FACULTY OF ELECTRICAL ENGINEERING

ANALYSIS AND DEVELOPMENT OF LOW POWER AND PORTABLE 12V DC TO 220V AC INVERTER

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Bachelor of Electrical Engineering

2016

“ I hereby declare that I have read through this report entitle “Analysis and Development of Low Power and Portable 12V DC to 220V AC Inverter” and found that it has comply the partial fulfilment for awarding the degree of Bachelor of Electrical Engineering (Industrial Power)”

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ANALYSIS AND DEVELOPMENT OF LOW POWER AND PORTABLE 12V DC TO 220V AC INVERTER

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A report submitted in partial fulfilment of the requirements for the degree of Bachelor of Electrical Engineering (Industrial Power)

Faculty of Electrical Engineering
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2016

I declare that this report entitle "Analysis and Development of Low Power and Portable 12V DC to 220V AC Inverter" is the result of my own research except as cited in the reference. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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To my beloved parents and siblings

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First and foremost, all praises to Allah the Almighty that by His blessings I have been able to complete this Final Year Project in time. I would like to express my great appreciation to my supervisor Dr Jurifa Binti Mat Lazi who have contributed immeasurable amount of guidance, advice and assistance along my project progress.

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ABSTRACT

Inverter, regardless of size, is an electrical device that capable of converting a DC power supply to an AC power supply with different type of output waveform produced depending on the design. There are many power inverter available at the market but most of inverter often comes with higher price. Many circuitry example are also available from the internet for people who wish to make their own cheap and low power inverter. However, the performance of the design are still not being analyzed whether the inverter are capable to be used and marketed. This project proposed an analysis and development of low power inverter design to be used as alternative basic emergency back-up supply by proposing two circuit based on simplicity, inexpensive and light designs with different component used, the project aims to develop and analyze the low power 12V DC to 220V AC. Both circuit designs are operated using a signal generates from 555 Timer integrated circuit. The performance of inverter designs are analyzed in term of voltage, current and total harmonic distortion before proceed to hardware development. In addition, the experimental results of the hardware developed are analyzed based on its performance capability.

ABSTRAK

Inverter, tanpa mengira saiz, adalah alat elektrik yang mampu menukar bekalan kuasa DC kepada bekalan kuasa AC dengan pelbagai jenis bentuk gelombang keluaran yang dihasilkan, bergantung kepada reka bentuk. Terdapat banyak inverter kuasa yang ada di pasaran tetapi kebanyakan inverter dijual dengan harga yang lebih mahal. Banyak contoh litar juga boleh didapati dari internet untuk pengguna yang ingin membuat inverter kuasa yang rendah dan murah. Walau bagaimanapun, prestasi reka bentuk masih belum dianalisis sama ada inverter tersebut mampu untuk digunakan dan dipasarkan. Projek ini mencadangkan analisis dan reka bentuk inverter berkuasa rendah untuk digunakan sebagai bekalan asas kecemasan dan alternatif melalui dua litar yang telah dicadangkan berdasarkan kesederhanaan, reka bentuk murah dan ringan dengan komponen yang berbeza, projek ini bertujuan untuk membangunkan dan menganalisis kuasa yang rendah 12V DC untuk 220V AC. Kedua-dua reka bentuk litar dikendalikan menggunakan isyarat yang dijana dari litar bersepadu 555 Timer. Prestasi reka bentuk inverter dianalisis dari segi voltan, arus dan jumlah herotan harmonik sebelum meneruskan pembangunan reka bentuk. Di samping itu, hasil eksperimen yang dihasilkan dianalisis berdasarkan keupayaan prestasinya.

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CHAPTER 1

INTRODUCTION

This chapter provides the overview of the Development of Low Power and Portable Inverter 12V DC to 220V AC. The background of the study, problem statement, objective and scope are presented briefly in this chapter.

1.1 Background of Study

Power supply is a hardware component or also known as electrical device that widely used in electronic equipment which provides electric energy and supplies power to the electrical load by performing the conversion of electrical energy. There are two main formation of electrical power; alternating-current (AC) and direct-current (DC). The output voltage of an inverter can be stepped up or down using transformers.

Nowadays, it is compulsory to convert the DC power from storage batteries to AC power because most of the design in electrical devices are in AC. Practically, the conversion of the DC power to AC power can be done by using power inverter. There are two methods that can be used to invert the low voltage DC power. The first method is by converting the low voltage DC power to high voltage DC source. After the conversion, the high voltage DC source then will be converted to an AC waveform using switching signal. Second method is by converting the low voltage DC power to AC , and then the low voltage AC power obtained will be improved or step up to a higher voltage level by using transformer.

There are three considerable types of DC to AC inverter which are pure sine wave, modified sine wave and square-wave. Pure sine wave produces an output sine wave that identical to the power coming out from electrical outlet with low harmonic distortion while modified sine wave which can be seen as more of square wave; in particularize amounts of times will passes the high DC voltage so that the average power and RMS voltage are alike as if it were a sine wave. Modified sine wave is a good alternative as it can work fine in most equipment and much cheaper than pure sine wave. However, the efficiency or power will be reduced and cause damage to some equipment; laptop computers, power tools and etc.. In addition, square wave is rarely used in any equipment but it is the cheapest type of inverter which also can be used to run simple things without problem; like tools with universal motors.

1.2 Problem Statement

Blackout can happen at any time. Therefore, it is very crucial to have a backup power for emergency basic electrical supply in a house. Various types of emergency backup device were introduced depend on the type of energy source used to produce electricity. Study in [1] shows that Malaysia experienced power outages due to lightning of more than 70 percent and thus called as the "Crown of Lightning" in the world. Therefore, when it happens, there may be power supply at the grid down for days or even weeks, especially in rural areas. In order to provide emergency power supply for basic use in short period of time, an alternative house backup power such as battery power supply is more effective and reliable alternative solution, as the DC power can be convert to AC using an inexpensive inverter.

There are many choices of power inverters that consumers can obtain from markets which provided with different range of quality, efficiency, and power output capability. However, the high efficiency and better quality of the inverter often comes in expensive cost. For example, Tripp Lite manufactures a 100 Watt pure sine wave inverter with cost of RM219.62, while Whistler manufactures a 100 Watt inverter with modified sine wave output that cost only RM93.13. This shows that, consumer can get inexpensive type of power inverter by using the modified sine wave units which can be slightly efficient and has not much process perform on the output voltage, but the device may effect sensitive equipment as the result of higher number of harmonics in a waveform [2], but as long as it can provides supply as consumer needed, this type of power inverter is considered.

Many cheap devices with square wave output or may be modified square wave, provided with proper RMS voltage, and close to the right frequency. As points mentioned, there are many inverter which vary in their strengths and weaknesses. Many circuitry examples are also available in internet that can be use as an inverter for basic supply needed. However, the performance of most of the low power inverter circuitry examples are still not being analyse and determine whether they are capable to be market. This project goal is to analysis and develop a low power inverter, by considering a cheap, portable and low power inverter design for basic supply back-up.

1.3 Objectives

The objectives of this project are to:

1. Develop a low power portable of 12V DC to 220V AC power supply.
2. Analyse the performance of 12V AC to 220V AC power supply in term of current, voltage and total harmonic distortion (THD).
3. Compare the simulation and experimental results in term of voltage , current, THDv and THDi.

1.4 Project Scope

The development of portable 12V DC to 220V AC power supply is consist of five scopes which are:

a) Battery of 12V used as a power supply.
b) The simulation and analysis are executed using MATLAB/Simulink and PSpice.
c) Design an inexpensive, simple and low power portable inverter.
d) Step up the 12V AC to 220V AC using transformer.

CHAPTER 2

LITERITURE REVIEW

2.0 Introduction

This chapter presents the literature review of the history of inverter. The inverter topology, implementation of pulse width modulation, total harmonic distortion, element of inverter, previous studies of the development of the DC to AC converter, and new design that have been applied before are discuss to providing better understanding for implementation of the inverter design.

2.1 History of Inverter

Edward L. Owen stated in [3], the originator of this engineering term was well founded by David Prince. In 1925, Prince was recognized in his article, “The Inverter” as the individual who get hold of Alexanderson’s expression “inverted rectification” and developed a single English-language by the word, inverter. However, the use of word inverted may be misunderstood with the idea of turning the rectifier circuit in reverse mode. In order to makes reader understandable, Prince stated its function is to push out alternating current by draw in direct current (direction is not reversed) which clearly meant as to invert function or operation of the rectifier.

The inverter emulating power available in an typical household electrical outlet by transforming DC power source that stored in a battery such as 12V car battery into AC power source operating at 50 Hz (standard frequency used by utility power supply in Malaysia). Inverter also useful in regulating the output voltage effective value before the electricity is supplies to the load. In World war II, the earliest inverter was originated as motor generator. Although it is inefficient, the inverter was utilized to provide the necessity and the only way to convert DC power to AC power in that era[4]. Then, in early 1960s, a new type of inverter invented by replacing mechanical vibrators with solid state transistor; which is not a motor generator is produced in square waveform but with compatibility problems.

After various achievement in prolonged developments, today, the inverter was widely used in large electric utility applications; such as power supplies. Consumers can easily find and select different brands of power inverter either in pure sine wave or modified sine wave with different levels of efficiency and distortion provided in markets.

2.2 Direct-Current (DC) and Alternating-Current (AC)

There are two forms in electrical transmission which is Direct Current (DC) and Alternating Current (AC). Direct current is when the electrons flow in one direction (current in uniform direction) while alternating current, on the other hand, has direction of flow in constantly changes in amplitude and reverse direction periodically at regular intervals.

Most of the developed digital electronics use direct current as its allowed constant high and low values representing bits used by computers, basic 1 and 0 bits. In the beginning of the electrical age, only direct current existed. However, due to its power lost in long-distance lines, alternating current were soon developed by Nicola Tesla as the result of the need to improve the efficiency of current transmission [5].

$$P = VI \tag{2.1}$$

DC power line is ineffective to transmit electricity in long distances because there is no available technology that can step-up the voltage along the transmission path over. Equation (1) proved that, the power loss can be decreases by increasing the voltage, while the current is decreases. Therefore, to decrease power losses, the high voltage is needed. AC power which alternating in between of two voltages at particular frequency and very efficient at transmitting power, making it is very useful and easier for transformer to step up or step down [6]. However, both of these forms of electricity is very crucial to be exist as today, there are many appliances around the world that need different electricity source to operate.

2.3 Inverter Topology

In particular, there are three type of wave-forms that can be produced by an inverter; square wave, modified sine wave and pure sine wave. For this section, all the waveform will be discuss including the advantages and disadvantages in powering the appliances.

2.3.1 Square Wave

As mentioned before, the square wave inverter is the first type of inverter made and usually used in some type of electrical tools and universal motors. The inverter produces a square wave by switching the set frequency of the DC sources in opposite direction across the load. In other word, the current waveform depend on the load component. Unfortunately, this type of inverter are obsolete due to its relatively large 3^{rd} and 5^{th} harmonic components thus it is deficiency in running modern appliances. As the result of the rough approximation from square wave output, devices with timing circuits cannot be operate.

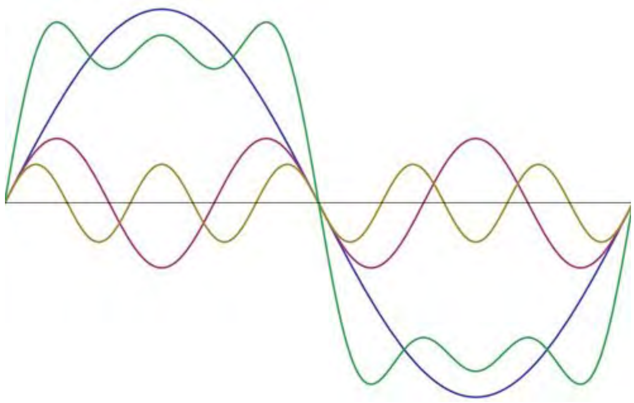


Figure 2.1: The partial construction of a square wave

In addition, square waves consist of odd harmonic and don't have even harmonics. Figure 2.1 shows different forms of wave in the partial construction of a square wave which the wave is in green colour, presented by fundamental sine wave (blue), 3rd harmonic (purple), and 5th harmonic (brown). The amplitude of 3rd harmonic is 1/3 of the fundamental wave and has three times the fundamental frequency with three periods. On the other hand, the 5th harmonic has 1/5 amplitude of the fundamental with five periods. The wavy horizontal line of the green wave will be perfectly square wave if it was added by more different level of harmonics.

2.3.2 Modified Sine Wave

Modified sine wave inverter or as known as quasi-sine wave inverter is an upgrade of square wave inverter. The waveform of the inverter is in square wave but the waveform has a "stepping" look that more likely in rough approximation shape to a sine wave. Basically, it is the square wave with a dead time; the wave is in positive output, then sits at zero for a moment in off position switch before it goes to negative output and next, sit to zero back before it repeating the operation and emulating the sine wave. The different type of those waveform is shown as in Figure 2.2.

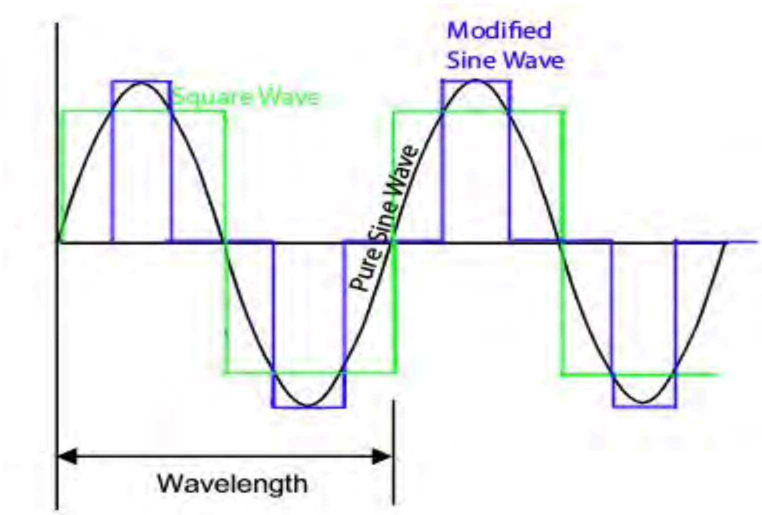


Figure 2.2: Different waveform of square wave, modified sine wave, and pure sine wave inverter

Modified sine wave is very inefficient compared to pure sine wave because it has excessive harmonic frequencies causing high power losses in product such as computers and medical equipment which are not resistant to the distortion of the signal. An inverter with modified sine wave output usually have a harmonic distortion around 40 percent. However, for the household standard basic appliances, the operation of modified sine wave can be outstanding with enough low harmonic that not cause problem although the efficiency or power will be diminish.

2.3.3 Pure Sine Wave

Pure sine wave is the most pre-eminent type of inverter as the waveform has very less harmonic frequencies and probably the same or better than the power provided from the grid sourced by supplier. The total harmonic distortion of pure sine-wave is just around 3 percent and nearly identical to sine wave. Every most of appliances operates smoothly with the pure sine wave power which has much more advanced efficiency that previous ones. The circuit of the inverter is very complex to design and actualize thus, the difficulty to effectuate the progress of circuits causing this type of inverter is very expensive.

2.4 Literature Study

There are many studies was conducted in order to provide better waveform of inverter in power supply application. In [7], the study of the single phase 50Hz inverter simulation was conducted in detail about small-voltage AC or DC supply source as demanded to powering small electronic devices. In the study, DC source was provided by solar panel that will soon converted into AC using inverter. The circuit of inverter comprised five power MOSFET switches, four switches connected in H-bridge configuration and one switch for generating sampling frequency.

The switches in H-bridge configuration generate sinusoidal AC output by the formation of the positive and negative half cycle produced from four switching devices which operated in 50Hz frequency. In order to generate sampling frequency, switch S5; operates in 5-20 kHz range, was connected in series to one leg of the bridge (S1 and S4) and in series to the other leg (S2 and S3) as shown in Figure 2.3. The output shape of the sinusoidal can be achieve in better shape if the larger sampling frequency is used. In addition, to remove high switching rise and fall time of the large sampling frequency, the low-pass filter was used. The different load applied in the circuit causing the sine pulses gets noisy and distorted. However, these problem can be adjusted by tuning the configurations of the filter and thus refine the high frequency transition and produces sine wave.

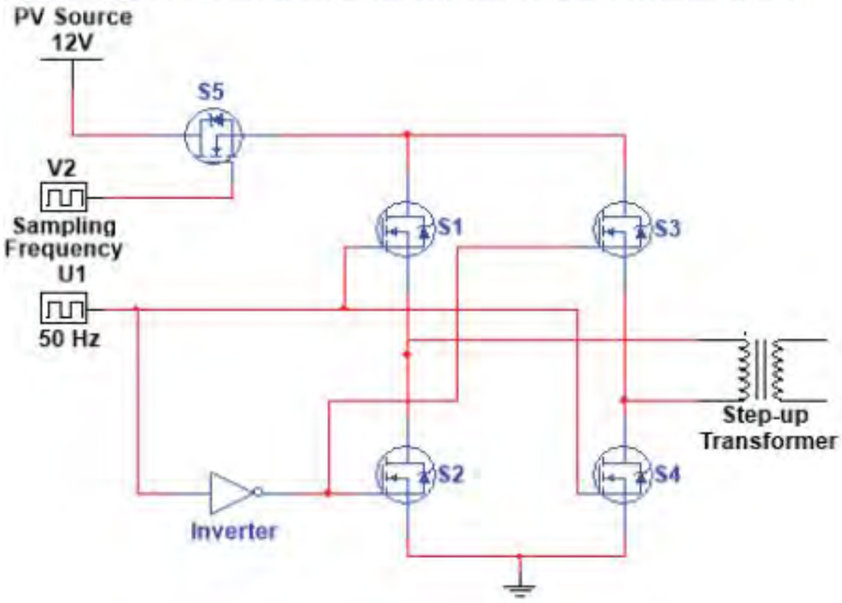


Figure 2.3: A single-phase inverter using five power switches

On the other hand, study conducted by Zeeshan Shahid et al [8] proposed low power timer-based inverter with pure sinusoidal output of 50Hz frequency using a 555 Timer in duty cycle-based configuration. The DC source which suggested to be received by renewable energy generator; such as solar panel, converted into AC supply using two BJT transistor (NPN and PNP).Integrated circuit (IC), LM555 timer is configured in astable multi-vibrator mode by connecting two resistors and a capacitor to performed as time constant (τ) to generates pulses for the switching device providing 50 Hz 220V of square wave AC cycle output. However, this square wave contains high harmonic level.

