Simpler packaging and layout

The disadvantages of cascaded H-bridge multilevel inverter (Sejpal 2013):

- Requires separate DC sources for each of the H-bridge
- The separation of batteries causes the inverter very bulky with higher levels
- Need to consider for the charge equalization for the separate bridges problem

Cascaded multilevel inverter can be built by using single-phase configuration and also a three- phase configuration.

2.3.3.1 Single-Phase Configuration of Cascaded Multilevel Inverter

The AC outputs of each H-bridge cells is connected in series. The synthesize voltage waveform is the sum of inverter outputs. The number of output phase voltage levels, m can be determined by the equation of

$$m = 2s+1 \quad (2.1)$$

where, m = phase voltage levels

s = number of separate DC sources

As the example, a three-level output phase voltage waveform can be obtained with one-separated DC sources and one H-bridge cells. The phase voltage is given as

$$V_{an} = V_{dc1} + V_{dc2} + \dots + V_{dc(s-1)} + V_{dcS} \quad (2.2)$$

Figure 2.8 shows the single-phase configuration of an m -level cascaded inverter (Sivagamasundari & Mary 2012).

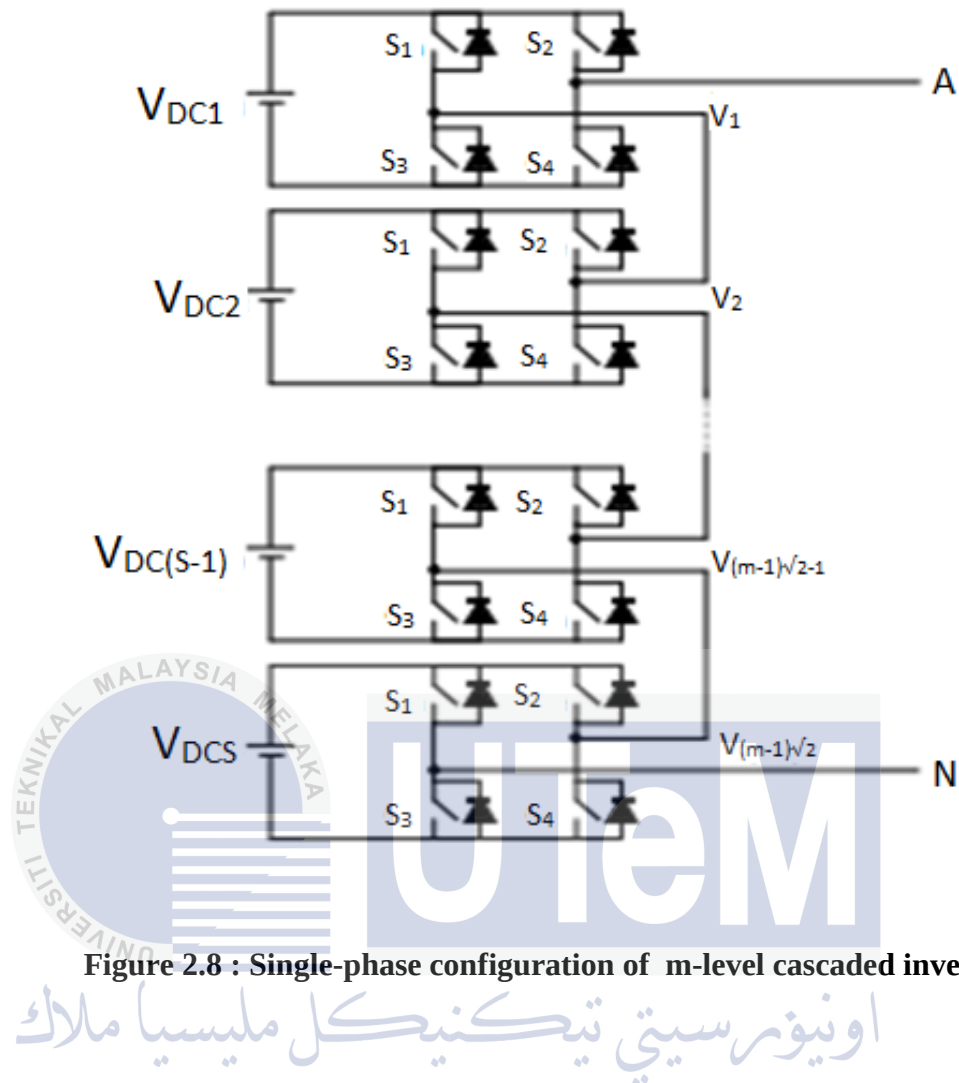


Figure 2.8 : Single-phase configuration of m-level cascaded inverter

2.3.3.1.1 Switching State of Single-Phase Cascaded Multilevel Inverter

Understanding the switching state of the multilevel inverter is important. By setting the correct switching state, the expected output waveform can be obtained. The switching state will be different as the level of output voltage is different. This is due to the number of switches that every level have is different but using the same switching concept. Therefore, as the level of output voltage phase is decided, the switching state according to the level need to be understood. Table 2.1 shows the example of switching state of cascaded multilevel inverter.

S ₁	S ₂	S ₃	S ₄	S ₅	S ₆	S ₇	S ₈	OUTPUT
1	0	0	1	0	0	1	1	0.5V _{DC}
0	0	1	1	1	0	0	1	V _{DC}
1	0	0	1	1	0	0	1	1.5 V _{DC}
0	0	1	1	1	0	0	1	V _{DC}
1	0	0	1	0	0	1	1	0.5 V _{DC}
0	0	0	0	0	0	0	0	0
0	1	1	0	0	0	1	1	-0.5 V _{DC}
0	0	1	1	0	1	1	0	- V _{DC}
0	1	1	0	0	1	1	0	-1.5 V _{DC}
0	0	1	1	0	1	1	0	- V _{DC}
0	1	1	0	0	0	1	1	-0.5 V _{DC}

Table 2.1 : Switching State for 5-level Cascaded Multilevel Inverter

2.3.3.2 Three-Phase Configuration of Cascaded Multilevel Inverter

The three-phase system is the wye or delta connected output of three identical structure of single-phase cascaded inverter. Figure 2.9 shows the three-phase wye-connected seven-level inverter. This design consists of three H-bridge cells and three SDCSs per phase.

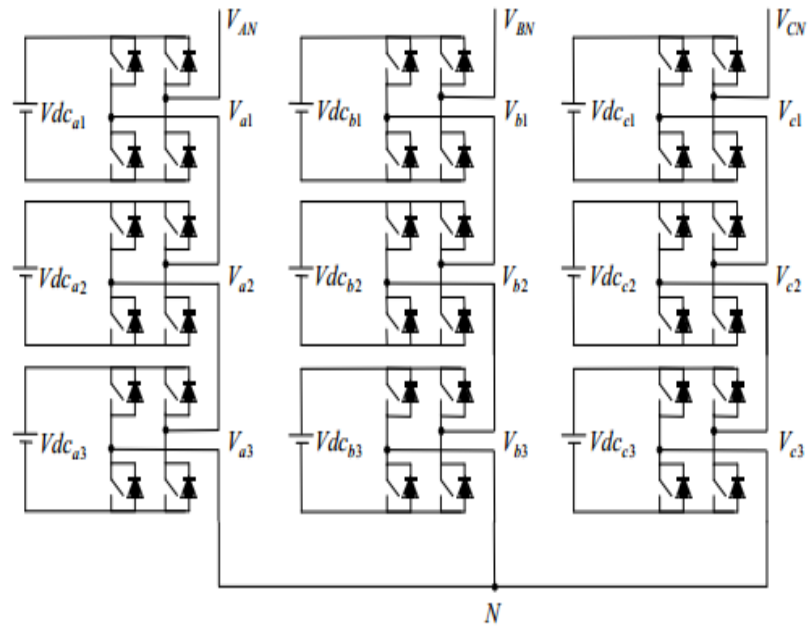


Figure 2.9 : Three-Phase Wye-Connected Seven Level Inverter

Referring to Figure 2.5, V_{AN} , V_{BN} , and V_{CN} are the total voltages of each phase. Three firing angles which are 0, 120, and 240 electrical degrees for phase A, B, and C are needed in this case. By following the three-phase theory, the line voltage can be expressed in term of two-phase voltages. This concept can be understood by following equations:

$$V_{AB} = V_{AN} - V_{BN} \quad (2.3)$$

Where, V_{AB} = line voltage

V_{AN} = voltage of phase A with respect to point N

V_{BN} = voltage of phase B with respect to point N

Theoretically, the maximum number of line voltage levels is defined as:

$$2m - 1 \quad (2.4)$$

Where, m = the number of phase voltage levels

The number of line voltage level depends on the modulation index and also the given harmonics that need to be eliminated. A seven-level cascaded inverter can synthesize up to thirteen-level line voltages.

2.4 Modulation

The modulation techniques that have been proposed for the multilevel inverters are the traditional pulse-width modulation method (PWM), space vector PWM method, space vector control method, and selective harmonics elimination method.

2.4.2 Pulse-width Modulation (PWM)

Pulse-width modulation is a modulation technique of carrying information on a train of pulses. It is the most famous method used to produce a controlled output for the inverters. It is quite popular in the industrial applications. This type of modulation has constant amplitude of pulses. However, its duration is indirect proportion to the amplitude of the analog signal (Monhanty & Sahoo 2010). There are three types of PWM which are linear modulation, saw tooth PWM, and regular sampled PWM. There are several advantages of PWM which are as follows:

- The output voltage control is much easier and also can be achieved without any usage of additional components

- The lower order harmonics can be eliminated or minimized
- The filtering requirements are minimized since the lower order harmonics will be eliminated and the higher order harmonics will be filtered
- Low power consumption
- The whole control circuit will be digitized

Figure 2.10 shows the sine modulated, unmodulated signal and Figure 2.11 shows the sinusoidal PWM technique.

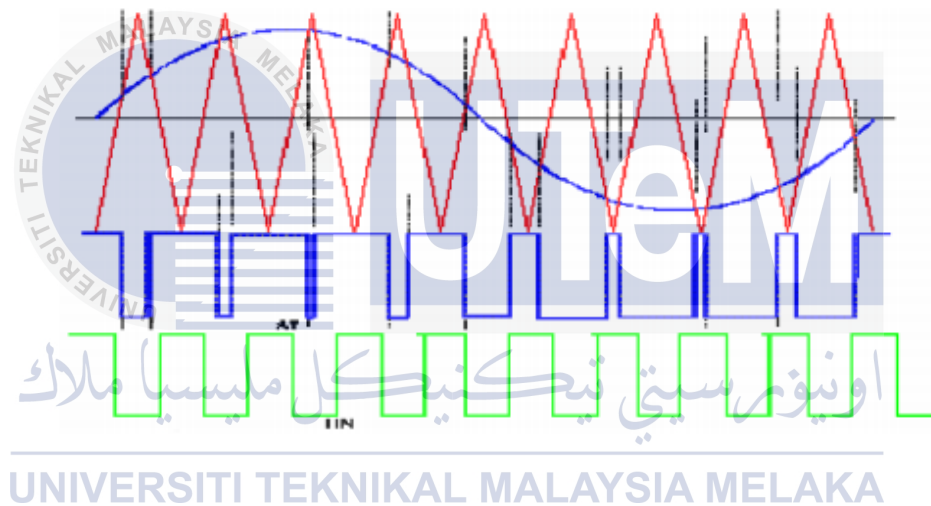


Figure 2.10 : Sine modulated, unmodulated signal

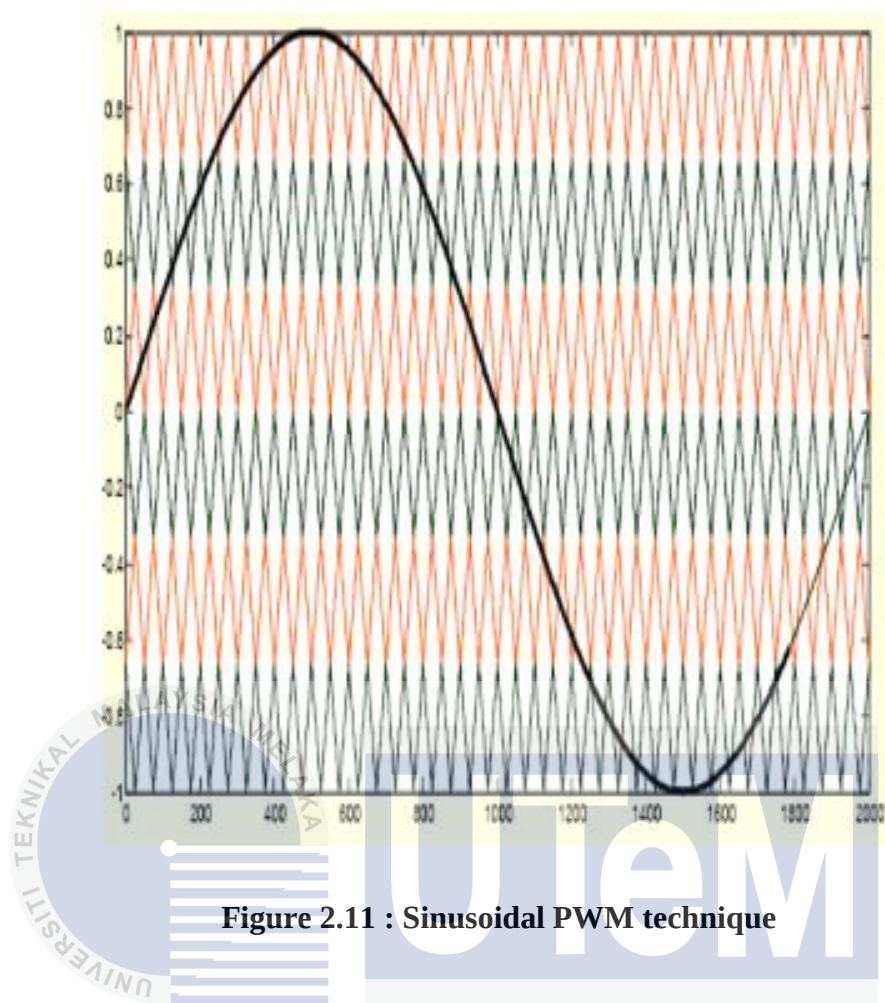


Figure 2.11 : Sinusoidal PWM technique

2.4.1.1 Linear Modulation

Its simplest method is to vary the ON time proportionally to the modulating signal. The advantage is the demodulating process is easier. The modulating can be recovered by the process of low pass filtering. The example is shown in Figure 2.12.

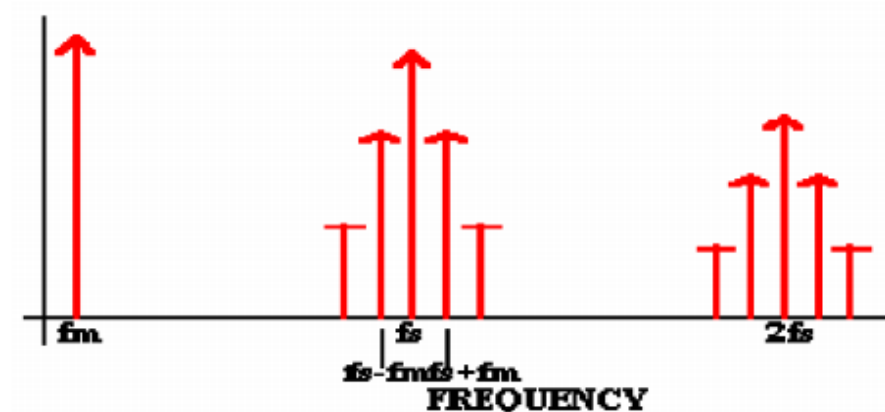


Figure 2.12 : Linear Modulation

2.4.1.2 Saw Tooth PWM

Saw tooth waveform can form a fixed frequency PWM by comparing it with a linear slope waveform. The output becomes high as the amplitude of the sine wave is greater than the saw tooth as shown in the Figure 2.13 and Figure 2.14. This situation can be achieved by a comparator with logic HIGH and higher input of the non-inverting.

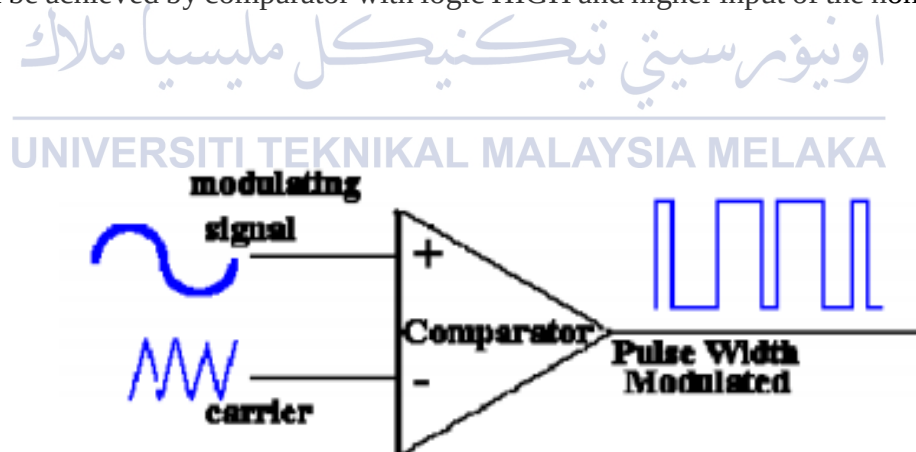


Figure 2.13 : Saw Tooth PWM System

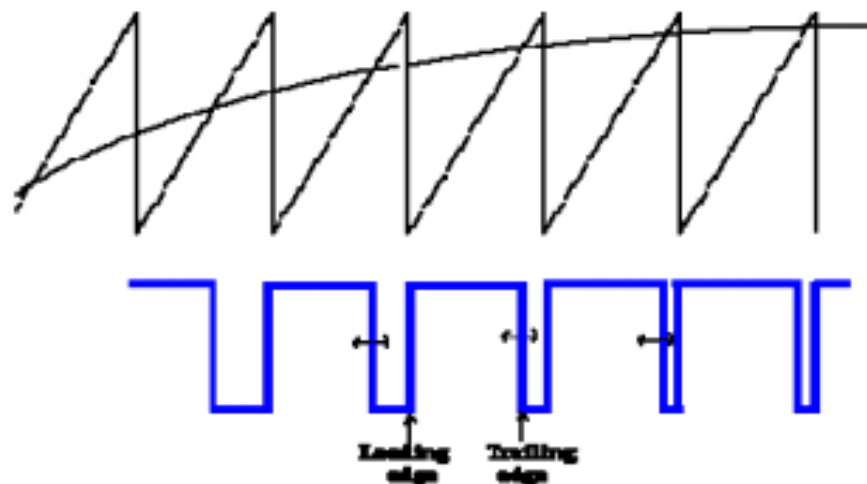


Figure 2.14 : Saw Tooth PWM waveforms

2.4.1.3 Regular Sampled PWM

A switching edge at the intercept of carrier and modulating signal is generated from the regular sampled PWM concept. Figure 2.15 shows the interceptions of sampled sine values and triangular wave. The edges of the pulses are then generated.