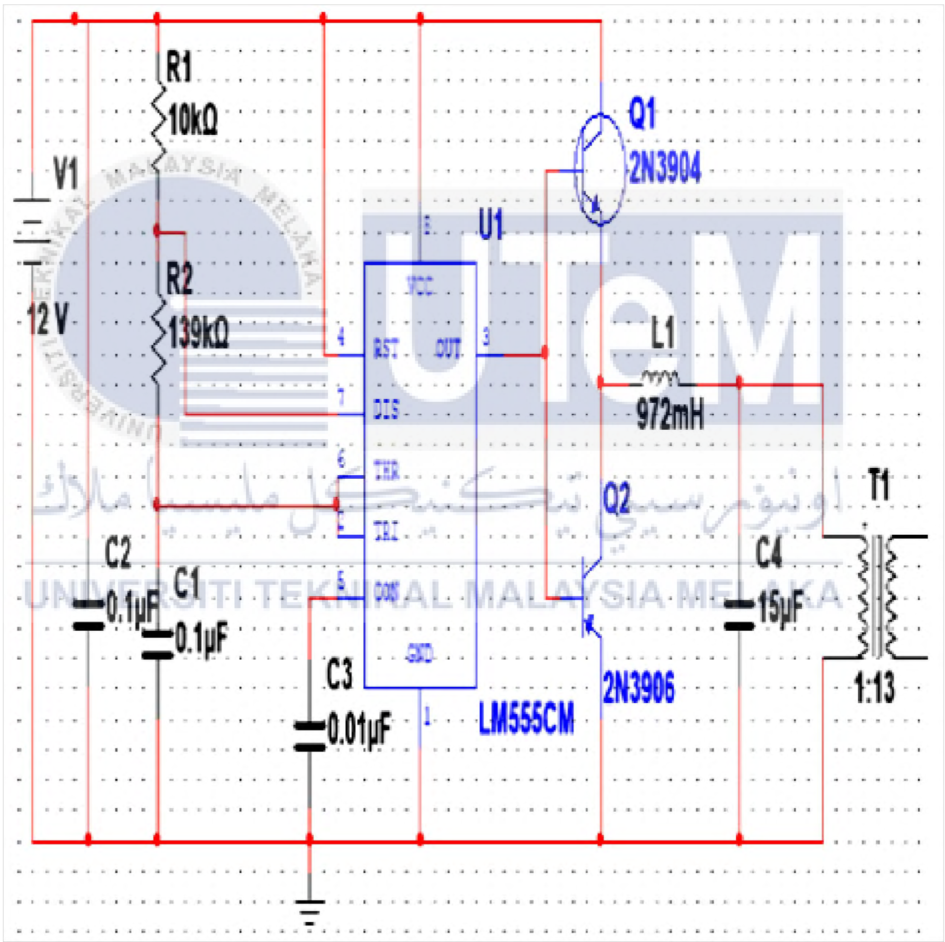
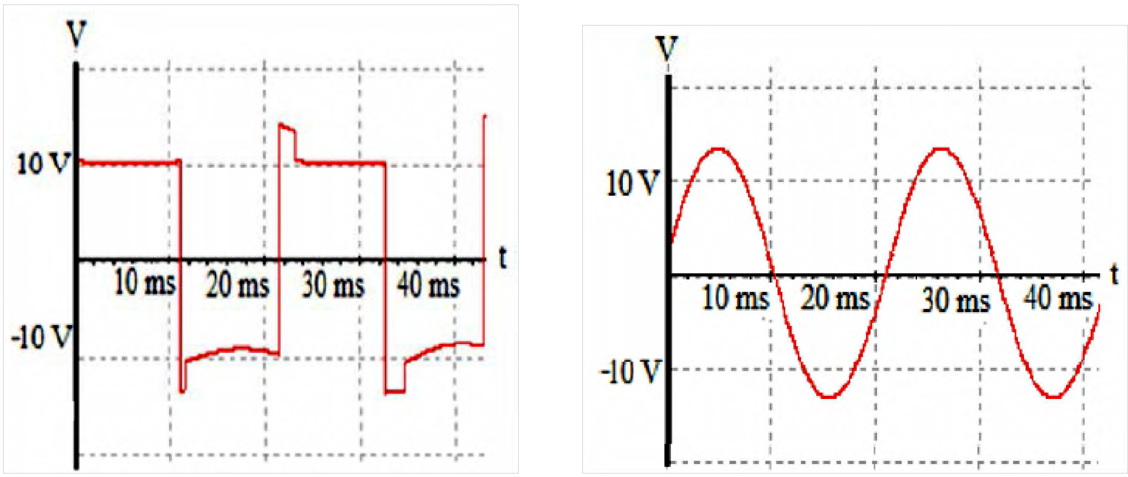


Figure 2.4: Time-based inverter circuit

Under this circumstance, the 50Hz frequency harmonic was reduced and square wave form was altered via the additional of pass filter configuration in the circuit to produce proper shape of 220V AC sinusoidal-like output waveform with lower harmonic level.



(a) (b)

Figure 2.5: Timer-based inverter wave form; a) Output waveform at transistor terminals, b) Output waveform after low pass filter

Alternatively, based on [9], the micro-controller pure sine wave inverter for house back-up was developed using PWM switching scheme in full H-bridge configuration regulated by generating unipolar modulating signal from a PIC. [9] aims to develop low-priced, flexible and productive inverter with pure sine-wave output. Inexpensive micro-controller (PIC16F877A) with built in PWM modules was used to drive two MOSFET drivers and generating four control signals. Then, the signals from the drivers were used to drive four N-Channel MOSFET switches arranged in H-bridge configuration via IR2110 MOSFET driver integrated circuit.

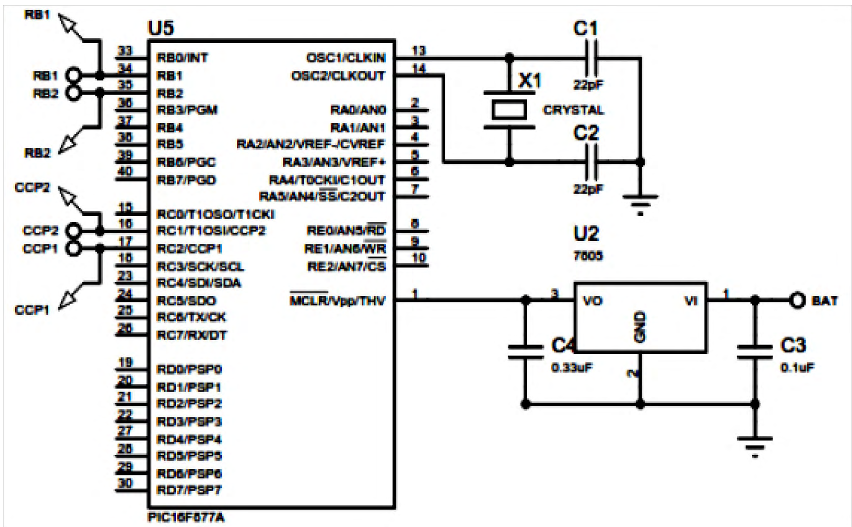


Figure 2.6: Signal generator from PIC

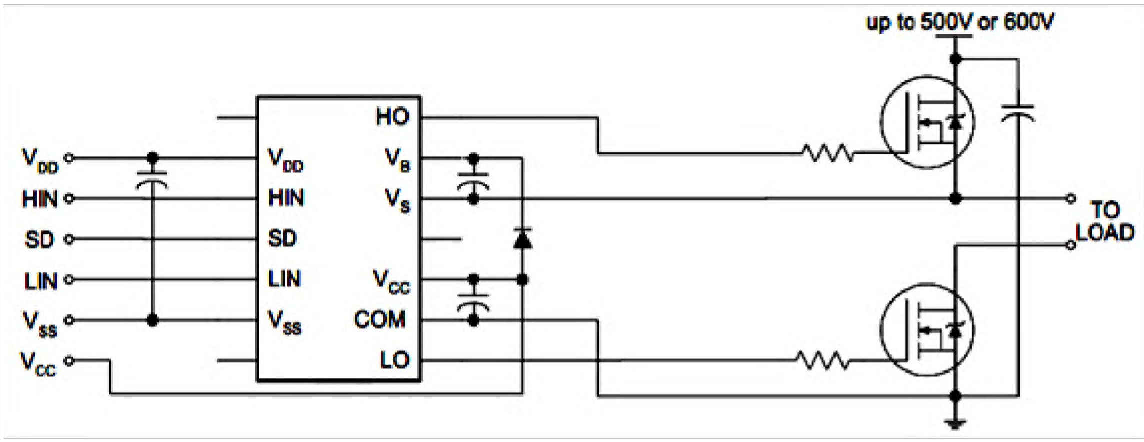
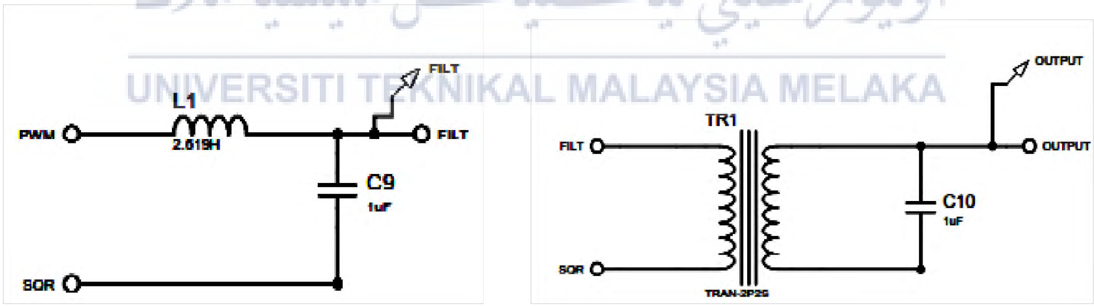


Figure 2.7:IR2110 MOSFET Connection

As a matter of fact, operation of the IR2110 device was used for level conversion between PWM and square signals, and voltage required to forward bias the high side of N-Channel MOSFETs. 305 micro seconds time delay was introduced to prevent two legs of H-bridge configuration form switch ON simultaneously. Above all, transformer was used to step up the AC voltage output and similar to the past studies stated before, the low pass filter is used in order to reduce high harmonic level and filter out the excess noise above the critical frequency.



(a) (b)

Figure 2.8: Filter and boost configuration; (a) Passive Low Pass Filter design, (b)Step-up Transformer

Another study was conducted by V. D. Broeck et al. in [10], experimenting on the inverter about what happens when using unipolar PWM on voltage and current. Current ripple and voltage ripple peak and RMS values was evaluated by time domain and frequency domain methods. The higher harmonic level of the design resulting a larger size of filter is required to reducing the harmonic, thus, increasing the cost of outcome product.

Obviously, most of the inverter used pass filter to reduce the harmonic distortion in AC output waveform. Studies in [11] and [12] which both dealing in the analysis Sinusoidal Pulse Width Modulation comes up of various parameter used of filter design in development of inverter with different configuration. Those elements in filter design modifies the designed values of the element in circuit. Large value of capacitor and low value of inductor will eliminate more distortion. However, the efficiency of the filter components will maximize the cost of the design. Therefore, to minimizing it, the way of the circuit design must be considered in the way to overcome the large parameter of filter design used in the circuit.

To summarize the overall progressed study, there are many different configuration of the inverter design can be developed and refurbished to provide better efficiency in inexpensively. The signal of the switching devices can be generated by different kind of method; using integrated circuit, micro-controller, and etc. The diversion of the design comes in many kinds of benefits and drawback, soon can assist users in selecting the appropriate inverter according to individual requirements, priorities, and needs.

CHAPTER 3

METHODOLOGY

3.0 Introduction

To design and innovate the project, this chapter describes the method and procedure applied to develop low power and portable inverter. An analysis of basic configuration and proposed circuit regarding to choose better designation of inverter circuit, is carried out by conducting simulation study using Simulink and PSpice. Besides, the 555 timer equations used to obtained certain parameters applied for the simulation of both design are described. Next, the hardware develop by using PCB layout designed in Proteus Software .

3.1 Project Flowchart, Gantt chart and Key Milestone

Figure 3.1 shows the flowchart of the project. For project planning, the problem statement and study of previous designs are identified. In order to understand the conceptual design, the simulation of inverter topology is done by using Simulink. Next, two designs are suggested and will be analysed by using Pspice software. For hardware development, a design with most optimum output will be selected and experimental result obtained will be analysed.

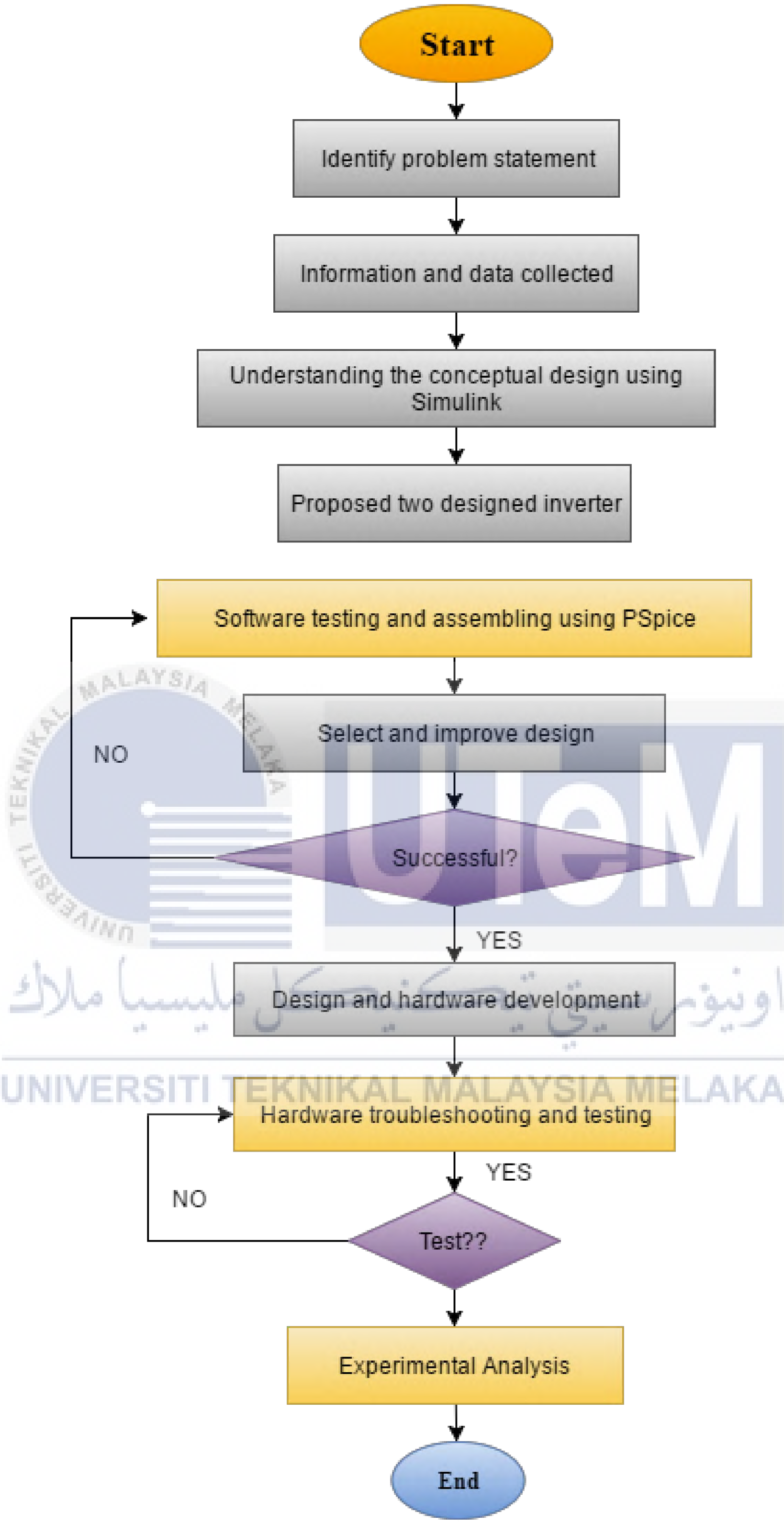


Figure 3.1: Project flowchart

3.1.1 Milestone

Below are the milestone for this project:

Milestone 1- Research on the development and previous study of inverter
Milestone 2- Study of inverter theory and propose two designs.
Milestone 3- Analysis of theory and proposed designs using Simulink/PSpice
Milestone 4- Select an optimum design and construct hardware
Milestone 5- Preparation of report and slide for presentation

3.1.2 Gantt Chart

The Gantt chart in Table 3.1 shows the monthly tasks being held starting in September 2015, and will be end in May 2016 for planning and developing the hardware.