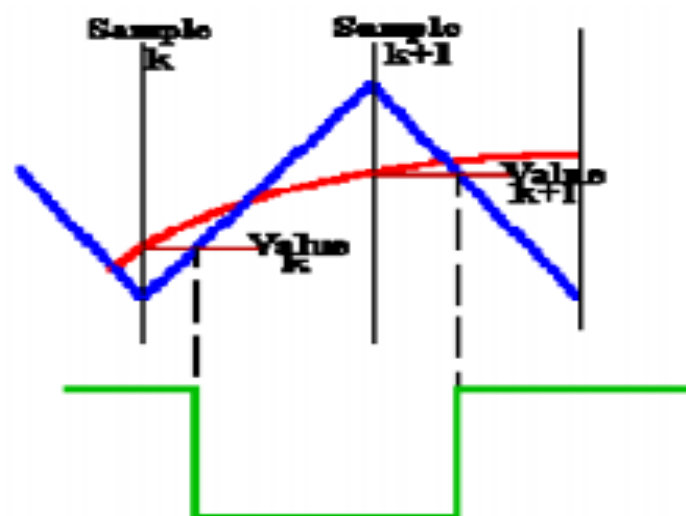


Figure 2.15 : Regular Sampled PWM

CHAPTER 3

METHODOLOGY

3.0 Introduction

This chapter will discuss about the methodology of conducting this research. There are seven stages need to be completed in order to achieve the objective and scope of this project successfully. As for starting, the first step that needs to be done is the literature review. Next, is designing the multilevel inverter circuit. Then, after designing, the circuit needs to be simulated to make sure it is suitable to be used or not. If it is not suitable to be used, the circuit needs to be redesigned. But, if the circuit is able to produce the expected results, the fabrication process can be started followed by experimental setup. By setting up the experiment, the results can be obtained and the data will be analysed and compared with the simulation. If the results are not tally or nearly the same, the experiment needs to be setup again. However, if the results are tally or nearly the same, the report writing of discussion and conclusion can be proceed. Therefore, the steps of conducting this research are completed. Figure 3.1 shows the overall process of the methodology.

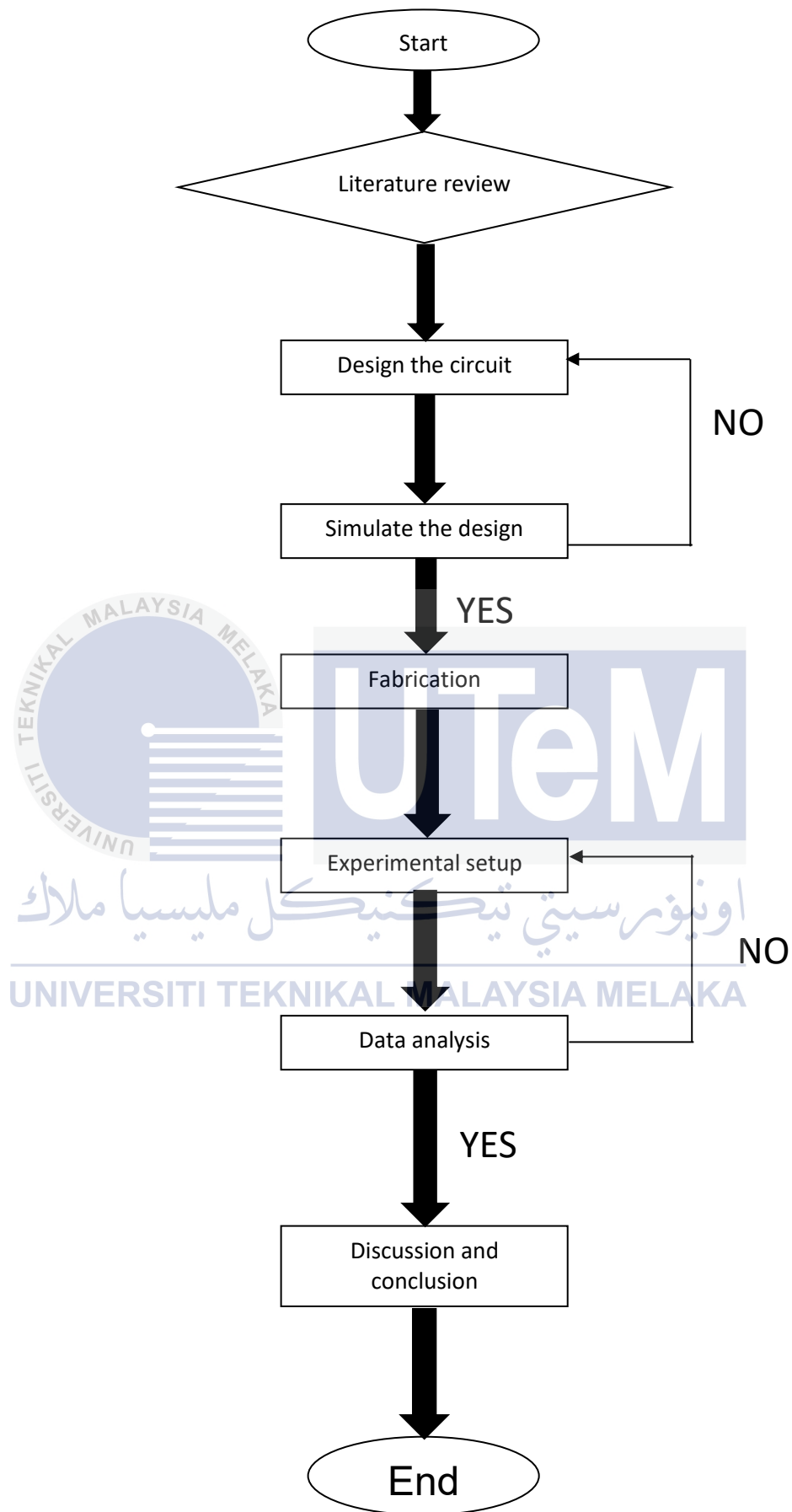


Figure 3.1 : Methodology flow chart of project research

3.1 Literature review

The first step of this project research methodology is the literature review. In this part, the concept of multilevel inverters needs to be understood. The topologies proposed of multilevel inverters need are studied and differentiate. Moreover, the advantages and disadvantages of each topologies need to be found out. Other than that, the switching method and also the modulation techniques need to be studied. As the literature study is done, the components, softwares, switching method and modulation techniques that will be used can be decided. Furthermore, the construction of circuit design is also can be built.

3.2 Inverter circuit design

3.2.1 Cascaded H-bridge multilevel inverter circuit design

Basically, an H-bridge cell consists of four switches and four free-wheeling diodes. The construction of an H-bridge cell is shown in Figure 3.2.

A single H-bridge cell with separate DC source can achieve a three-level voltage output waveform. Therefore, as for the design of the cascaded H-bridge multilevel inverter is constructed by the combination of four MOSFETs with four switches and also a separate DC source for each single-phase full-bridge.

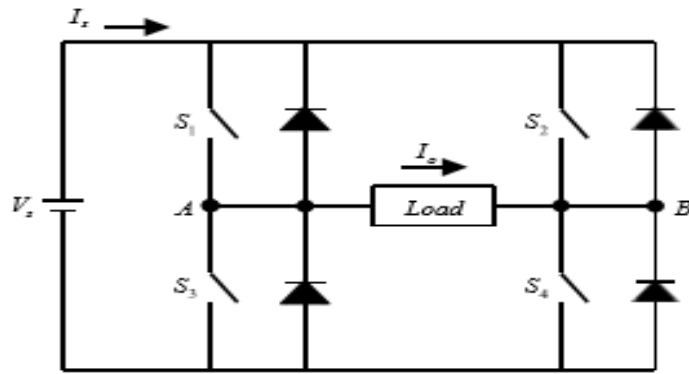


Figure 3.2 : H-bridge cell circuit formed

Regarding to the combination of four switches in the H-bridge cell, three output voltage levels can be formed which are $+V$, $-V$ and 0 . According to Figure 3.2, as if the S_1 and S_4 are turned on, a positive voltage output is performed. If S_2 and S_3 are turned on, a negative output is synthesized. As for the zero level case, it can be synthesized when either S_1 and S_2 are turned on, S_3 and S_4 are turned off or S_3 and S_4 are turned on, S_1 and S_2 are turned off. The switching pattern of a full bridge is as shown in Figure 3.3 below.

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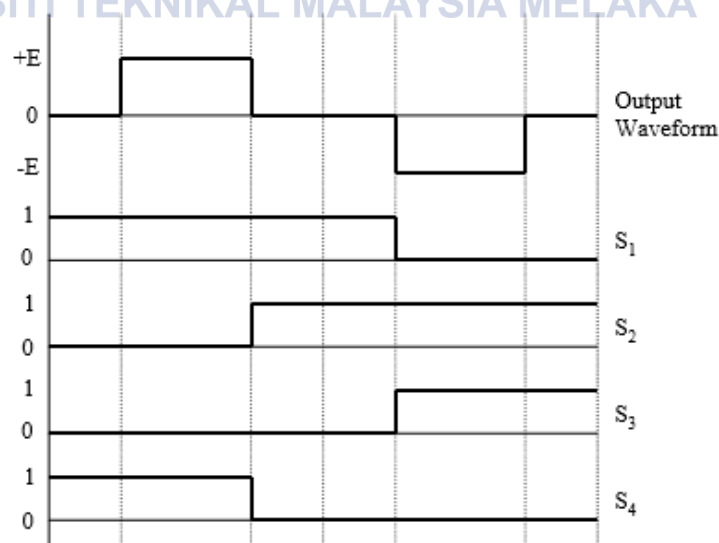


Figure 3.3 : Switching pattern of an H-bridge cell

3.2.2 Calculations

Given formula:

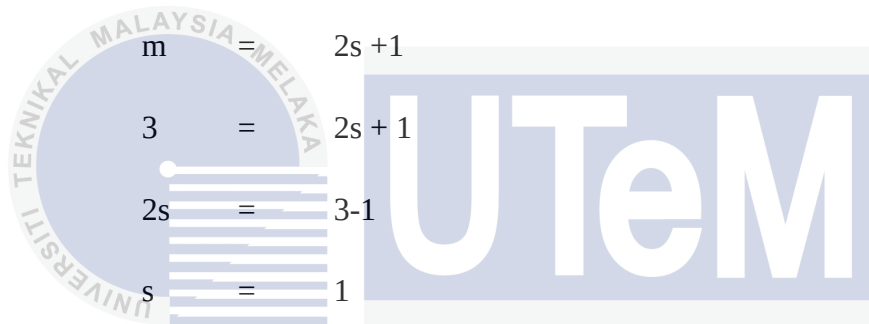
$$m = 2s + 1$$

where, m = output phase voltage level

s = number of DC sources

*note : every each DC source consist four MOSFETs connected as the full bridge formed.

Three-level (single phase):


$$\begin{array}{rcl} m & = & 2s + 1 \\ 3 & = & 2s + 1 \\ 2s & = & 3 - 1 \\ s & = & 1 \end{array}$$

Therefore, the number of DC source needed is 1

So, the number of MOSFETs needed is 4

Five-level (single phase):

$$m = 2s + 1$$

$$5 = 2s + 1$$

$$2s = 5 - 1$$

$$s = 2$$

Therefore, the number of DC source needed is 2

So, the number of MOSFETs needed is 8

3.3 MATLAB simulation

The cascaded H-bridge multilevel inverter circuit is designed by using MATLAB. The components that are used in the simulation are MOSFETs, DC source, voltage measurement, pulse generator, scope, ground and also powergui. The three-level and five-level multilevel inverter circuit design is shown in Figure 3.4 and Figure 3.5. The type of components used for both levels is the same, but the quantity of components differs the both levels. The number of MOSFETs and separate DC sources needed in specific output voltage level is based on the calculations that has been made.

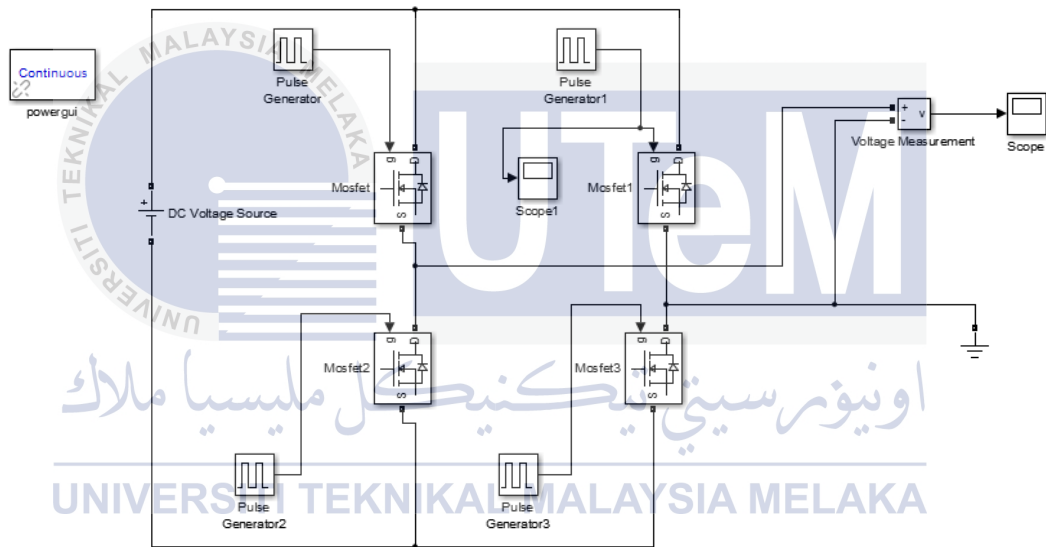


Figure 3.4 : MATLAB Simulink 3-level cascaded H-bridge multilevel inverter circuit design

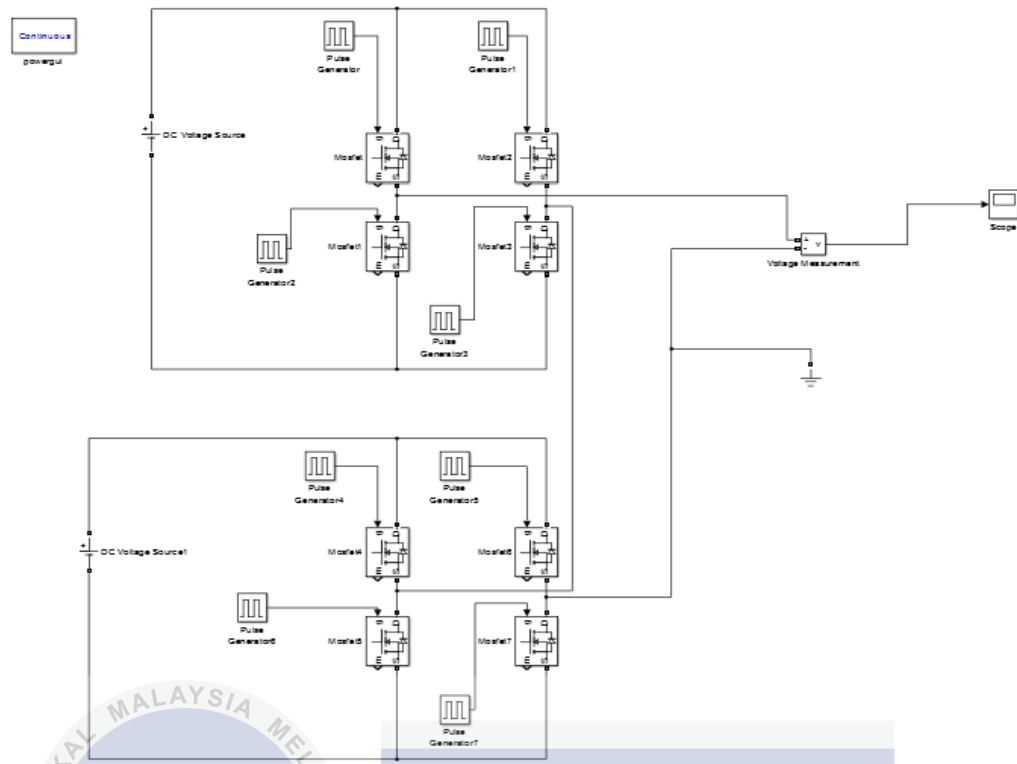


Figure 3.5 : MATLAB Simulink 5-level cascaded H-bridge multilevel inverter circuit design

3.4 Inverter fabrication

The designated circuit will be fabricated from the printed circuit board (PCB) and followed the normal PCB development process. It is the process of creating the integrated circuits in the electronic devices. In the PCB process involves the etching process. During this process, the unwanted material will be removed from the surface of the PCB. Figure 3.6 shows the example of a PCB.

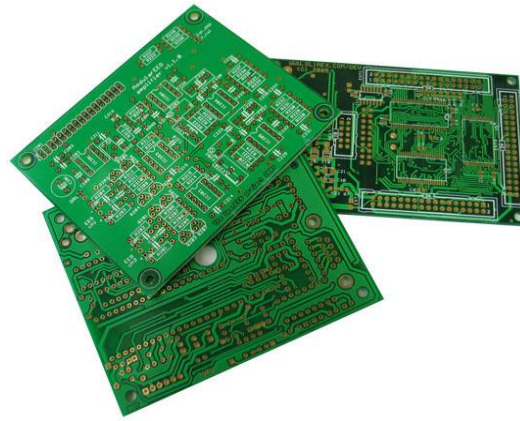


Figure 3.6 : PCB board

The process of etching is undergone as the initial step of constructing the multilevel inverter circuit. Positive Ultra Violet (UV) board is used for this process. Before printing the circuit at the UV board by using vacuum scanner, the circuit is drawn by using PCB Wizard software and printed on a special paper. Figure 3.7 and Figure 3.8 show the inverter and MOSFET driving circuit that has been undergone the etching process.

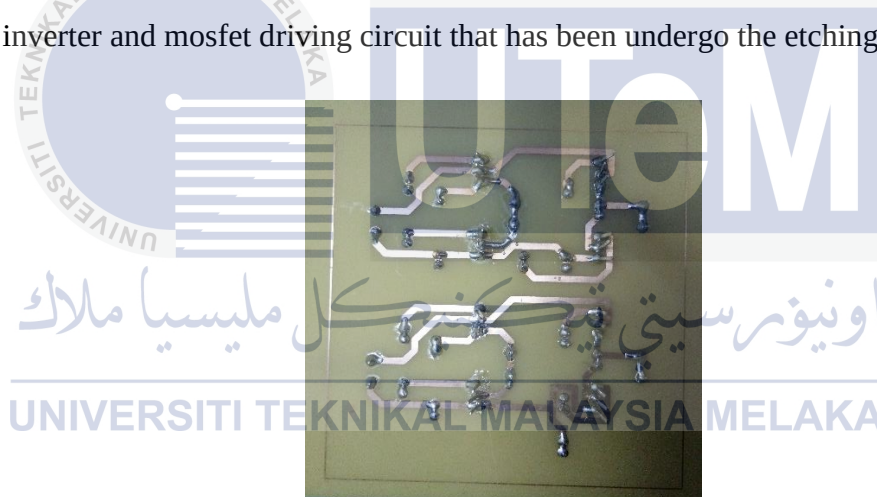


Figure 3.7 : Cascaded Multilevel Inverter Etching Circuit



Figure 3.8 : MOSFET Driving Etching Circuit

3.4.1 Material Selection

The materials or components that will be used for the hardware construction of the cascaded H-bridge multilevel inverter are decided. The components that are used are MOSFETs, HCPL-3120, Switch Mode Power Supply (SMPS), Power Converter (IQ0515SA) and microcontroller.