Table 3.1 : Gantt Chart

Milestone	Year	2015				2016				
	Task	9	10	11	12	1	2	3	4	5
1	Research on the development and previous study of inverter	■	■	■						
2	Study and understanding of inverter theory using Simulink and propose two designs.			■	■					
3	Analysis of inverter designs using PSpice.					■	■	■		
4	Select an optimum design and construct hardware.						■	■	■	
5	Preparation of report and slide for presentation	■	■	■	■	■	■	■	■	■

3.2 Pulse Width Modulation (PWM) Technique

In the development of DC to AC conversion, PWM is broadly applied as a means of powering alternating current (AC) devices with available source of direct current (DC) in most of electronic power converters and motors. The distinction of the duty cycle in PWM signal is modulated and appears to the load as an AC signal with the average voltage of the waveform corresponds to a pure sine wave, providing a DC voltage across the load in peculiar pattern. The PWM can be formed through simple analog components, a digital micro-controller, or specific PWM integrated circuit. PWM technique provides a way to decrease the Total Harmonic Distortion (THD) of load current, and also in reducing acoustic noise, radio frequency interference, torque/speed ripple effects, etc[13]. The requirement of the THD can be done more easily by filtering the output of the PWM inverter.

To power the switches, this PWM of sinusoidal output involved a reference/control signal (sinusoidal) and a carrier signal (triangular wave) which are then produce switching scheme by scrutinize the variant of both signals as shown in Figure 3.2. There are two basic PWM techniques, which are commonly used in switching; single pulse width modulation and multiple pulse width modulation.

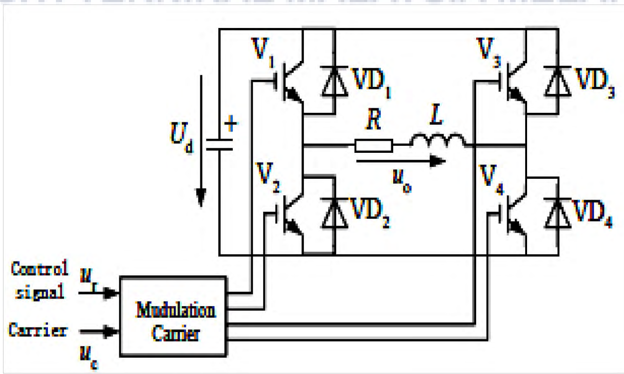


Figure 3.2: Full bridge converter with PWM sampling

3.2.1 Single Pulse Width Modulation

There is only one output pulse per half cycle in this modulation which the output is adjusted by regulating the width of the pulse. This is the simplest way of producing the PWM signal. Single or 2 level PWM generate the gate signals by comparing the rectangular waveform with triangular reference as in Figure 3.3.

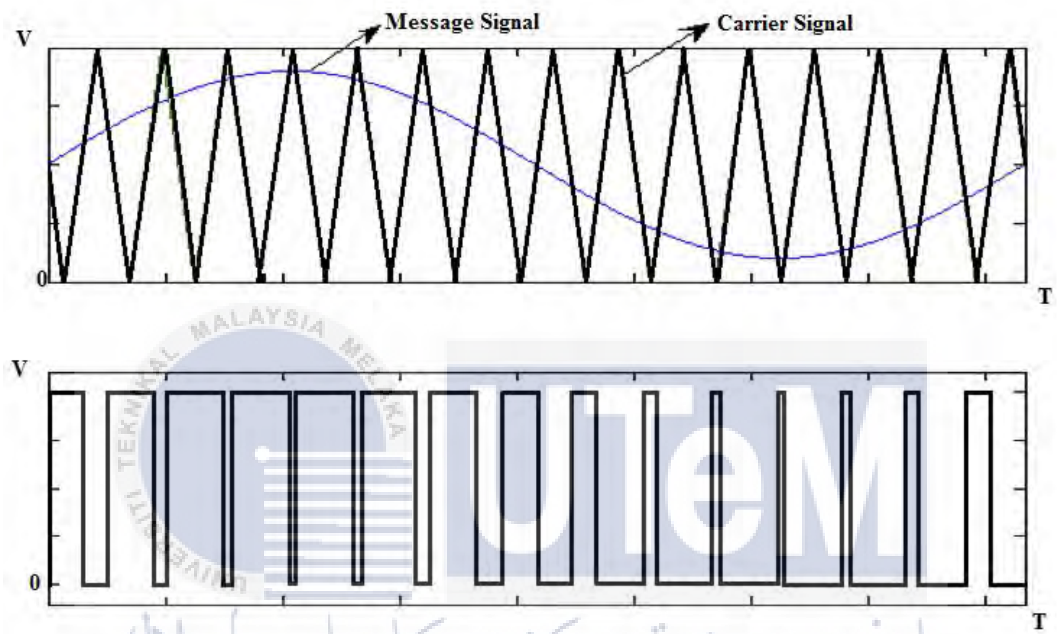


Figure 3.3: Message signal and carrier signal of Single PWM

The rms output voltage of AC can be calculated using equation (3.1) below. This shows that the pulse width t_{on} can be adjusted from 0 to T/2 secs and the rms output voltage V_o from 0 to V_s by varying the control signal amplitude V_r form 0 to V_c.

$$V_o = V_s\sqrt{\frac{2t_{on}}{T}} = V_s\sqrt{2\delta} \tag{3.1}$$

Where $\quad \text{dutycycle} = \delta = \frac{t_{on}}{T}$ (3.2)

And $T = \frac{1}{f}$ (3.3)

Modulation Index, $(MI) = \frac{V_r}{V_c}$ (3.4)

Where V_r = Reference signal voltage
V_c=carrier signal voltage

3.2.2 Multiple Pulse Width Modulation

Multiple pulse width modulation consist of multiple number of output pulse per half cycle and all pulses are of equal width. The method of gating signals is the same as single PWM which by comparing the reference signal with triangular carrier wave. The switching instances can be decisive by the intersection of these two wave. The number of pulses per half cycle, p can be ascertain by using formula (3.6). To varying the output voltage, the pulse width is varied by adjusting the amplitude of the control signal [14]. The pulse from 0 to π /p and the output voltage from 0 to Vs van be vary by adjusting the modulation index (MI) from 0 to 1. The output voltage generates by fundamental and carrier signal is shown in Figure 3.4.

The rms AC output voltage

$$V_o = V_s\sqrt{\frac{p\delta}{\pi}} \tag{3.5}$$

and

$$p = \frac{f_c}{f_o} \tag{3.6}$$

where p = number of pulses per half cycle
f_c = carrier frequency
f_o = output frequency

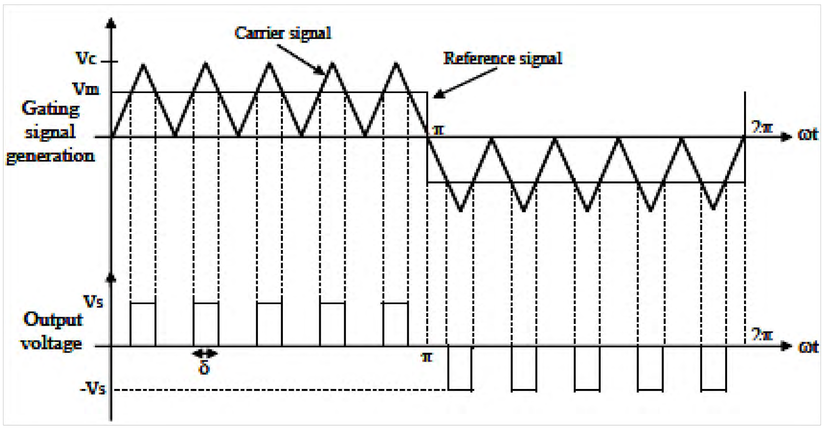


Figure 3.4: Three level PWM

Compared to 2-level PWM, this multilevel PWM provides more likely close to the desired sine wave with lower harmonics. In addition, this application of PWM reduced the filter requirement thus the sizing of the inverter can be reduced. However, PWM is very strenuous to implement as the circuit switching is more complex and has a higher switching loss as the result of the frequent switching.

3.3 Elements in Inverter

The requirements of the components used for the inverter may be vary depending on the needs of the inverter design. However, the elements commonly used in designing an inverter can be an indication to provides a better understanding of the design. The inverter elements discussed in this sub-chapter consist of switching devices, filter, and transformer.

3.3.1 Switching Devices

Different type of power switching devices in inverter has different potential of operation with its own advantages and disadvantages in control application. There are four basic type of switching device groups which are the most important devices in inverter switching. These switching device will be controlled by PWM signal generator produced using component such as micro-controller. The group of switching devices include:

a) Bipolar junction transistor (BJT)

BJT was known as the first device used in power switching. The device consist of three-layer "sandwich" of doped semiconductor materials named as base, emitter, and collector that can be divided into two type which are PNP and NPN. PNP transistor controls current flows from collector to emitter while NPN transistor will controls current flows from emitter to collector[15]. The symbol of PNP and NPN transistor can be depicted as in Figure 3.5 below.

(a) (b)

Figure 3.5: BJT schematic symbol ;(a) PNP transistor, (b)NPN transistor

b) Metal oxide semiconductor field effect transistor (MOSFET)

The MOSFET is a voltage controlled device that needs very small input current. Like BJT, MOSFET also comes in two different configuration;n-channel and p-channel with three different terminal;source, gate, and drain as shown in Figure 3.6. The device is usually used for switching of electronic signal as the device has high switching speed capability. The main function of MOSFET is to control the voltage and current flow between the source and drain.

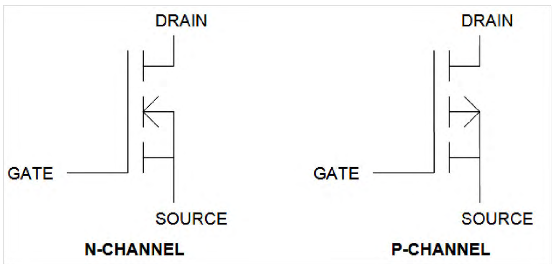


Figure 3.6: MOSFET schematic symbol of n-channel and p-channel

c) Insulated gate bipolar transistor (IGBT)

IGBT, as shown in Figure 3.7, is a hybrid device of the best features of MOSFET and BJT that consisted of three-terminal power semiconductor device and usually used in solid state switching device. The result of this hybrid combination produce the output switching and conduction characteristics of BJT with voltage-controlled as good as MOSFET.

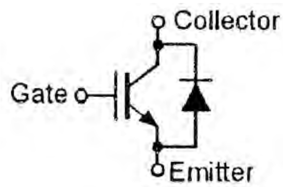


Figure 3.7: Common circuit symbol of IGBT

Devices that commonly applied in switching circuit of commercial inverter is IGBT and MOSFET. IGBT has a low duty cycle compared to MOSFET with high-current handling capability and can produced more than 5kW output power. However, the disadvantages of IGBT are it has slow turn-off characteristics and no body drain diode.

The ideal devices for inverter usually would followed a few requirement. Low internal losses of ideal devices allowed higher efficiency in operation and switching frequency in order to generate a variable frequency sine wave with low harmonics. The surge rating of the device must be high in order to provide protection from over current and over voltage and also, enhanced the reliability of inverter [16].

3.3.2 Filter

Mix of frequencies contained in inverter sometimes are recommendable to be range or filter to improve the non-sinusoidal voltage waveform in the circuit and the capability of its operation running some electronic devices. The filtration of these frequencies can be done by using a filter. In principle, filter do not add new frequencies or change the frequency of a signal, otherwise it change either the relative frequency components, phase characteristics respect to frequency, or both[17]. In addition, the terminal of the output of the bridge in inverter circuit usually filtered by low pass filter to eliminate switching frequency and other multiples of the switching frequency.

Low pass filter only allows frequencies below the cut off-frequency to pass and can be classified in to active and passive. Active filters usually can be built using op-amps while passive filters, which are low in cost and non-complexity design, consisting solely of resistors, inductors, and capacitors. The active filter may be expensive than passive filter, but the filters avoid the impedance loading issues in passive filters.

(a) (b)

Figure 3.8: Low pass filter, (a) RC Filter, (b) RL Filter

There are several forms of passive elements that can be use to design a low pass filter such as combination of resistor and capacitor, or resistor and inductor as can be seen in Figure 3.8.The cut-off frequency of both design can be set by using equation (3.7) and (3.8).

For RC Filter,

$$f_o = \frac{1}{2\pi RC} \tag{3.7}$$

For RL filter

$$f_o = \frac{R}{2\pi L} \tag{3.8}$$

Where,
Fo = cut-off frequency
R = value of resistor
C = value of capacitor
L = value of inductor

3.3.3 Transformer

The main function of transformer used in inverter is to step-up and step-down the voltage through electromagnetic induction. To produce electromagnetic coupling, the transformer was configured with two winding of wire called primary and secondary winding that wound around a common core which often in laminated iron material. The secondary winding will receives the electrical input energy before its is transferred to the output coil at secondary winding.

3.4 Total Harmonic Distortion (THD)

The quality of the AC output voltage and output current can be expressed in term of total harmonic distortion which are determine by measuring of closeness in shape between a waveform and its fundamental components [18]. For inverter, THD can be defined as the ratio of all odd non-fundamental frequency to the value of fundamental calculated in RMS. Which indicates as in equations below:

$$THDv = \sqrt{\frac{\sum_{n=2}^{\infty} (V_{n,\ rms})^2}{V_{1,\ rms}}} = \frac{\sqrt{V^2{}_{rms} - V^2{}_{1,\ rms}}}{V^2{}_{1,\ rms}} \qquad (3.9)$$

$$THDi = \sqrt{\frac{\sum_{n=2}^{\infty} (I_{n,\ rms})^2}{I_{1,\ rms}}} = \frac{\sqrt{I^2{}_{rms} - I^2{}_{1,\ rms}}}{I^2{}_{1,\ rms}} \qquad (3.10)$$

Usually, to determined the THD in PSpice software, FFT(Fast Fourier Transform) analysis was used as the the equation given in (3.9) and (3.10) are based on Fourier series. The odd harmonic value will be used in order to find the percentage of the THD in the output desired.

3.5 Simulation Study using MATLAB/Simulink

This part focuses on the simulation based on two basic configuration of inverter which are half bridge and full bridge. Before choosing the configuration of the inverter along with circuit design, these both configuration are simulated with load of a resistor R=10 Ω and an inductor of L=25mH. The current waveform depends on the load component. The inductor used as its filtering properties provides a more sinusoidal quality of current[19].

3.5.1 Inverter Configuration

The design of inverter circuit can be divided into two configuration which are half bridge and full bridge configuration. In the application of a single phase power supply, the half bridge configuration consists of two power switches while full bridge is built by four power switches. These switches was used to allow current moves in both direction in order to form a positive and negative output voltage. Before choosing the best configuration of the inverter along with circuit design, these both configuration are analysed.

A. Half-bridge

The half-bridge configuration is a single drive technology which commonly used in power electronics switch circuit topology. This configuration known as "inverter leg" usually used for three phase and higher order inverters. The configuration of the circuit is shown as Figure 3.9 below along with the output voltage formed.

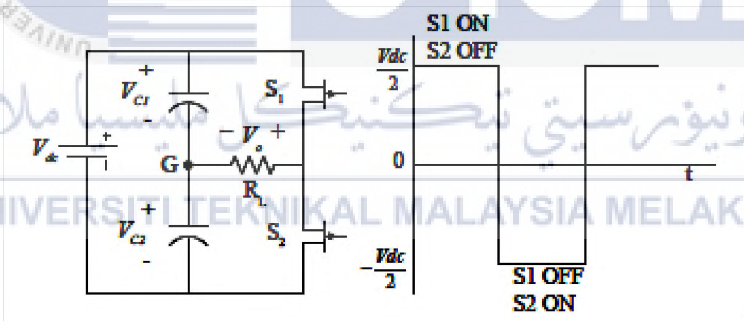


Figure 3.9: Single phase half bridge with output voltage.

Literally, the switches of the half-bridge configuration is supply with DC source voltage that will be divided using two capacitors with the same values to providing the half of the DC source voltage values for each of switches. However, to simplified arrangement of the circuit in Simulink as shown in Figure 3.10 but still assembling the same idea of the circuit, two identical values of DC voltage sources behave as the two divided capacitors. Pulse generator used to produce a simplest switching scheme for both switches. When switch D1 is ON, D2 is OFF and vise versa.

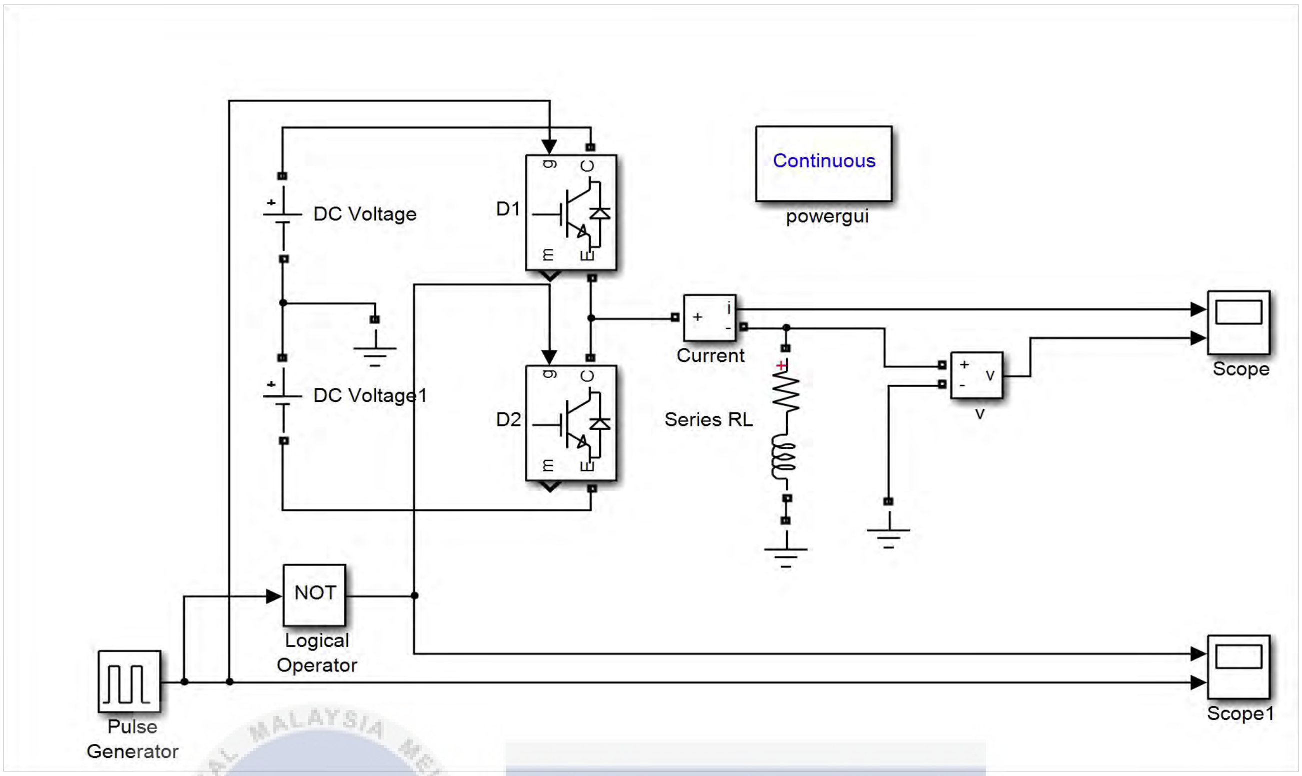
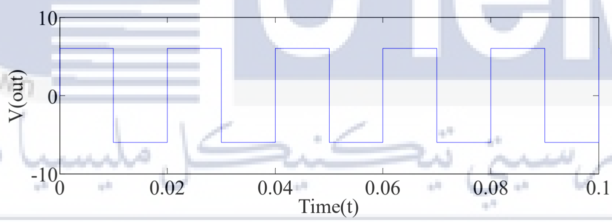
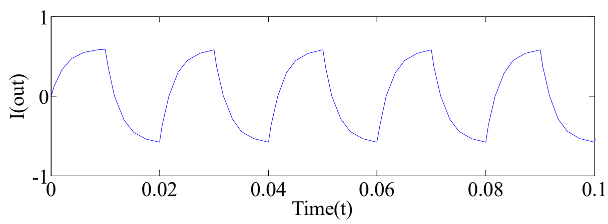


Figure 3.10: Half-bridge configuration; R=10Ω L=25mH



(a)



(b)

Figure 3.11: Output waveform of Half-bridge configuration using pulse generator; a) Square wave output voltage, b) Current output

Figure 3.11 presents the output waveform of the half bridge configuration. Square wave generated as illustrated in Figure 3.11 (a) as the result of using a pulse generator, while Figure 3.11(b) shows the sinusoidal-look of current output wave form produced using an inductor.

B. Full-Bridge

The full-bridge or as known as H-bridge configuration consists of four switches which is constructed from two half-bridge leg as shown Figure 3.12. This configuration may be accessible as integrated circuits or applied in component application. The operation by turning ON the upper switch at one of the half bridge circuit and lower switch of another leg while the other two switches are OFF produced a half-cycle output voltage. Indeed, the output voltage at the load can be obtain by using four possible switching positions as shown in Table 3.2. Note that shoot-through switching are excluded.

Table 3.2: Full-bridge switching state

HIGH SIDE		**LOW SIDE**		
Left	Right	Left	Right	**Output Voltage**
ON	OFF	OFF	ON	+VE
OFF	ON	ON	OFF	-VE
ON	ON	OFF	OFF	0
OFF	OFF	ON	ON	0

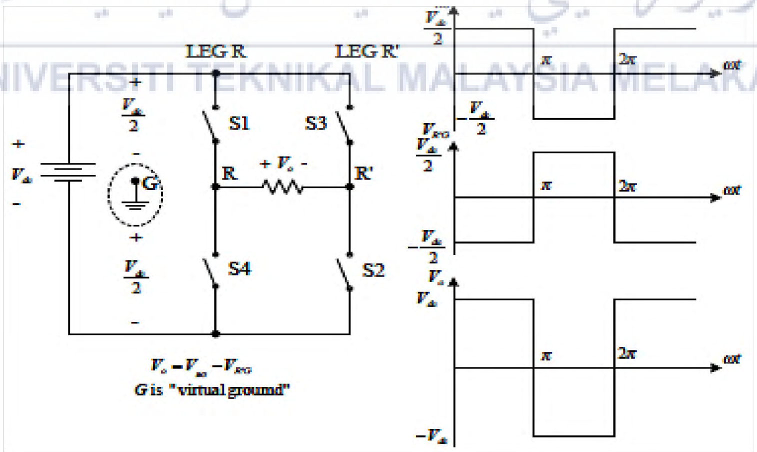


Figure 3.12: Single phase full bridge configuration with switching time

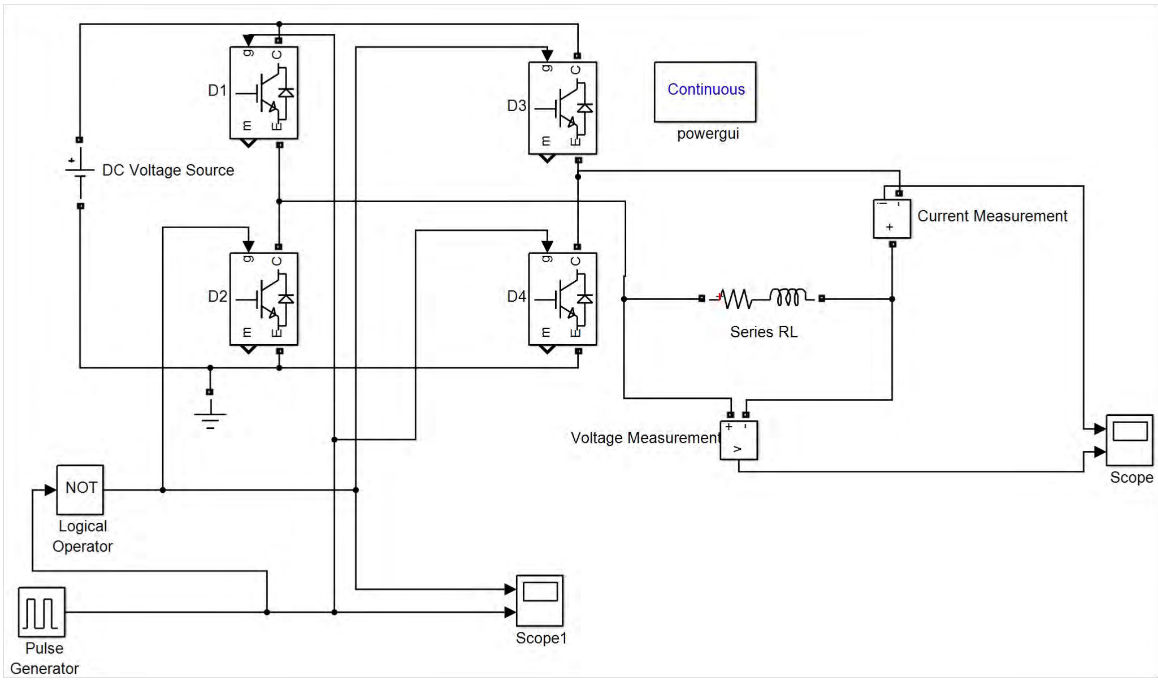
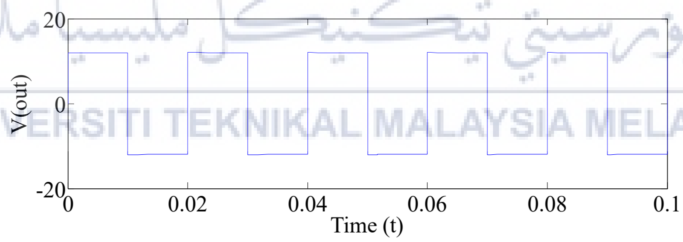
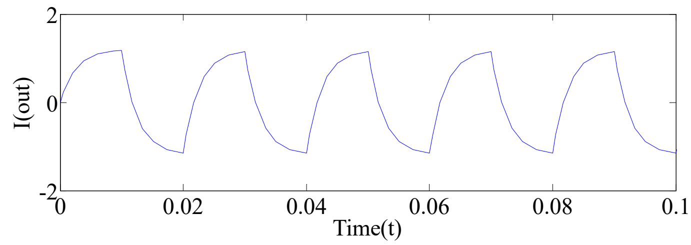


Figure 3.13: Full-bridge configuration; R=10 Ω L=25mH

Figure 3.13 depicts the configuration of full bridge inverter which consisted of two leg from half-bridge configuration. The wave form of the output voltage and current produced from the configuration are as shown in Figure 3.14 below.



(a)



(b)

Figure 3.14: Output waveform of Full-bridge configuration using pulse generator;a) Square wave output voltage, b) Current output

Overall, the square wave output voltage waveform in both half-bridge and full-bridge configuration appeared as the result of periodic switching across RL series branch load. The waveform of the current was produced in the form that depends on the type of load. In this case, the load consists of a resistor and an inductance. Therefore, the wave form produced is more of a sinusoidal quality as the result of the filtering property of the inductance.

3.6 Circuit Designs

There are two designed inverter circuit was suggested to produced an AC output voltage. The first model is based on 555 Timer integrated circuit which operates in astable multi-vibrator to produce triangular signal and sample frequency. The second model is also based on 555 Timer but with a different components and configuration of the circuit. Both of model suggested was simulated by using PSpice software in order to analyse the voltage, current and THD (Total Harmonic Distortion) before selecting optimum design.

3.6.1 Model 1

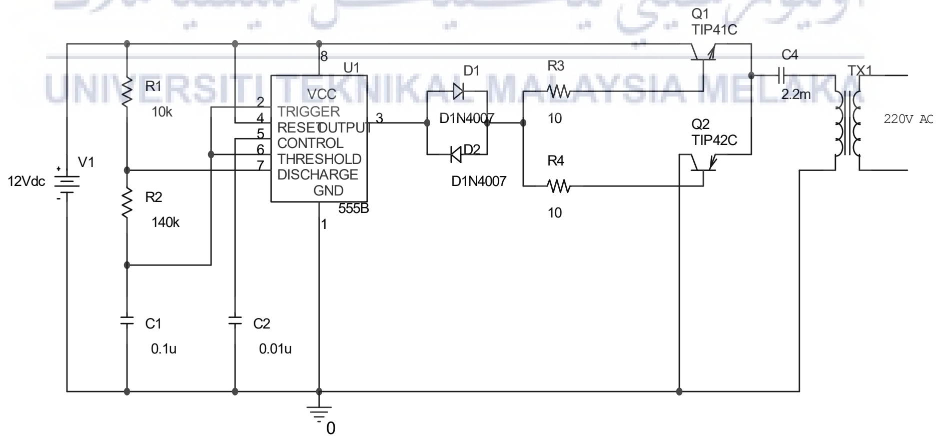


Figure 3.15: Design of inverter using 555 Timer integrated circuit

Figure 3.15 presents the first designed model of inverter. The model consist of a 555 timer that configured in astable mode producing 50Hz frequency of square wave signal. The current will passing through diode D2 and across R2 to the base Q1 during logic high level of the output and thus, the transistor Q1 will switches ON.

On the other hand, during the output is at logic low level, the current flows in D2 and R3 before passing through the base Q2, causing Q2 to switched ON. After filtered by a capacitor, the switching sequence produced positive and negative cycle output periodically at the primary transformer before it is step up to 220V AC.

3.6.2 Model 2

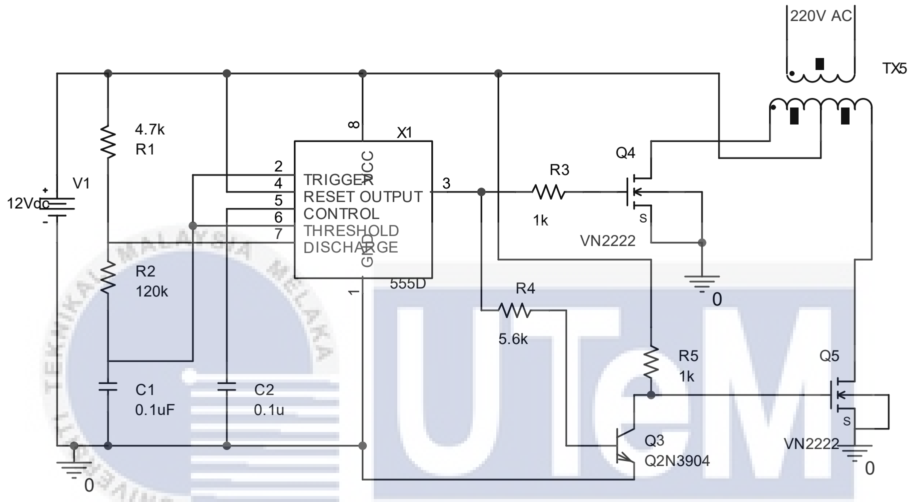


Figure 3.16: The 555 Timer inverter with different configuration and components

Figure above shows the design configuration of the inverter that also used 555timer as an oscillator but using power MOSFETs switches for power switching. As previous circuit, the 555 timer produced square wave frequency generator of 50Hz frequency in astable multi-vibrator. The current from the output of the timer flows in two different ways. First, it will flow across R3 and to the Q4 MOSFET, the second way will flow across R5 and direct to Q1-transistor to reverse signal different from the first ways. Next, the current will flow to gate of Q5 to driver the step-up transformer.

3.7 Simulation Implementation

The design of Model 1 and Model 2 inverter circuits are simulate using ORCAD PSpice software. This user friendly software is a vital circuit simulation environment for analysing the circuit design and commonly used by user before proceeding to hardware implementation. The simulation of proposed models discussed in sub-chapter 3.6 are conducted using 12V DC power supply and several fixed parameter as listed in Table 3.3. 12K Ohm of resistor is selected and placed at the output of the transformer as a load.

Table 3.3: Parameter used in simulation.

Parameter	Value
Frequency	50Hz
Duty cycle	50%

3.7.1 Simulation Approach

In order to follow the international voltage standard in Asia and The Pacific frequency which are 50Hz, 555 timer is configured in astable mode operation. The generated the carrier and sample signal for switching consisted of two resistor and a capacitor. The value of R_1, R_2, and C_1 are connected to the 555 Timer for both models and will be calculated to obtain the parameter listed in Table 4.0. According to 555Timer data sheet(refer APPENDIX A), the frequency of 555 timer oscillation configure in astable operation can be achieve using equation (3.11) and (3.12) below.

$$frequency = \frac{1}{T} = \frac{1.44}{(R_1 + 2R_2)C_1} \tag{3.11}$$

$$DutyCycle = \frac{(R_1 + R_2)}{(R_1 + 2R_2)} \tag{3.12}$$

As a result, the astable operation of frequency oscillation and duty cycle needed can be obtained by setting up the value of R_1 = 10K Ω , R_2 = 140K Ω and C_1 = 0.1uF which are calculated using the equations given.

3.8 Hardware Implementation

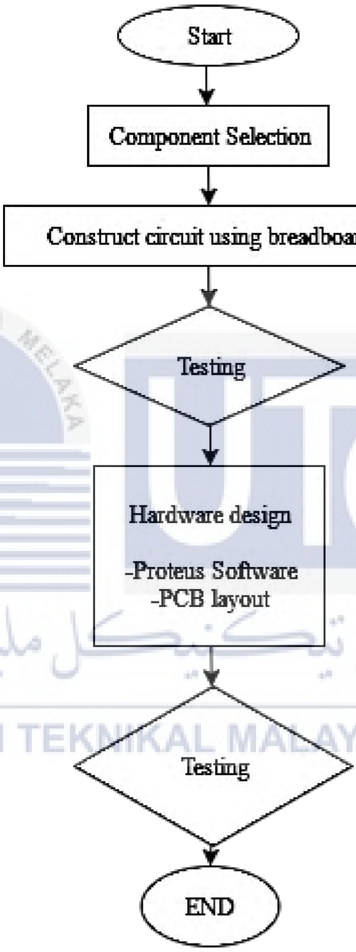


Figure 3.17: Flowchart of hardware implementation

The process of the hardware implementation is as shown in Figure 3.17. The first step of the hardware implementation is component selection for the design. After that, the design will be constructed using breadboard for testing purpose. As the design pass the testing, the circuit was designed again using Proteus to develop PCB layout for hardware prototype.

A power inverter is a circuit which is use to modified an input varying or non-varying DC voltage to AC of a specified voltage and frequency. For this project, Model 1 design was chosen and the power supply used is a lead acid rechargeable battery with rated voltage of 12V DC. The desired AC output is 220V with a frequency of 50Hz. The components required for better performance are selected and PCB layout was design using Proteus before prototype hardware constructed.

This design can be group into three different modules which are PWM signal generation module, transistor switches, filter and step up transformer as illustrated in the flow diagram below.