3.4.1.1 MOSFET

Metal-oxide semiconductor field-effect transistor (MOSFET) is a special type of field-effect transistor (FET) which works by electronically varying the width of a channel along which charge carriers flow. The reason why MOSFET is chosen for the construction of cascaded multilevel inverter is because it has a very low switching losses. Moreover, it can withstand with higher frequency level compared to IGBT. The type of MOSFET that has been chosen is IRF540. Figure 3.9 below shows the illustration of the MOSFET.

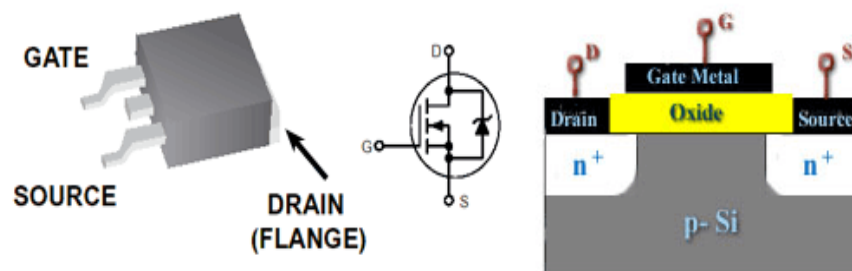


Figure 3.9 : MOSFET

3.4.1.2 HCPL-3120

HCPL-3120 is an optocoupler that is suitable to be used to drive the MOSFETs in the multilevel inverter. It provides drive current to the MOSFETs. It helps to isolate the low voltage control circuitry from the high voltage loads. Its high output voltage helps to turn on the MOSFET while the low voltage caused the MOSFET to turn off. It is able to prevent the catastrophic failure of the whole drive. Figure 3.10 shows the HCPL-3120 optocoupler that is used in the project.

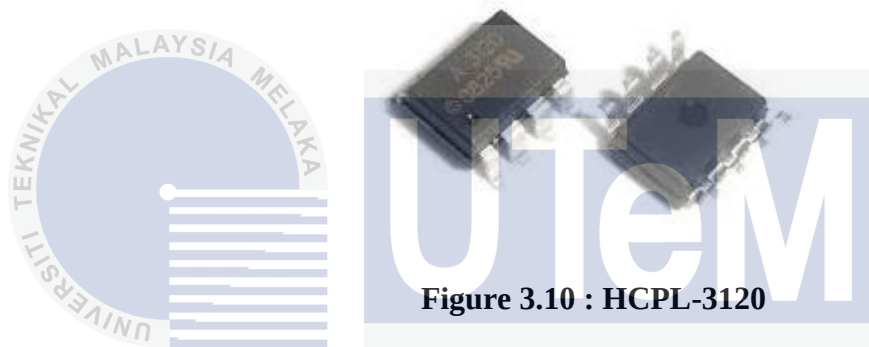


Figure 3.10 : HCPL-3120

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3.4.1.3 Switch Mode Power Supply (SMPS)

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A power supply is able to provide electrical power to the appliances or loads. Switch Mode Power Supply in this project to supply voltage to the MOSFET driving circuit. In order to activate the optocoupler, some value of voltage is needed. Therefore, Switch Mode Power Supply is the source of voltage supply for the activation. The value of voltage that is provided by the SMPS is 5 V. Figure 3.11 shows the SMPS that is used for the hardware construction.



Figure 3.11 : Switch-Mode Power Supply (SMPS)

3.4.1.4 Power Converter (IQ0515SA)

IQ0515SA is a type of DC-DC power converter which produced by XP Power which having the ability to convert the input voltage of 5 V_{DC} to 15 V for the output voltage. This converter is used in the MOSFET driving circuit to convert the 5 V_{DC} to 15 V to be supplied to the HCPL-3120. Figure 3.12 below shows the IQ0515SA.

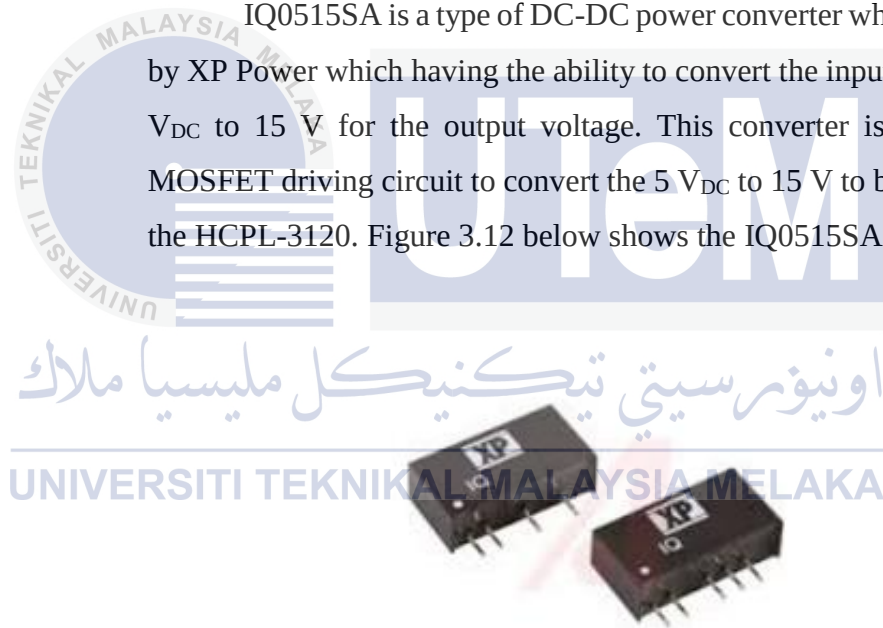


Figure 3.12 : IQ0515SA Power Converter

3.4.1.5 Microcontroller

In this project, the types of microcontroller that is used is Arduino Uno. Arduino Uno is a microcontroller board that has 14

digital input/output pins and 6 analog inputs. 6 of the digital input/output pins can be used as PWM outputs. It has an operating voltage of 5 V and able to receive the input voltage by simply connecting it to the computer by using the USB cable provided. This microcontroller helps to give pulses to the circuit. The pins that is used for the circuit need to be set before connecting it to the circuit by programmed the Arduino with the coding that has been created. The pin that is used is declared in the program. Figure 3.13 shows Arduino Uno R3 that has been used in this project.

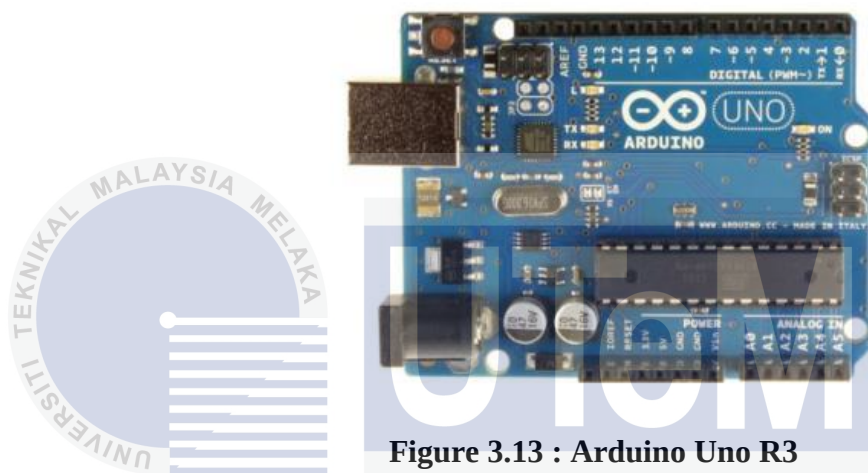


Figure 3.13 : Arduino Uno R3

3.5 Experimental setup

To understand the working principle of cascaded multilevel inverter, the experimental setup needs to be done. The experimental process consist of two methods of conduction which are software and hardware development. The overall experiment setup is as follows, Figure 3.14.



Figure 3.14 : Overall experiment setup

3.5.1 Input DC voltage

9 V batteries are used in this project and connected to the inverter circuit. It is used to give a value of DC supply input voltage to operate the inverter circuit and perform the expected results. The value of input DC voltage that is given to each bridge in the inverter will give the same output voltage value. Figure 3.13 shows the types of battery that is used in this project.



Figure 3.15 : Battery

3.6 Data analysis

As the cascaded H-bridge multilevel inverter hardware construction has been set up, the experiment need to be conducted and the data obtained need to be analysed. The output gained by running the experiment needs a medium to visualize it. The oscilloscope is used as a medium to perform the waveform of output voltage for the constructed cascaded H-bridge multilevel inverter system. If the data analysed by performing experiment are not tallying with the simulation, the experiment needs to be repeated and make some changes that are needed. Figure 3.16 shows the oscilloscope.



Figure 3.16 : Oscilloscope

3.7 Hardware Implementation of Single Phase Cascaded Multilevel Inverter

The hardware implementation of the single phase cascaded multilevel inverter consists of two circuits. The circuits are inverter circuit and MOSFET driving circuit. The inverter circuit is the construction of cascaded multilevel inverter that should be tested. The MOSFET driving circuit is used to drive the MOSFET that is used in the inverter circuit. Figure 3.17 and 3.18 shows the inverter circuit and MOSFET driving circuit that has been constructed.

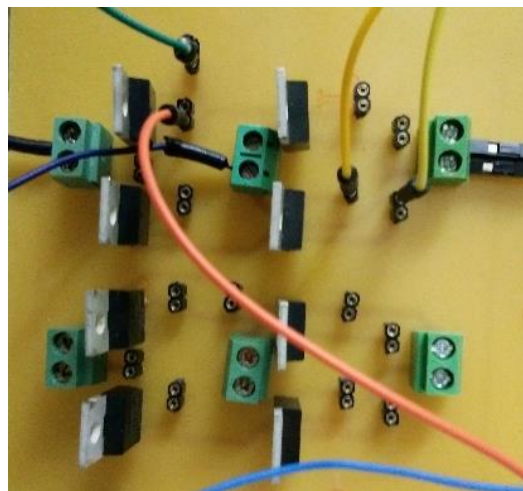


Figure 3.17 : Inverter Circuit



Figure 3.18 : MOSFET Driving Circuit

3.8 Writing discussions and conclusion

The final stage of completing the project report is by writing the discussions and conclusion. By obtaining the expected results of project by completing the simulation and hardware experiments, the results will be discussed in detailed. The project will be concluded whether it is succeeded or not succeeded.

CHAPTER 4

RESULTS AND DISCUSSION

4.0 Introduction

As a project is decided to be done, the result expectation is also has been set. The result expectation for this project research is able to design the single phase H-bridge multilevel inverter for low voltage by using microcontroller. Besides that, by doing this project, it is expected to be able to simulate the design of single phase H-bridge multilevel inverter by using MATLAB. Lastly, it is expected to be able to replicate and test the designated input and output single phase H-bridge multilevel inverter. In this chapter, the performance of Cascaded Multilevel Inverter using simulation and hardware construction will be discussed.

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4.1 Simulation and Result of Single Phase Three-level Cascaded Multilevel Inverter by using MATLAB

A circuit of single phase three-level cascaded multilevel inverter is constructed as shown in Figure 4.1.

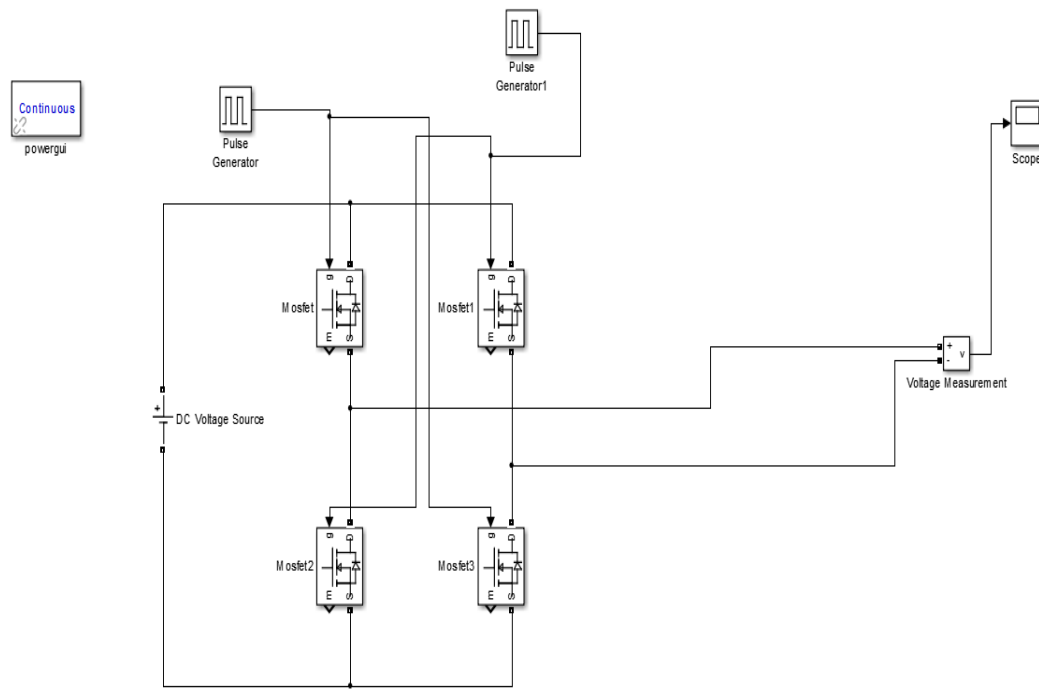


Figure 4.1 : Design of Single Phase Three-Level Multilevel Inverter by using MATLAB

The circuit that is designed as shown in Figure 4.1 is simulated and tested by using the source voltage of $100V_{DC}$. Regarding to the design, as for the Pulse Generator settings, the amplitude is set as 10, the period is set to $5e^{-5}$ seconds, and the pulse width is set to 70% of period for both “Pulse Generator” and “Pulse Generator1”. While, the phase delay is set differently for different Pulse Generator. This is due to the cascaded concept, where Mosfet and Mosfet3 will be activated at the same time to perform positive waveforms besides Mosfet1 and Mosfet2 will be activated after the activation of Mosfet and Mosfet3 to perform negative waveforms. Therefore, the phase delay for “Pulse Generator” is set to “0” seconds while “Pulse Generator1” is set to “ $2.5e^{-5}$ ”. The results for the simulation of the designated circuit is shown in Figure 4.2.

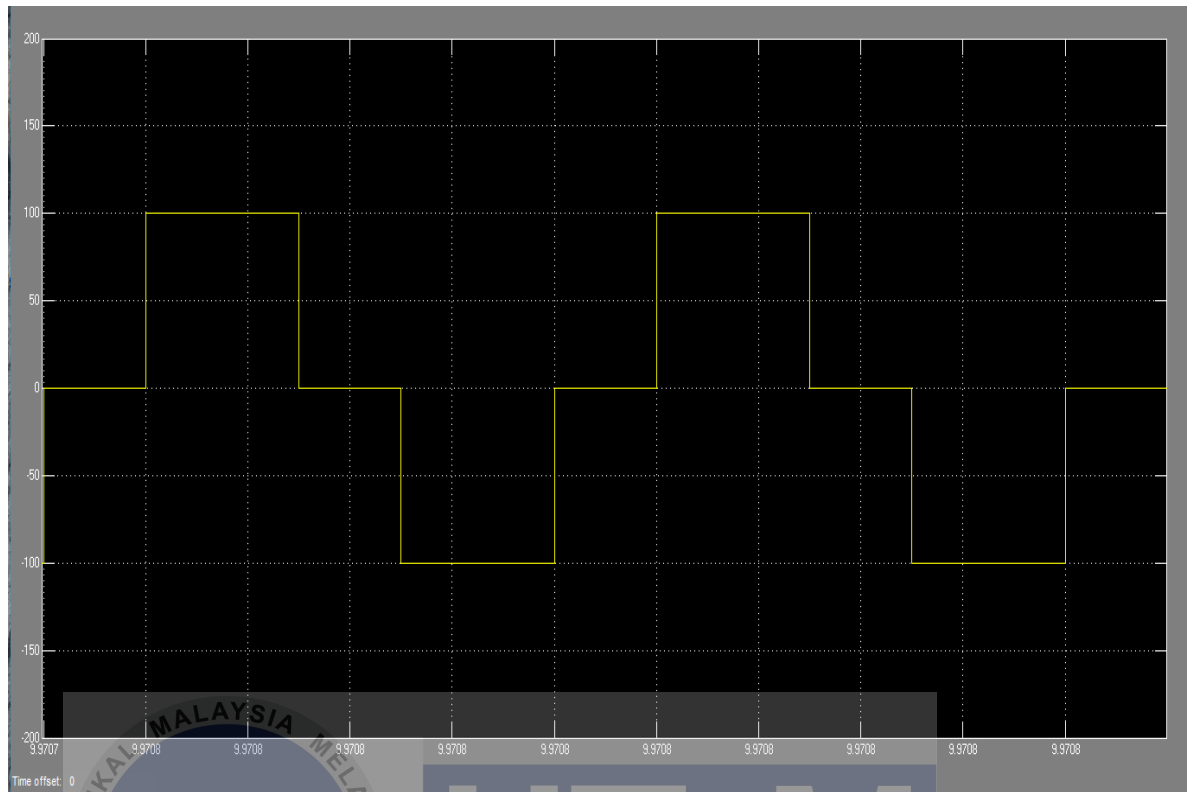


Figure 4.2 : Waveform of Single Phase Three-Level Cascaded Multilevel Inverter by using MATLAB.

From Figure 4.2, we can see the output voltage that is formed is 100 V and the pattern of waveform that is generated as the circuit is being simulated is a staircase square wave.

4.2 Simulation and Result of Single Phase Five-level Cascaded Multilevel Inverter by using MATLAB

The circuit of single phase three-level cascaded multilevel inverter is designed in MATLAB as shown below in Figure 4.3.

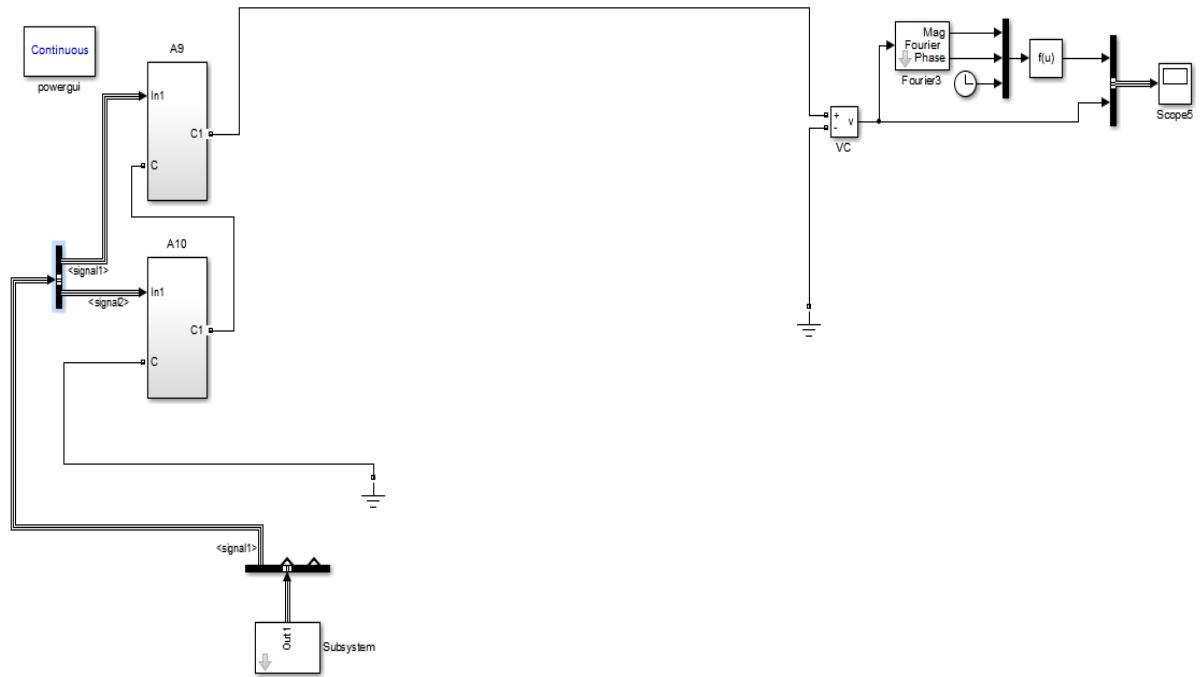


Figure 4.3 : Design of Single Phase Five-Level Multilevel Inverter by using MATLAB

Regarding to the designed circuit, there are two subsystems that is constructed which are A9 and A10 which consist of a set of cascaded inverter each as shown in Figure 4.4 and Figure 4.5. The combination of two sets of cascaded inverters make the circuit fulfilled the criteria of Five-Level Cascaded Multilevel Inverter. Both of the circuit is supplied with $100V_{DC}$.