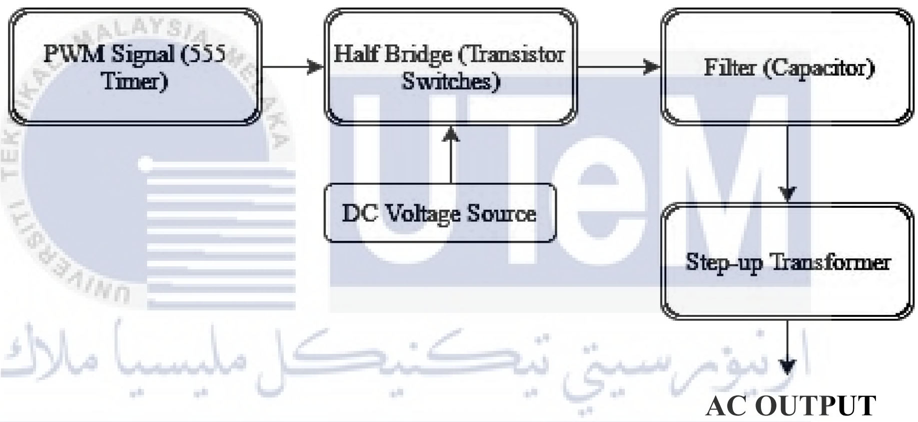


Figure 3.18: Inverter design flow diagram

3.8.1 Component Selection

The important aspect of the design is oscillator. The NE555P timer is used and configured in astable multi-vibrator mode to produce switching signal using two resistor and a capacitor. The value of R_1 and C_1 used are 10K Ohm and 0.1uF respectively. To fine tune the output signal, the value of R_2 = 140K Ω is replaced with variable resistor of 150KΩ.

To allow the maximum amount of current flows to the load, the high power transistor of NPN, TIP 41C which rated with 6A maximum collector current is use. The base current can be calculate by dividing the collector current with DC current gain Bias current calculated which is around 4A is more than the maximum base current of the transistor which is 2A (refer APPENDIX B). Thus, value of less than the maximum base current is preferred. From here, the bias current is assume to be 1A. As the design required for both PNP and NPN are the same, the PNP power transistor TIP42C is used.

$$R_b = \frac{V_{CC} - V_{BE(ON)}}{I_{bias}} \tag{3.13}$$

Where,
R_b = bias resistor
V_{cc} = Voltage source
$V_{BE(ON)}$ = Base-Emitter voltage when switched ON

The bias resistor of R_3 and R_4 are then given by using equation (3.13). For each transistor, the VBE(ON) is about 2V. Therefore, the value of R_3 and R_4 calculated are both 10Ohms. For biasing purposes, diodes 1N4007 are use as the needs of the forward voltage drop across the diodes should be equal to the forward voltage drops in the transistors. In addition, to filter the switching sequence and frequency harmonic that may produced from the switching circuit, an electrolyte capacitor is used. A transformer with rating of 240V/12V, 1A is used in reversed feeding to obtained the desired output of AC voltage.

3.8.2 Hardware Design

The hardware circuit is develop as described in the steps below:

I. All the components used in the development of designed circuit of low power inverter was arranged and constructed using breadboard as shown in Figure. Without transformer, the designed circuit then connected to the 12V DC power supply and oscilloscope for testing purpose with the load of 12KΩ resistor.

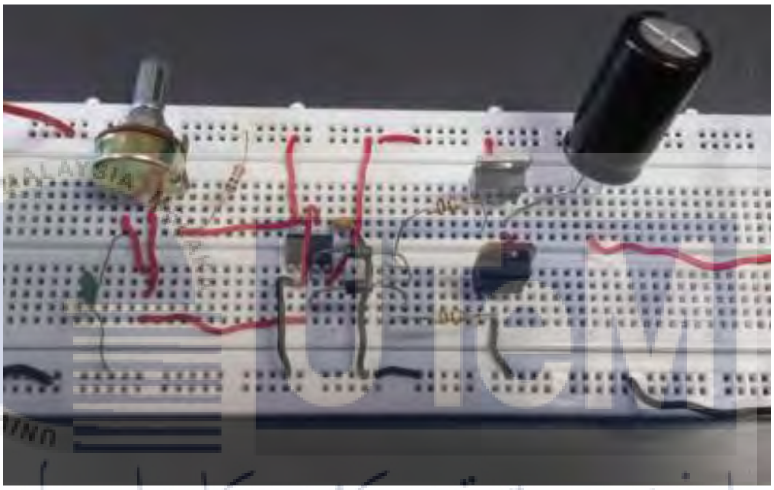


Figure 3.19: Testing circuit

II. After testing and troubleshooting, the schematic design of inverter constructed again using Proteus software in order to make a PCB layout as shown in Figure 3.20 and Figure 3.21.

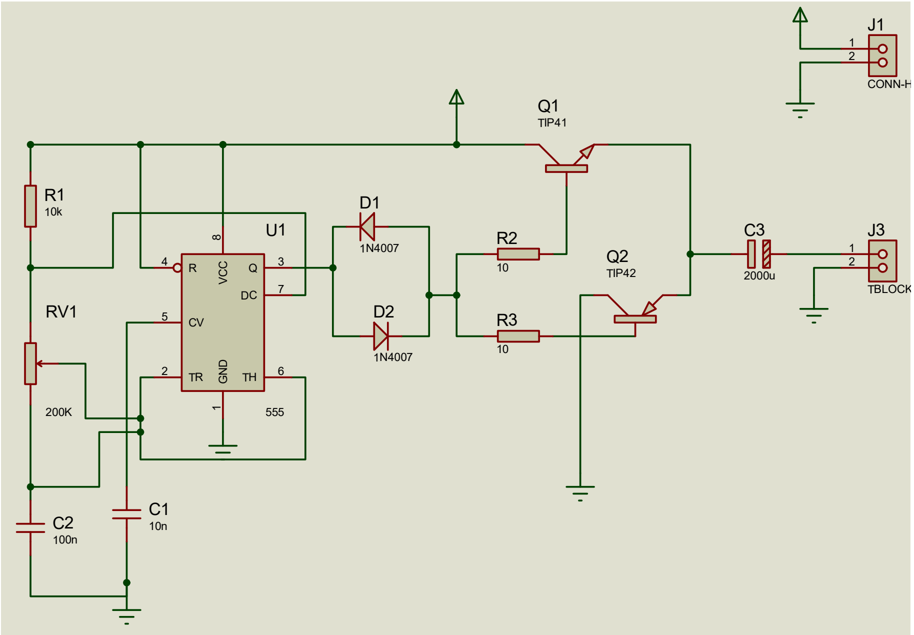


Figure 3.20: Schematic design of inverter using Proteus .

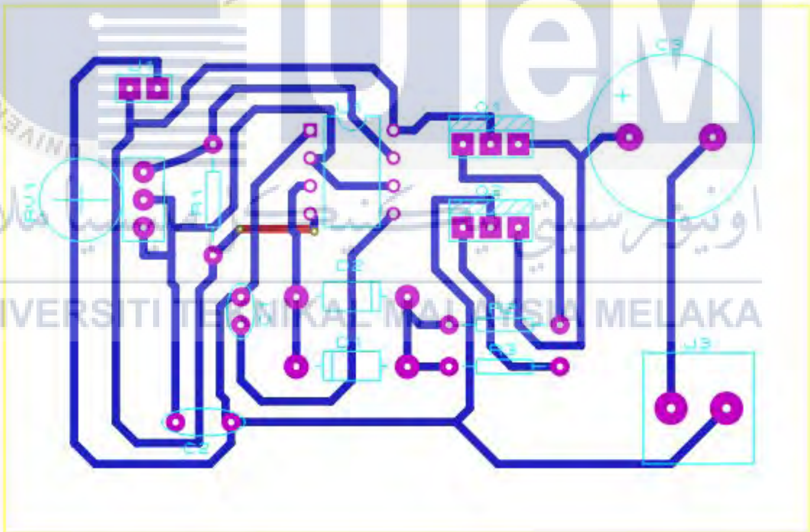


Figure 3.21: PC Board Layout design

III. The method use for PC Board development is based on home made procedure. The mirror designed circuit of PC Board layout are printed using OHP paper. The printed OHP paper then will be iron onto the board before etching and soldering are taken place. The complete prototype using PC board are shown in Figure 3.22.

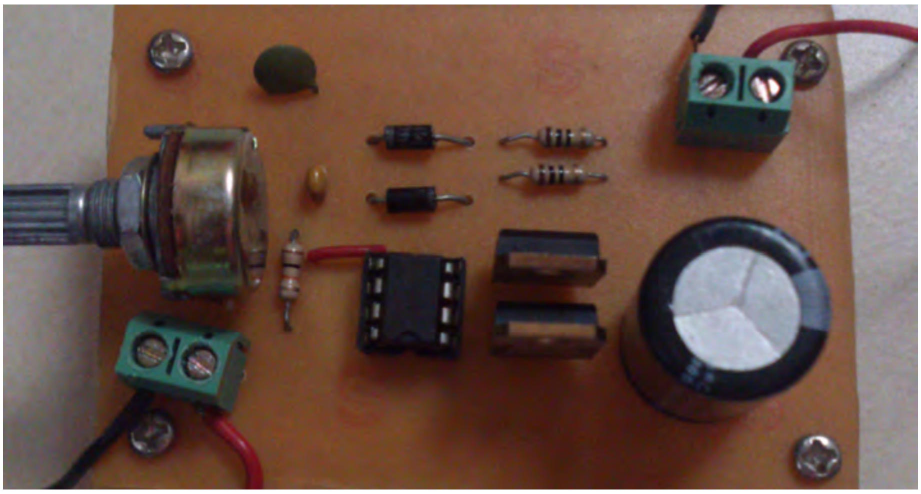


Figure 3.22: Hardware prototype (PCB)

CHAPTER 4

RESULT AND DISCUSSION

4.0 Introduction

This chapter presents the simulation results by using PSpice Software of Model 1 and Model 2 designs. A resistor of 12K Ohm was used as a load at the output of the secondary transformer. The analysis of voltage, current and Fast Fourier Transform analysis at the load of every designs are obtained from ORCAD PSpice simulation. Odd harmonic contained are listed and compared.

Besides, using the data of Fourier analysis simulation in the software, the percentage of THD for both voltage and current of every existed harmonic in every model has been recorded and analysed. After the differences of both designs are compared, based on several consideration, Model 1 is chosen for hardware development. The comparison of experimental results obtained from the hardware analysis and simulation of Model 1 are discussed and concluded in the last section of this chapter.

4.1 Simulation result using PSpice Software

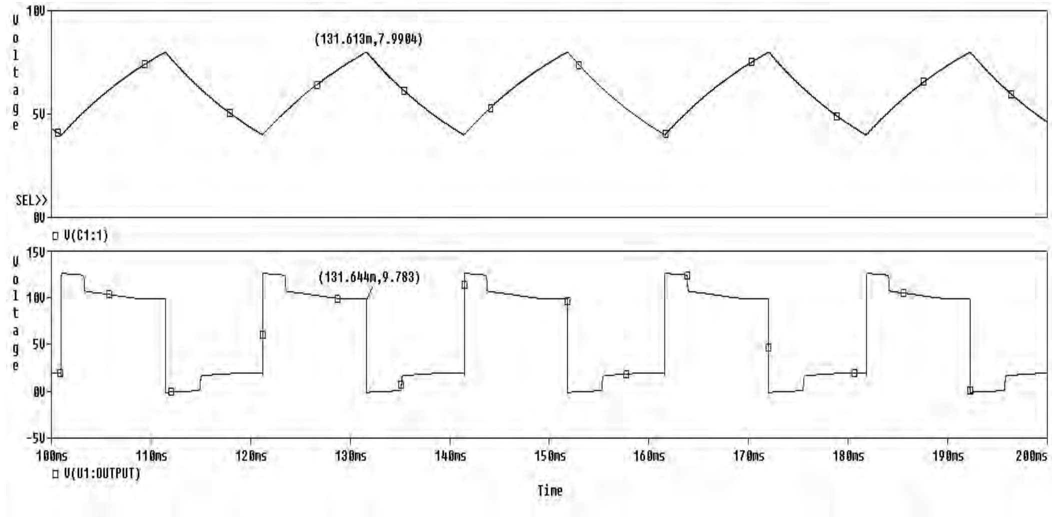


Figure 4.1: Switching Signal of 555 Timer Circuit

Figure 4.1 shows the switching signal of 555Timer used in both designs. The oscillation of the integrated circuit was generated with a 50Hz frequency of sample square wave of 9.78V and triangular carrier of 7.99V.

4.1.1 Model 1 Simulation

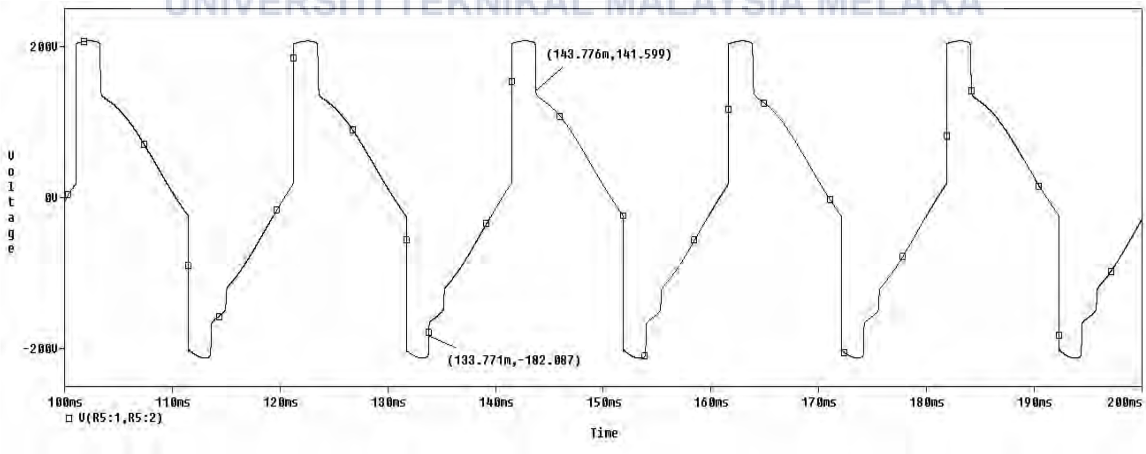


Figure 4.2: Voltage at the load.

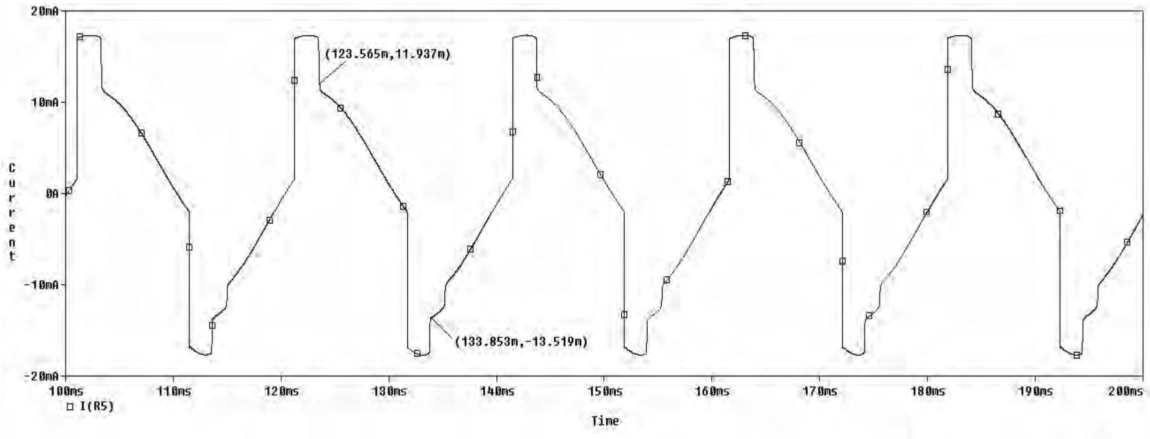


Figure 4.3: Current at the load

Figure 4.2 and Figure 4.3 show the load voltage and load current waveform obtained from simulation results. The waveform produced a square wave shape that nearly close to looks like sine wave shape. The voltage and current across the load obtained is 141.6V and 11.94mA respectively.

4.1.1.1 Performance Analysis

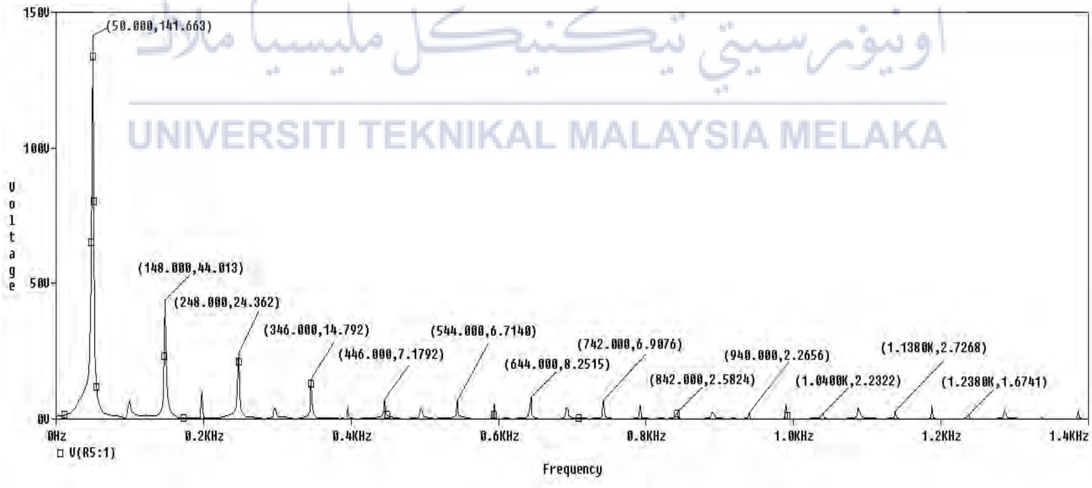


Figure 4.4: FFT Analysis of the voltage at the load.