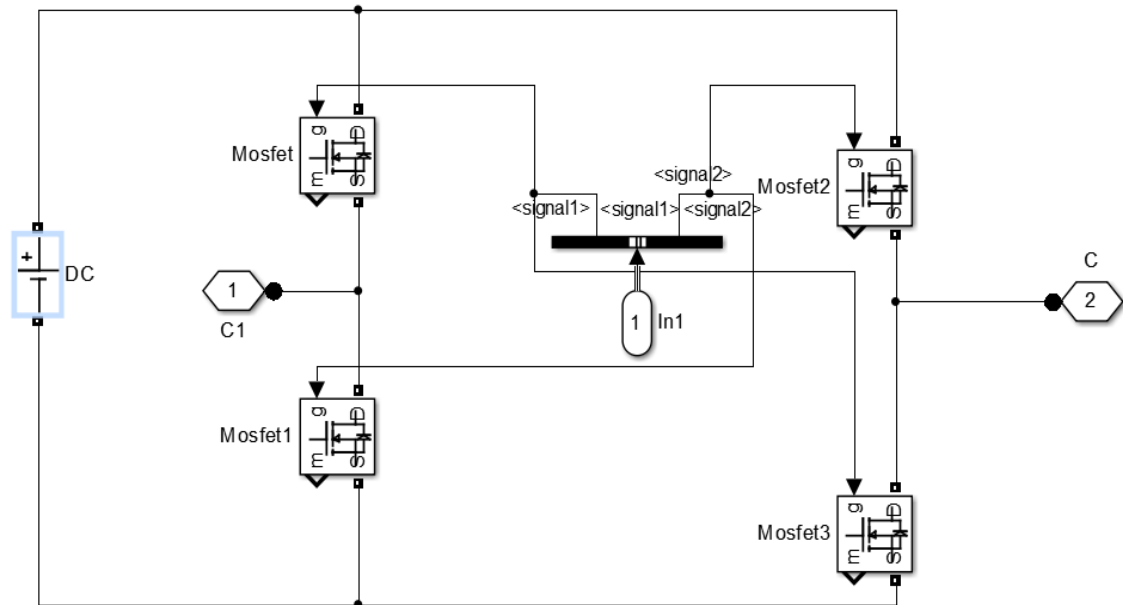


Figure 4.4 : Circuit Construction of Subsystem A9

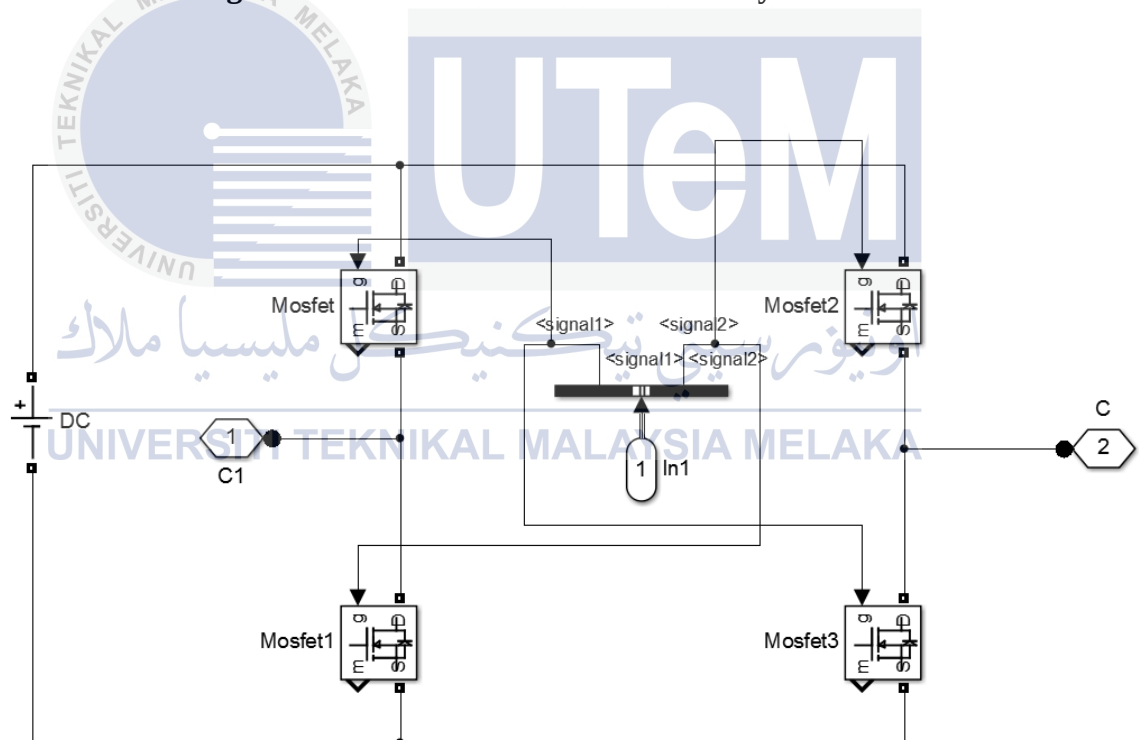


Figure 4.5 : Circuit Construction of Subsystem A10

As the circuit designed is run, the waveform that is generated are as shown below in Figure 4.6.

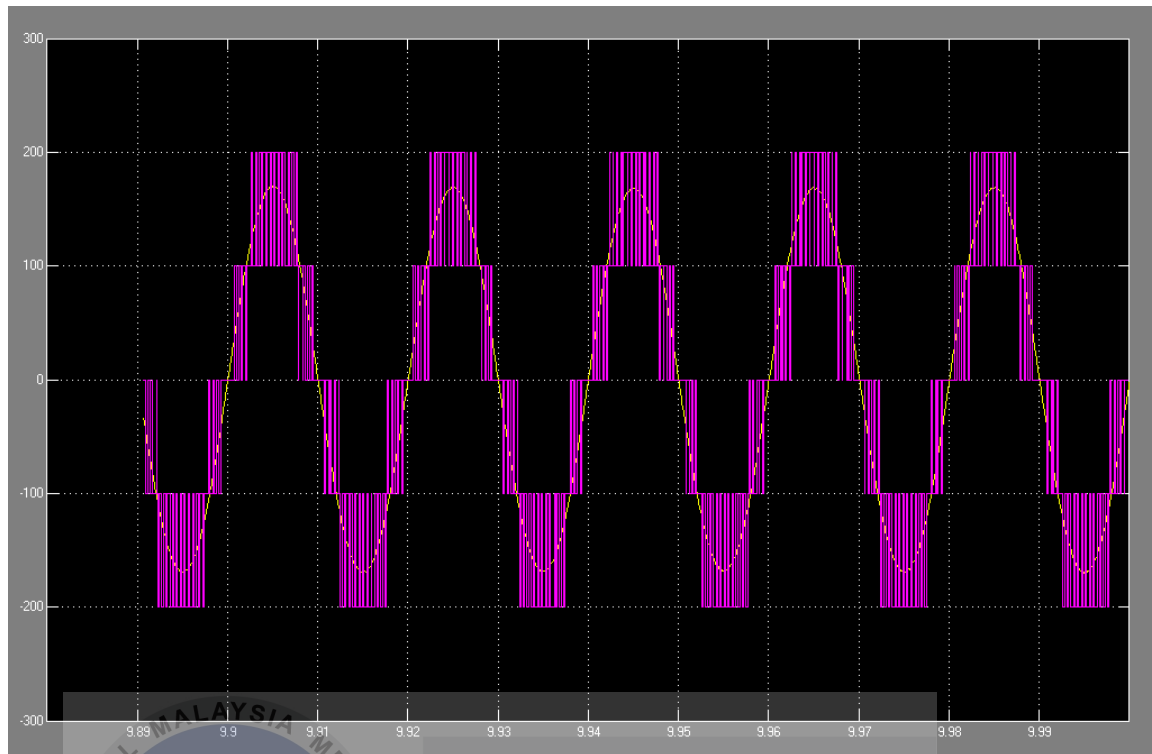


Figure 4.6 : Waveform of Single Phase Five-Level Cascaded Multilevel Inverter by using MATLAB.

As we can see from the waveform of the simulation Single Phase Five-Level Cascaded Multilevel Inverter in Figure 4.2, an output voltage of 100 V and a staircase square wave pattern is generated.

Regarding to the waveform pattern for Three-Level and Five-Level Cascaded Multilevel Inverter, both performed staircase waveform. The difference of both inverter is the output voltage and the level of the staircase waveform. For Three-Level, the output voltage is 100V while Five-Level is 200V. This is due to the total number and values of DC voltage that is supplied to both circuit. As we compare both waveforms from two different level of circuit construction, Five-Level inverter is more to sinusoidal wave compared to Three-Level inverter. Therefore, due to the simulation that has been made, we know that as we go up the level of inverter, the more the pattern of waveform to sinusoidal which brings to lesser distortion.

4.3 Hardware Construction of Single Phase Three-level Cascaded Multilevel Inverter

As mentioned before, there are two circuits involve in developing a single-phase cascaded multilevel inverter hardware. The circuits are the MOSFET driving circuit and inverter circuit. The combination of the circuits can results in the cascaded multilevel inverter.

4.3.1 MOSFET Driving Circuit

In order to make sure that the driver is able to supply enough voltage to the MOSFET, the output of the driver is tested by using the oscilloscope. The output of the driver is tested as it has been supplied with 5 V_{DC} input voltage by the SMPS. The power converter then will increase the voltage up to 15 V_{DC} and supplied to the HCPL-3120. Therefore, the output of the driver that comes from the output of HCPL-3120 is 15 V. 15 V output voltage of the driver is needed to drive the MOSFET in the inverter circuit. The insufficient voltage output from the driver will caused the MOSFET to not be fully activated. Figure 4.7 below shows the tested results of the MOSFET driver.

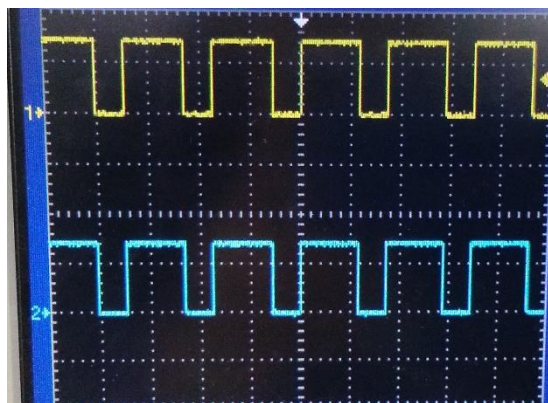


Figure 4.7 : Waveform of MOSFET Drivers

Regarding to the Figure 4.7, the output of the drivers are successfully reached to 15 V. Therefore, the drivers are able to provide enough voltage to run the MOSFET in the inverter circuit.

4.3.2 Inverter Circuit

As the MOSFET driving circuit is succeeded to perform an output voltage of 15 V, it is ready to be connected to the inverter circuit. For each cascaded configuration, there will be a DC supply which is received by the battery. There is also a positive and a negative cycle of waveform for each cascaded configuration. The positive and negative cycle of each cascaded configuration is made separately in this project.

4.3.2.1 Positive Cycle Waveform

To get a positive cycle waveform, the first and fourth MOSFET which are positioned oppositely in the cascaded configuration will be activated while the second and third MOSFET will be inactive. Figure 4.8 below shows the result that is obtained as the positive configuration is run.

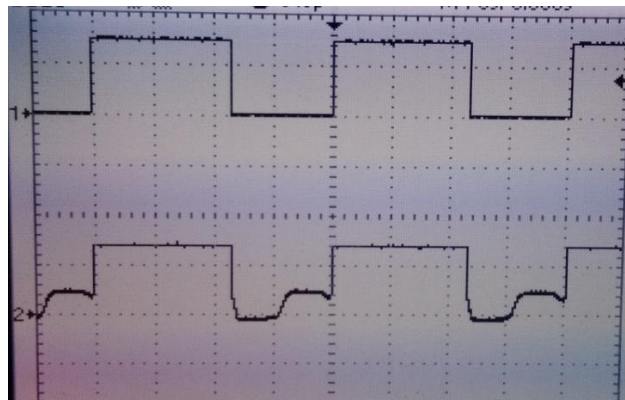


Figure 4.8 : Waveform of Inverter Output for Positive Cycle

Based on the figure shown above, Figure 4.8, Channel 1 is the driver's output and Channel 2 is the inverter's output waveform. The output voltage of the inverter is almost the same as the input voltage given to the inverter circuit which is 9V. Therefore, the experiment of performing a positive cycle output of the inverter is succeeded.

4.3.2.2 Negative Cycle Waveform

To perform a negative cycle output waveform of the inverter, the second and third MOSFET is activated while the first and third MOSFET is inactivated. Figure 4.9 below shows the result of the negative cycle of cascaded inverter configuration.

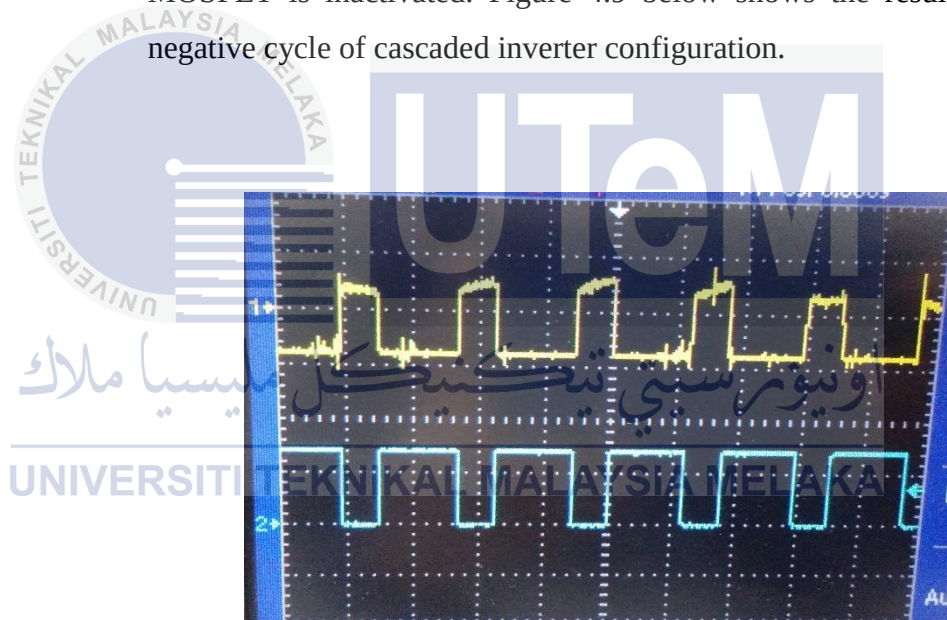


Figure 4.9 : Waveform of Inverter Output for Negative Cycle

Referring to the figure shown above (Figure 4.9), Channel 1 is the output waveform of the inverter while Channel 2 is the output waveform of the MOSFET driver. As we can see from the graph that is generated, the output voltage that is performed is lesser than the expected output voltage. This might cause by the insufficient voltage produced by the gate driver. The insufficient of voltage might cause the

MOSFET not to be fully activated and not functioning on its optimum state. The other reasons that might cause the output voltage of the inverter that is generated is not like the expected result is that the insufficient voltage supply by the battery. Therefore, the experiment on the negative cycle cascaded inverter configuration is not succeed. The negatively waveform is successfully performed but reaching the expected voltage is not succeed.



CHAPTER 5

CONCLUSION

5.0 Introduction

This chapter discusses the conclusion and the recommendation of the future work to overcome the consequences faced during undergo the process of designing and replicating this project. Besides that, this chapter also outline about the problem faced during constructing this project and ways to prevent the constraints.

5.1 Summary of Research

This project of research entitled “Design of Single Phase H-Bridge Multilevel Inverter by Using Microcontroller” is having three objectives. The first and second objectives are successfully achieved but the third objective is not been achieved. This matter due to the value of the output voltage does not satisfy the criteria of cascaded multilevel inverter for the hardware development. The designing of the cascaded multilevel inverter by using MATLAB is successfully achieved the objective as the output waveform generated is the same as the expected results. The comparison of the three-level and five-level design can also be made to get a clearer view of lesser harmonic distortion when the level increases. The comparison cannot be seen and proves by the development of hardware since the negative cycle of the three-level cascaded multilevel inverter did not reached the expected output voltage. Some

improvement need to be made to the hardware in order to perform a correct output result.

5.2 Project Constraints

The constraints that is faced in this project is to energize the MOSFET in the inverter circuit. To energize the MOSFET, a sufficient supply from the driver is needed. If the voltage supply that is needed is insufficient, the MOSFET will not be fully energized and the expected output is hard to obtain. Secondly, the constraint that is faced during the experiment is, the battery that supply voltage to the inverter circuit. The voltage of the battery is drop after using it or keep on connecting it to the circuit without uninstalled it. Besides that, the MOSFET is another reason of the unsuccessful of getting the exact output. A MOSFET should be tested before connecting it to the inverter circuit. A damaged MOSFET will be the cause of not getting the correct output result. Lastly is the power converter. Power converter IQ0515SA is a very sensitive type of power converter. It also should be tested before applying it to the driver circuit. This component is important as it increase the voltage and gives enough supply to the HCPL-3120.

5.3 Recommendation

Power supply is the most important factor in this project. As if there is no enough supply, the driver will not able to energize and produce enough voltage to activate the MOSFET. Therefore, it is suggested to use more stable power supply for the driver and also the inverter.

Besides that, it is suggested to apply heat sinks on the MOSFET as it help in preventing the MOSFET to be burned. A burned MOSFET can affect the entire circuit. A heat sink can help in reducing the temperature of the MOSFET.

Lastly is the microcontroller. In order to improve the performance of the multilevel inverter is using the different types of microcontroller which is known as FPGA (Field Programmable Gate Arrays). This type of microcontroller is faster than normal condition. The conventional microcontroller is not suitable for higher frequency compared to FPGA. Moreover, the FPGA is having a better time based compared to conventional microcontroller.



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APENDICES

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