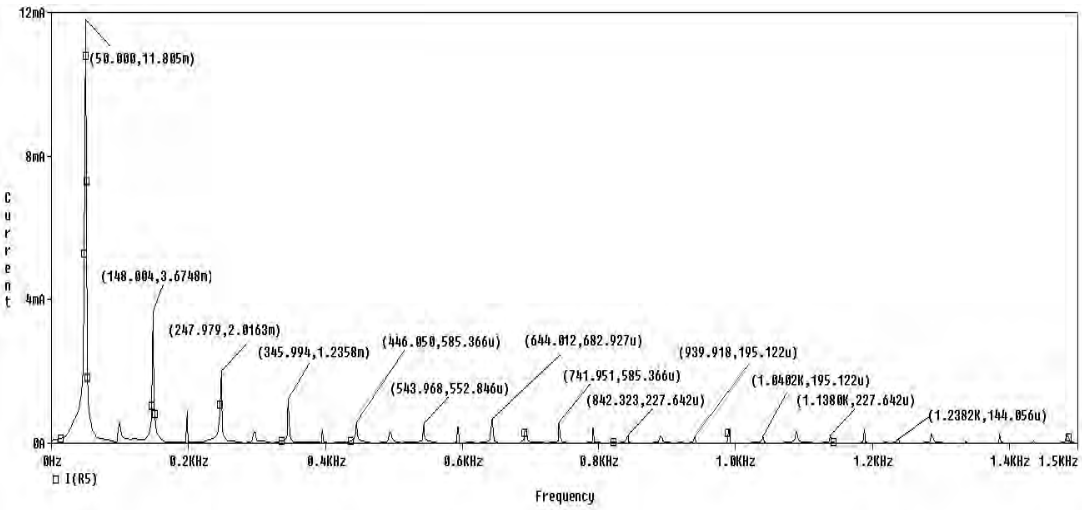


Figure 4.5: FFT Analysis of the current at the load.

Figure 4.4 and Figure 4.5 illustrate the voltage and current harmonics obtained from FFT analysis graph. The marking points indicate the odd harmonic values contained from the load. The value of voltage and current of these harmonics decrease as the frequency increase. From both figures, it can be seen that the odd harmonics contained are very small compared to odd harmonics. As the result of its low contribution, the even harmonics are been negligible for data record.

Table 4.1: Voltage and current harmonic in the load (Model 1)

Harmonic	Frequency (Hz)	Voltage (V)	Current (mA)
1st	50	141.66	11.81
3rd	148	44.01	3.67
5th	248	24.36	3.02
7th	346	14.79	1.24
9th	446	7.18	0.59
11th	544	6.71	0.55
13th	644	8.25	0.68
15th	742	6.91	0.59
17th	842	2.58	0.55
19th	940	2.27	0.68
21st	1040	2.23	0.59
23rd	1138	2.73	0.23
25th	1238	1.63	0.14

The odd harmonic value was recorded as in Table 4.1. Value of voltage and current obtained at first harmonic of fundamental frequency of 50Hz is 141.66V and 11.81mA respectively. Furthermore, it can be seen from the table that there are small non-uniform range of the frequency of the odd harmonic around the average which decreasing around 2Hz for every two odd harmonics. Using the Fourier analysis data in the output file of the simulation, THD of the load voltage obtained is 40.35 percent, while THD of the load current is slightly bigger than load voltage with value of 40.34 percent (refer APPENDIX C).

4.1.2 Model 2 Simulation

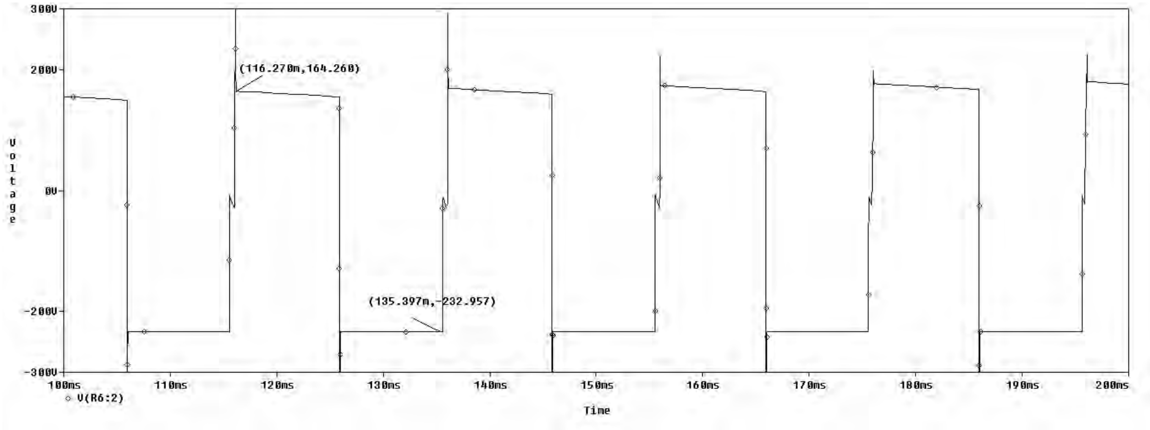


Figure 4.6: Voltage obtained at the load

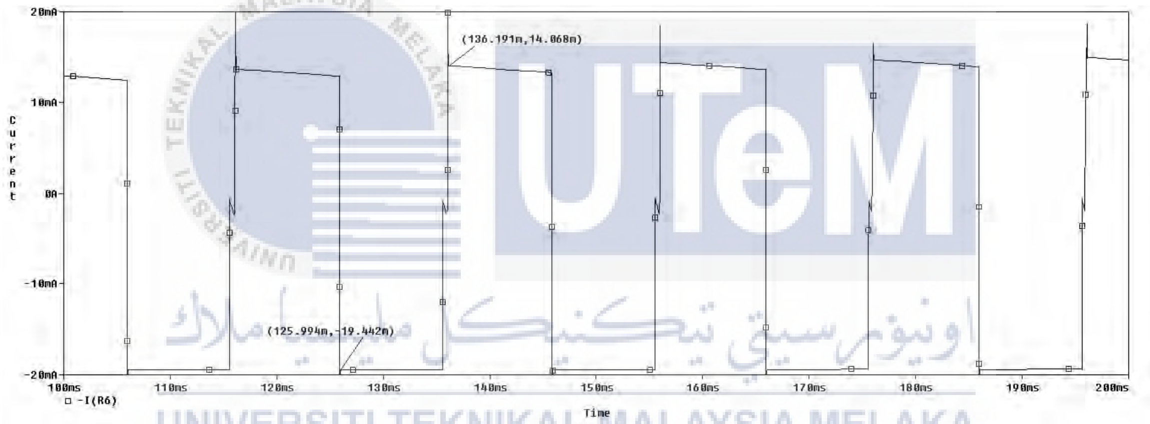


Figure 4.7: Current produced at the load

The load voltage and load current waveform illustrated in Figure 4.6 and Figure 4.7 are both in square wave shape and consist of noises which may be come from step up transformer. The peak value of load voltage and current are 116.27V and 14.07mA respectively.

4.1.2.1 Performance analysis

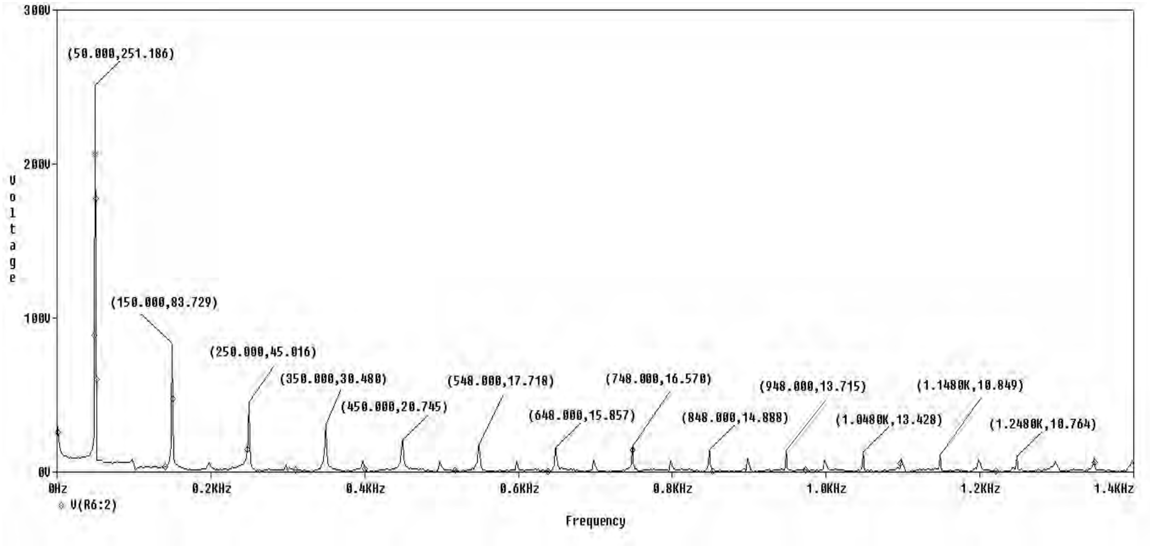


Figure 4.8: FFT analysis of load voltage

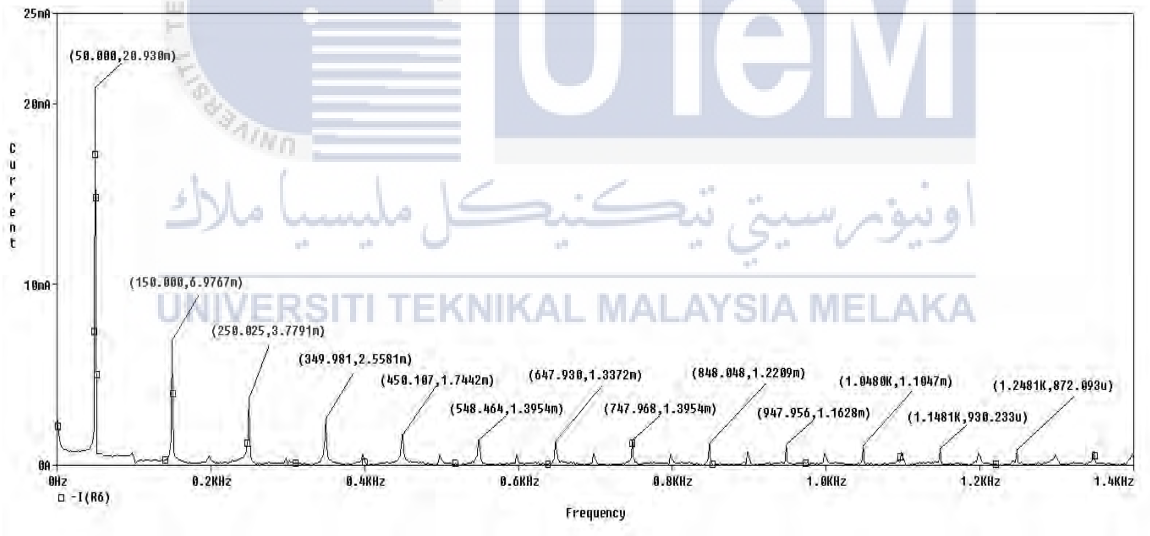


Figure 4.9: FFT analysis of load current.

The voltage and current odd harmonics obtained from simulation graph are as shown in Figure 4.8 and Figure 4.9. Same as model 1, even harmonic contained for both figures are very small and nearly closed to zero value.

Table 4.2: Voltage and current harmonic in the load (Model 2)

Harmonic	Frequency (Hz)	Voltage (V)	Current (mA)
1st	50	251.19	20.93
3rd	150	83.73	6.98
5th	250	45.02	3.78
7th	350	30.48	2.56
9th	450	20.75	1.74
11th	548	17.72	1.40
13th	648	15.86	1.34
15th	748	16.57	1.40
17th	848	14.80	1.22
19th	948	13.75	1.16
21st	1048	13.43	1.10
23rd	1148	10.85	0.93
25th	1248	10.76	0.87

The odd harmonic value was recorded in Table 4.2. At first harmonic of fundamental frequency of 50Hz, the value of voltage is 251.19 while value of current 20.93mA. Besides, the range frequencies value obtained from graph have decreasing of the actual range by 2Hz starting from11th harmonics and above. In addition, THD of the load voltage and load current obtained from Fourier analysis of the simulation are 47.02 and 47 percent respectively (refer APPENDIX D).

4.1.3 Comparison of Performance Analysis

The value of peak voltage obtained from design in Model 1 is moderately higher than design in Model 2. The waveform produced is fairly more sinusoidal wave looks than Model 2 which is a vivid form of square wave. However, the value of the voltage and current in Model 2 at fundamental frequency are very large compared to the values of voltage and current in Model 1. In addition, Model 2 has higher value . This shows that Model 1 design is more efficient and reliable low power inverter compared to Model 2.

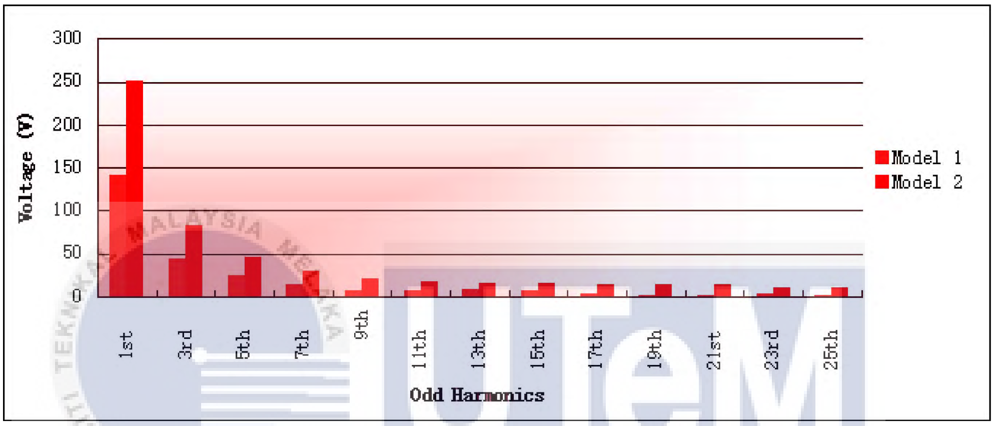


Figure 4.10: FFT analysis comparison of load voltage

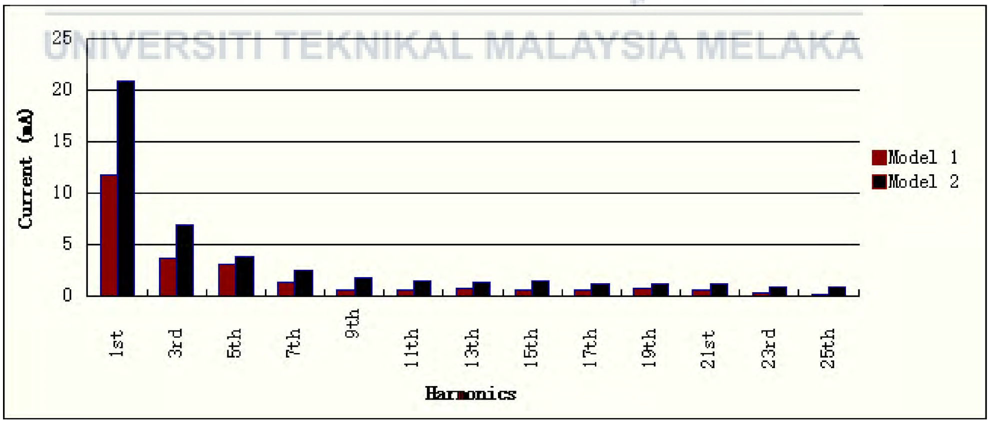


Figure 4.11: FFT analysis comparison of load current.

Figure 4.10 and Figure 4.11 show the FFT analysis comparison of load voltage and load current obtained from Model 1 and Model 2. The value of load voltage and load current from all the number of harmonics appeared in Model 2 are much more larger than values in Model 1 which has a very small values of 19th to 25th harmonic content. Furthermore, the THDv and THDi of Model 1 are surpassing the Model 2 with percentage of 40.35 % and 47.02 % respectively.

In addition, Model 1 design is much more simple and cost effective as it uses a non-complex and basic components, which also provides an optimum and lower number of harmonics of THD, thus the inverter design is selected for the hardware development of low power and portable inverter.

4.2 Hardware Development

After simulation of both proposed inverter design using PSpice Software are done and Model 1 is selected, the prototype are constructed and developed. The testing of the hardware design connected to the 12V DC rechargeable sealed lead acid battery with initial current rating of less than 2.36A. In order to conduct the experimental analysis, the breadboard which are constructed using same resistor load used in simulation, 12K Ohm is connected to the output of the transformer as shown in Figure 4.12. The waveform of the load obtained was observed and measured by using an oscilloscope. The hardware performance in term of harmonic and THD analysis using FLUKE measurement is recorded and discussed.

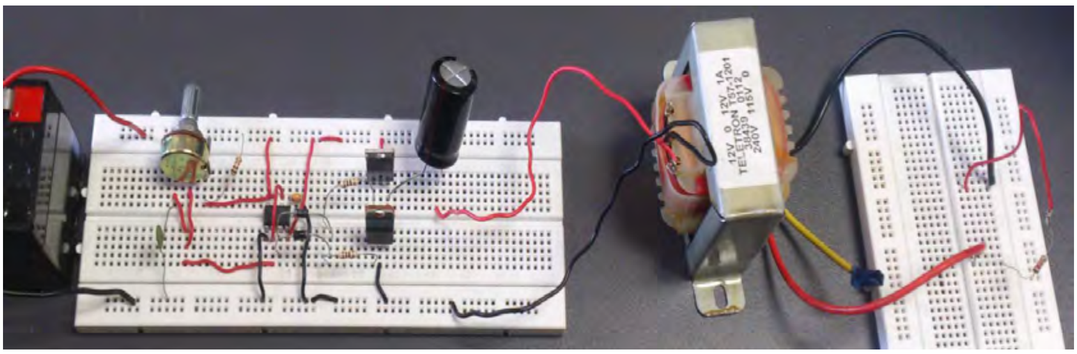


Figure 4.12: Configuration of experimental analysis using breadboard

4.2.1 Experimental Result

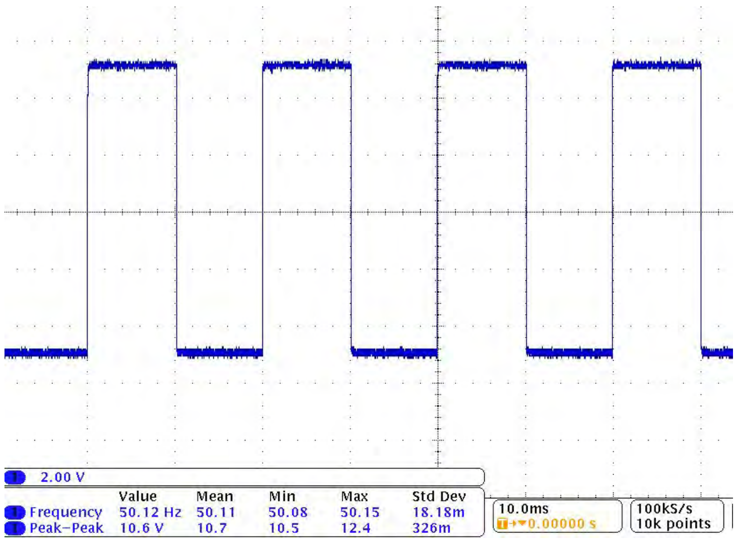


Figure 4.13: The load voltage form before connected to the transformer.

Figure 4.13 shows the value of voltage in resistor load of 12K Ohm before connected to step-up transformer of ratio 1:20. The waveform of AC square wave was formed with peak-to-peak value of 10.6V and 50Hz frequency.

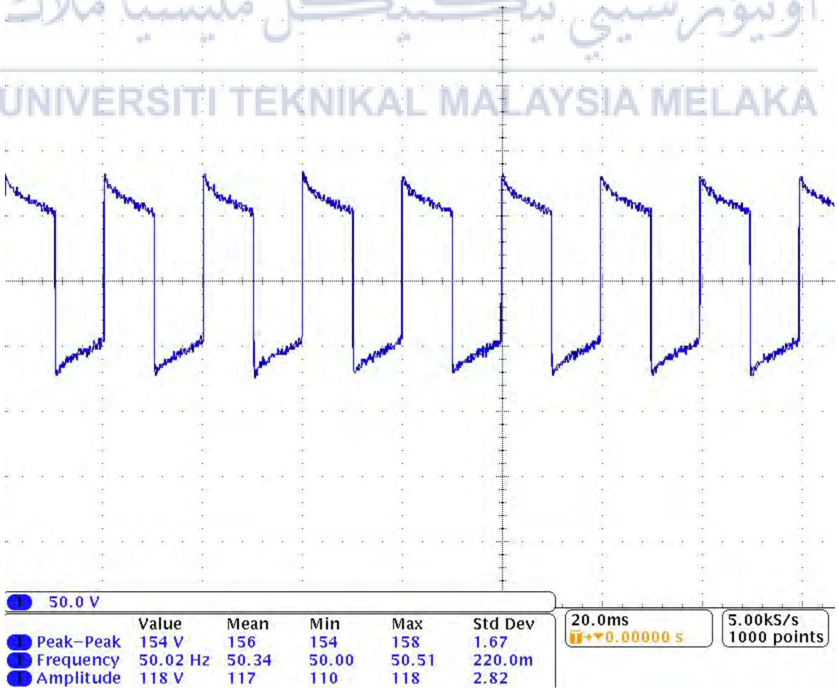


Figure 4.14: The voltage at the output of the secondary transformer with load of 12K Ohm

Figure 4.14 shows the measurement of the value of the peak voltage of the positive sequence and negative sequence from resistor load obtained at the secondary transformer is +76V and -72V respectively with amplitude of 118V. The peak-to-peak voltage obtained is 154V while the AC voltage measured using multimeter is 61.66V.

4.2.2 Performance Analysis

Figure 4.15:Harmonic content in the load voltage

Figure 4.16: Harmonic content in the load current

In experimental result , the voltage and current THD for the developed inverter were came out as 43.3 % and 52.2% respectively, as shown in Figure 4.15 and Figure 5.16.

4.3 Comparative Analysis of Hardware and Simulation Results

The peak voltage value obtained from experimental result is smaller than the value in simulation result. Besides, the designed hardware produced an output of a square wave inverter with more harmonic content compared to the simulation result as shown in Table 4.3 and Figure 4.17.

Table 4.3: Performance analysis of inverter

Result	THDv	THDi
Simulation	40.35	40.34
Experimental	43.30	52.20

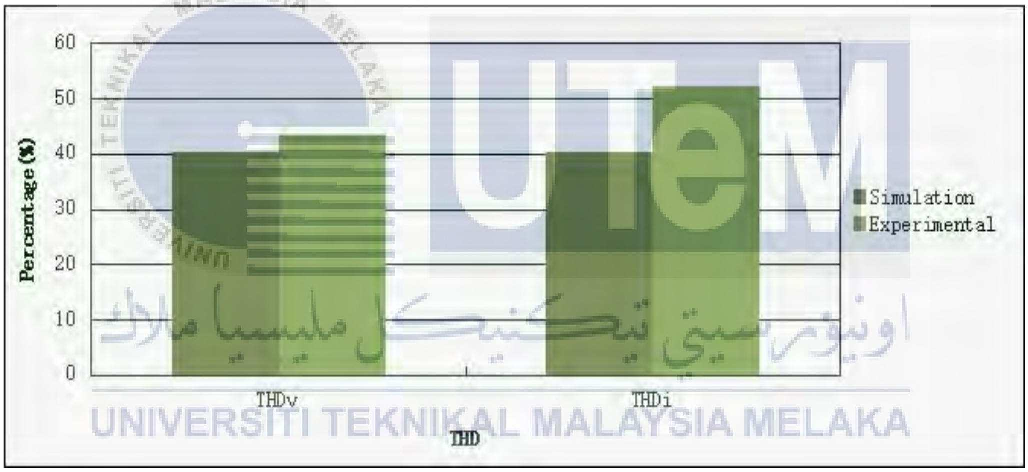


Figure 4.17: THDv and THDi performance comparison.

From Table 4.3, the percentage of THDv analysis in the experimental result is around 1.73 % higher from the value of THDv obtained from simulation analysis while the THDi percentage from the experimental result is much more bigger with 29 % higher from simulation result . As can be observed, the experimental results have 46% error decreasing from peak voltage from the simulation , but the THDv characteristic features and trend of the design are almost the same. The slightly difference of percentage for THDv, moderately higher value of THDi in experimental analysis and a huge different of peak voltage between simulation result and experimental result may cause by several factors.

As mentioned before, the experimental analysis was conducted using breadboard because of the non-functionality problem appeared in the designed of PC board. As matter of fact, the experiment leads to some external losses which may caused by resistance effect in jumper wire used and the connection of the breadboard. In addition, the smaller voltage value may caused as the result of equipment used for the measurement are not perfectly calibrated.

Furthermore,, the transformer used in the experiment is a step-down transformer. As it has two separate winding with rated 1A, the transformer was converted to step up transformer by switching the secondary and the primary terminal, which in several condition, can cause additional issue in current harmonic and also, an over-excitation of the winding as the result of the increasing of the core loss and exciting current than the rated value. The reverse feeding condition of the transformer usually cause 3-5% of voltage drop which also can lead s to 3-5% voltage drop of compensated winding ratio[20].

Besides, ORCAD PSpice software used for simulation only produced theoretical circuit with ideal environment (with temperature of 27^{o}), condition, and cannot represent specifically the parameters and aspects of real equipment[21]. As the result, there will be a a small error in the experimental result which usually acceptable if the result has ±10 % error from the value obtained from PSpice.

In addition, since the analogue 555timer is used in the design, the requirement of 50% duty cycle signal is hard to achieve as it may varying a little around the desire duty cycle. The efficiency of the circuit may decrease as the use of the transistor. The switching signal of the transistor may also possible to cause cross over distortion in the output signal. As matter of fact, the limitation has been reduced with the use of biasing diodes in the design.

As a conclusion, the value of voltage and current THD obtained from both simulation and experimental result are not suitable to be practice based on Total Demand Distortion(TDD) introduced in IEEE 516 which mentioned the THDv and THDi recommended to be practice are smaller or equal than 5% and 20% respectively. This shows that the capacitor used is not enough to filter the harmonic contain. Besides, the experimental results indicate that the hardware has a poor quality in its efficiency.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This project presented a low power and portable inverter to be used for basic power supply. A basic power supply is very crucial for emergency used especially during blackout. Two designs of inverter model was proposed and analysis of the performances of Model 1 and Model 2 are demonstrated through simulation by using PSpice. The inverter design selected is based on the output voltage, output current and percentage of total harmonic distortion value obtained from FFT analysis. The lower the harmonic content of the design, the higher the efficiency of the output power.

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The low power inverter designs has been successfully simulated and compared using ORCAD PSpice. 555 Timer configured in astable mode was used as a PWM generator. Model 2 is selected for hardware development as it has smaller harmonic content and simpler design compared to Model 2. The experimental result of the hardware performance is slightly different from the simulation result in around 1.73% of THDv analysis error. However, moderate error of 29% in THDi and the small value of the voltage obtained as the result of several factor such as different circuit condition, losses and disturbance in the hardware component.

Last but not least, the capacitor used in the design still not enough to filter the harmonic contained. The hardware developed are not suitable for practice as it contained larger value of THDv and THDi from the value recommended by standard and also has a poor efficiency of energy conversion. However, at the end, this project can be a learning tools before came out with the better design.

5.2 Recommendation

As recommendation, future work could be done to improve the waveform in term of efficiency and total harmonic distortion by carefully selecting the different combination of passive filter. Furthermore, the hardware design is recommended to be upgrade and improve using different type of analog integrated circuit or more advance micro-controller to increase the efficiency of low power inverter so that it can meet the standard requirement.

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APPENDIX A

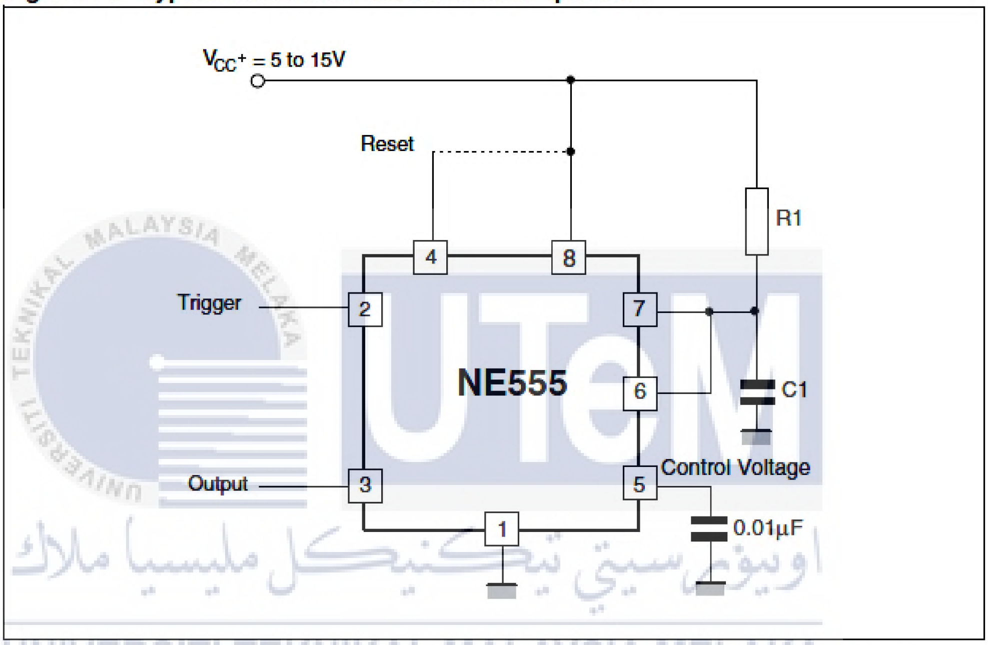
555 Timer Application Information

4 Application information

4.1 Monostable operation

In the monostable mode, the timer generates a single pulse. As shown in *Figure 12*, the external capacitor is initially held discharged by a transistor inside the timer.

Figure 12. Typical schematics in monostable operation



The circuit triggers on a negative-going input signal when the level reaches 1/3 V_{CC}. Once triggered, the circuit remains in this state until the set time has elapsed, even if it is triggered again during this interval. The duration of the output HIGH state is given by $t = 1.1\ R_1C_1$ and is easily determined by *Figure 14*.

Note that because the charge rate and the threshold level of the comparator are both directly proportional to supply voltage, the timing interval is independent of supply. Applying a negative pulse simultaneously to the reset terminal (pin 4) and the trigger terminal (pin 2) during the timing cycle discharges the external capacitor and causes the cycle to start over. The timing cycle now starts on the positive edge of the reset pulse. During the time the reset pulse is applied, the output is driven to its LOW state.

When a negative trigger pulse is applied to pin 2, the flip-flop is set, releasing the short-circuit across the external capacitor and driving the output HIGH. The voltage across the capacitor increases exponentially with the time constant $t = R_1C_1$. When the voltage across the capacitor equals 2/3 V_{CC}, the comparator resets the flip-flop which then discharges the capacitor rapidly and drives the output to its LOW state.

Figure 13 shows the actual waveforms generated in this mode of operation.

When Reset is not used, it should be tied high to avoid any possibility of unwanted triggering.

Figure 13. Waveforms in monostable operation

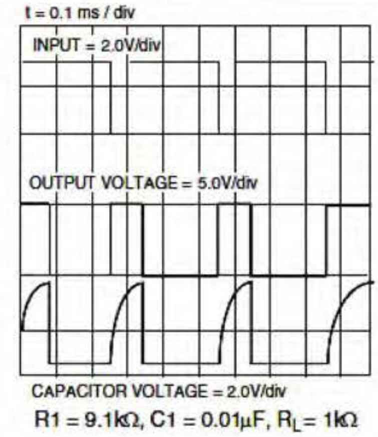
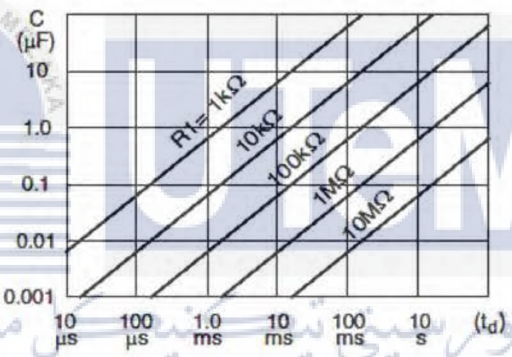


Figure 14. Pulse duration versus R1C1



4.2 Astable operation

When the circuit is connected as shown in *Figure 15* (pins 2 and 6 connected) it triggers itself and free runs as a multi-vibrator. The external capacitor charges through R_1 and R_2 and discharges through R_2 only. Thus the duty cycle can be set accurately by adjusting the ratio of these two resistors.

In the astable mode of operation, C_1 charges and discharges between 1/3 V_{CC} and 2/3 V_{CC}. As in the triggered mode, the charge and discharge times and, therefore, frequency are independent of the supply voltage.

Figure 15. Typical schematics in astable operation

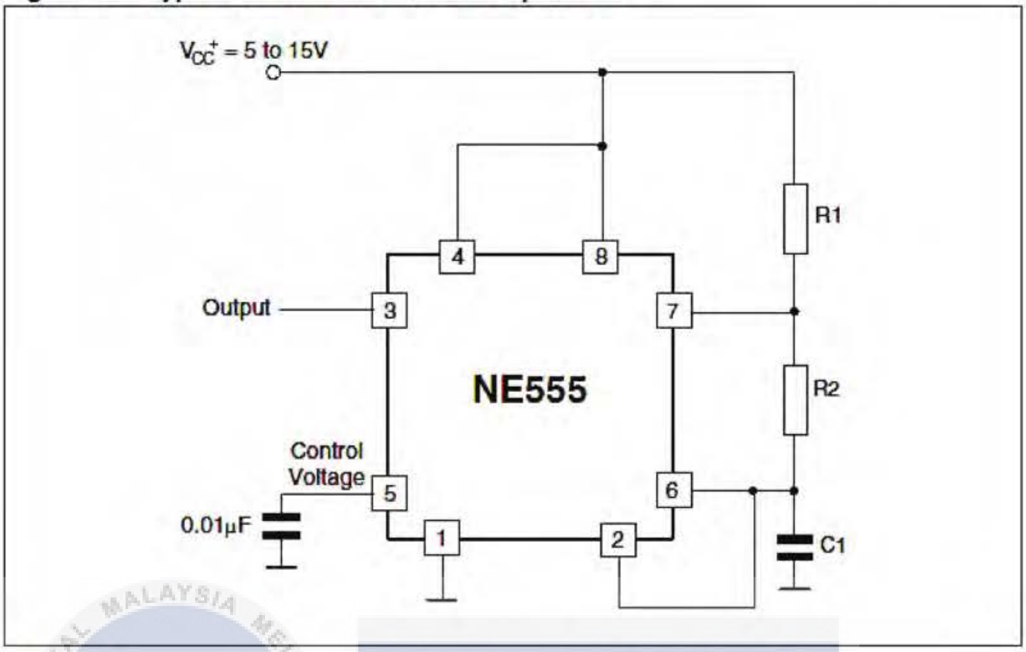


Figure 16 shows the actual waveforms generated in this mode of operation.

The charge time (output HIGH) is given by:

$t1 = 0.693\ (R_1 + R_2)\ C_1$

and the discharge time (output LOW) by:

$t2 = 0.693\ (R_2)\ C_1$

Thus the total period T is given by:

$T = t1 + t2 = 0.693\ (R1 + 2R2)\ C1$

The frequency of oscillation is then:

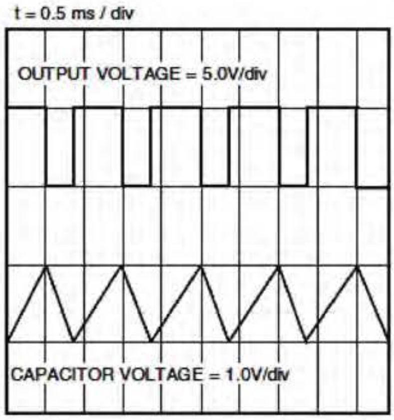
$$f = \frac{1}{T} = \frac{1.44}{(R1 + 2R2)C1}$$

It can easily be found from *Figure 17*.

The duty cycle is given by:

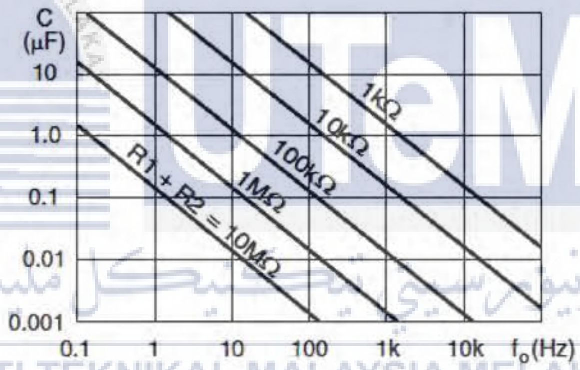
$$\frac{t1}{(t1 + t2)} = \frac{(R1 + R2)}{(R1 + 2 \bullet R2)} = 1 - \left[\frac{R2}{(R1 + R2)}\right]$$

Figure 16. Waveforms in astable operation



R1 = R2 = 4.8kΩ, C1= 0.1μF, R_L = 1kΩ

Figure 17. Free running frequency versus R_1, R_2 and C_1



APPENDIX B

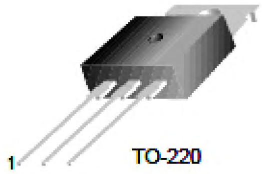
TIP Series Characteristics

FAIRCHILD SEMICONDUCTOR™

TIP41 Series(TIP41/41A/41B/41C)

Medium Power Linear Switching Applications

- Complement to TIP42/42A/42B/42C



1.Base 2.Collector 3.Emitter

NPN Epitaxial Silicon Transistor

Absolute Maximum Ratings T_C=25°C unless otherwise noted

Symbol	Parameter	Value	Units
V_{CBO}	Collector-Emitter Voltage: TIP41 : TIP41A : TIP41B : TIP41C	40 60 80 100	V V V V
V_{CEO}	Collector-Emitter Voltage: TIP41 : TIP41A : TIP41B : TIP41C	40 60 80 100	V V V V
V_{EBO}	Emitter-Base Voltage	5	V
I_C	Collector Current (DC)	6	A
I_{CP}	Collector Current (Pulse)	10	A
I_B	Base Current	2	A
P_C	Collector Dissipation (T_C=25°C)	65	W
P_C	Collector Dissipation (T_a=25°C)	2	W
T_J	Junction Temperature	150	°C
T_{STG}	Storage Temperature	- 65 ~ 150	°C

Electrical Characteristics T_C=25°C unless otherwise noted

Symbol	Parameter	Test Condition	Min.	Max.	Units
V_{CEO}(sus)	* Collector-Emitter Sustaining Voltage : TIP41 : TIP41A : TIP41B : TIP41C	I_C = 30mA, I_B = 0	40 60 80 100		V V V V
I_{CEO}	Collector Cut-off Current : TIP41/41A : TIP41B/41C	V_{CE} = 30V, I_B = 0 V_{CE} = 60V, I_B = 0		0.7 0.7	mA mA
I_{CES}	Collector Cut-off Current : TIP41 : TIP41A : TIP41B : TIP41C	V_{CE} = 40V, V_{EB} = 0 V_{CE} = 60V, V_{EB} = 0 V_{CE} = 80V, V_{EB} = 0 V_{CE} = 100V, V_{EB} = 0		400 400 400 400	μA μA μA μA
I_{EBO}	Emitter Cut-off Current	V_{EB} = 5V, I_C = 0		1	mA
h_{FE}	* DC Current Gain	V_{CE} = 4V,I_C = 0.3A V_{CE} = 4V, I_C = 3A	30 15	 75	
V_{CE}(sat)	* Collector-Emitter Saturation Voltage	I_C = 6A, I_B = 600mA		1.5	V
V_{BE}(sat)	* Base-Emitter Saturation Voltage	V_{CE} = 4V, I_C = 6A		2.0	V
f_T	Current Gain Bandwidth Product	V_{CE} = 10V, I_C = 500mA	3.0		MHz

* Pulse Test: PW≤300μs, Duty Cycle≤2%

Typical Characteristics

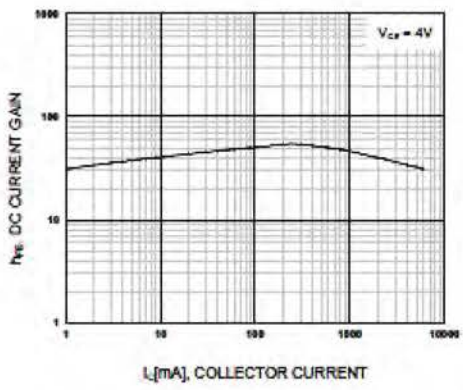


Figure 1. DC current Gain

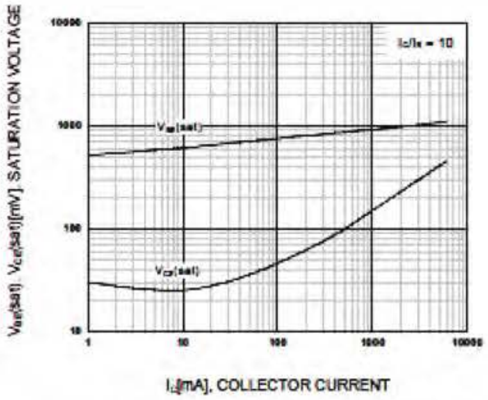


Figure 2. Base-Emitter Saturation Voltage Collector-Emitter Saturation Voltage

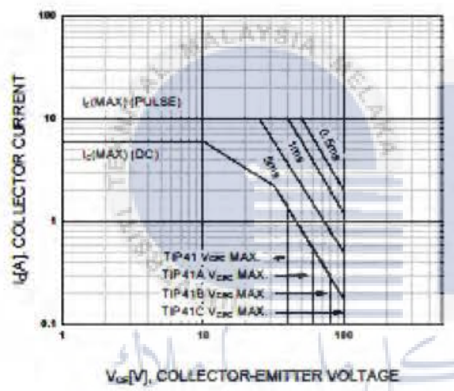


Figure 3. Safe Operating Area

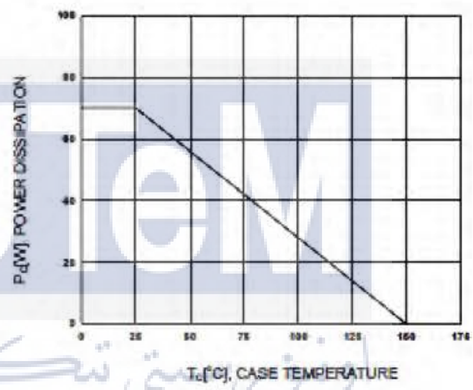


Figure 4. Power Derating

APPENDIX C

Model 1 PSpice Output File

**** 06/11/16 18:58:56 ********* PSpice 9.2 (Mar 2000) ******** ID# 0 ********

** Profile: "SCHEMATIC1-inv1" [C:\Program Files\Orcad\project\inverter-schematic1-inv1.sim]

**** INITIAL TRANSIENT SOLUTION TEMPERATURE = 27.000 DEG C

****

NODE	VOLTAGE	NODE	VOLTAGE	NODE	VOLTAGE	NODE	VOLTAGE
(N00729)	12.0000	(N00829)	3.9944	(N00890)	3.9976	(N01054)	7.9965
(N01182)	9.3310	(N01383)	9.3310	(N01518)	9.3310	(N01535)	9.3310
(N01716)	9.2846	(N01775)	0.0000	(N01946)	0.0000	(X_U1.9)	11.2660

(X_U1.10)	1.2660	(X_U1.11)	10.5420
(X_U1.12)	.6535	(X_U1.13)	.6543
(X_U1.14)	1.3078	(X_U1.15)	.0026
(X_U1.16)	.6344	(X_U1.17)	11.2840
(X_U1.18)	11.7960	(X_U1.19)	5.1715
(X_U1.20)	11.9240	(X_U1.21)	.5823
(X_U1.22)	.5580	(X_U1.23)	4.5317
(X_U1.24)	4.5320	(X_U1.25)	3.9983
(X_U1.26)	.6429	(X_U1.27)	.6401
(X_U1.28)	9.9434	(X_U1.29)	.6412

(X_U1.30) 7.4510 (X_U1.31) 6.9929

(X_U1.32) 6.8163

VOLTAGE SOURCE CURRENTS
NAME CURRENT

V_V1 -6.475E-03

TOTAL POWER DISSIPATION 7.77E-02 WATTS

**** 06/11/16 18:58:56 ********* PSpice 9.2 (Mar 2000) ******** ID# 0 ********

** Profile: "SCHEMATIC1-inv1" [C:\Program Files\Orcad\project\inverter-schematic1-inv1.sim]

**** FOURIER ANALYSIS TEMPERATURE = 27.000 DEG C

****

FOURIER COMPONENTS OF TRANSIENT RESPONSE V(N01946)

DC COMPONENT = 1.022532E+00

HARMONIC NO	FREQUENCY (HZ)	FOURIER COMPONENT	NORMALIZED COMPONENT	PHASE (DEG)	NORMALIZED PHASE (DEG)
1	5.000E+01	1.612E+02	1.000E+00	-5.336E+01	0.000E+00
2	1.000E+02	1.195E+01	7.411E-02	-5.666E+01	5.006E+01
3	1.500E+02	4.809E+01	2.983E-01	9.538E+01	2.555E+02
4	2.000E+02	1.299E+01	8.057E-02	7.305E+01	2.865E+02
5	2.500E+02	2.728E+01	1.692E-01	-1.080E+02	1.588E+02
6	3.000E+02	7.443E+00	4.617E-02	-1.311E+02	1.891E+02

7	3.500E+02	1.524E+01	9.453E-02	5.571E+01	4.292E+02
8	4.000E+02	5.894E+00	3.656E-02	7.021E+01	4.971E+02
9	4.500E+02	7.152E+00	4.437E-02	-1.256E+02	3.547E+02
10	5.000E+02	7.156E+00	4.439E-02	-1.123E+02	4.213E+02
11	5.500E+02	6.442E+00	3.996E-02	8.588E+01	6.729E+02
12	6.000E+02	7.466E+00	4.632E-02	6.164E+01	7.020E+02
13	6.500E+02	8.217E+00	5.097E-02	-1.138E+02	5.799E+02
14	7.000E+02	8.353E+00	5.181E-02	-1.319E+02	6.152E+02
15	7.500E+02	5.649E+00	3.504E-02	2.803E+01	8.285E+02
16	8.000E+02	6.591E+00	4.089E-02	2.543E+01	8.792E+02
17	8.500E+02	1.792E+00	1.112E-02	-1.678E+02	7.394E+02
18	9.000E+02	4.232E+00	2.625E-02	-1.399E+02	8.206E+02
19	9.500E+02	8.757E-01	5.432E-03	5.590E+01	1.070E+03
20	1.000E+03	5.893E+00	3.656E-02	4.406E+01	1.111E+03
21	1.050E+03	1.043E+00	6.467E-03	-8.182E+01	1.039E+03
22	1.100E+03	6.089E+00	3.777E-02	-1.519E+02	1.022E+03
23	1.150E+03	1.125E+00	6.981E-03	5.689E+01	1.284E+03
24	1.200E+03	5.567E+00	3.453E-02	1.332E+01	1.294E+03
25	1.250E+03	7.903E-01	4.902E-03	9.573E+01	1.430E+03

TOTAL HARMONIC DISTORTION = 4.034723E+01 PERCENT

JOB CONCLUDED

TOTAL JOB TIME 189.17

**** 06/11/16 19:08:48 ********* PSpice 9.2 (Mar 2000) ******** ID# 0 ********

** Profile: "SCHEMATIC1-inv1" [C:\Program Files\Orcad\project\inverter-schematic1-inv1.sim]

**** FOURIER ANALYSIS TEMPERATURE = 27.000 DEG C

****

FOURIER COMPONENTS OF TRANSIENT RESPONSE I(R_R5)

DC COMPONENT = 8.434968E-05

HARMONIC NO	FREQUENCY (HZ)	FOURIER COMPONENT	NORMALIZED COMPONENT	PHASE (DEG)	NORMALIZED PHASE (DEG)
1	5.000E+01	1.343E-02	1.000E+00	-5.253E+01	0.000E+00
2	1.000E+02	9.970E-04	7.421E-02	-5.504E+01	5.003E+01
3	1.500E+02	4.005E-03	2.982E-01	9.788E+01	2.555E+02
4	2.000E+02	1.081E-03	8.046E-02	7.636E+01	2.865E+02
5	2.500E+02	2.275E-03	1.693E-01	-1.038E+02	1.589E+02
6	3.000E+02	6.220E-04	4.630E-02	-1.260E+02	1.892E+02
7	3.500E+02	1.269E-03	9.445E-02	6.150E+01	4.292E+02
8	4.000E+02	4.896E-04	3.644E-02	7.679E+01	4.971E+02
9	4.500E+02	5.975E-04	4.448E-02	-1.181E+02	3.547E+02
10	5.000E+02	5.978E-04	4.450E-02	-1.040E+02	4.214E+02
11	5.500E+02	5.348E-04	3.981E-02	9.502E+01	6.729E+02
12	6.000E+02	6.206E-04	4.620E-02	7.158E+01	7.020E+02
13	6.500E+02	6.860E-04	5.106E-02	-1.029E+02	5.800E+02
14	7.000E+02	6.975E-04	5.192E-02	-1.202E+02	6.153E+02
15	7.500E+02	4.700E-04	3.498E-02	4.037E+01	8.284E+02
16	8.000E+02	5.488E-04	4.085E-02	3.859E+01	8.791E+02
17	8.500E+02	1.501E-04	1.117E-02	-1.531E+02	7.400E+02
18	9.000E+02	3.537E-04	2.633E-02	-1.248E+02	8.208E+02
19	9.500E+02	7.142E-05	5.317E-03	7.093E+01	1.069E+03
20	1.000E+03	4.895E-04	3.644E-02	6.058E+01	1.111E+03
21	1.050E+03	8.820E-05	6.566E-03	-6.454E+01	1.039E+03
22	1.100E+03	5.083E-04	3.784E-02	-1.334E+02	1.022E+03
23	1.150E+03	9.226E-05	6.868E-03	7.579E+01	1.284E+03
24	1.200E+03	4.635E-04	3.450E-02	3.311E+01	1.294E+03
25	1.250E+03	6.406E-05	4.768E-03	1.171E+02	1.430E+03

TOTAL HARMONIC DISTORTION = 4.034012E+01 PERCENT

JOB CONCLUDED

TOTAL JOB TIME 164.80

APPENDIX D

Model 2 PSpice Output File

**** 06/11/16 17:24:54 *********** Evaluation PSpice (Nov 1999) **************

* C:\Users\user\Documents\Documents\psPICE\inverter2.sch

**** INITIAL TRANSIENT SOLUTION TEMPERATURE = 27.000 DEG C

****

NODE VOLTAGE NODE VOLTAGE NODE VOLTAGE NODE VOLTAGE

NODE	VOLTAGE	NODE	VOLTAGE
($G_DGND)	0.0000	($G_DPWR)	5.0000
($N_0001)	12.0000	($N_0002)	11.4250
($N_0003)	.7595	($N_0004)	.0796
($N_0005)	12.0000	($N_0006)	8.0000
($N_0007)	12.0000	($N_0008)	11.4250
($N_0009)	12.0000	($N_0010)	12.0000
($N_0011)	0.0000	(X_X1.qb)	.0012
(X_X1.botm)	4.0000		

DGTL NODE : STATE DGTL NODE : STATE DGTL NODE : STATE DGTL NODE : STATE

(X_X1.r) : 1 (X_X1.sd) : 0 (X_X1.rd) : 1 (N_0002DtoA) : 1

(X_X1.strt) : 0 (X_X1.s) : 0 (X_X1.hi) : 1 (N_0005AtoD) : 1

(X_X1.qb$DtoA) : 0

VOLTAGE SOURCE CURRENTS
NAME CURRENT

V_V1 -1.091E+02
X$DIGIFPWR.VDPWR -5.000E-06
X$DIGIFPWR.VDGND -5.000E-06
TOTAL POWER DISSIPATION 1.31E+03 WATTS

**** 06/11/16 17:24:54 *********** Evaluation PSpice (Nov 1999) **************

* C:\Users\user\Documents\Documents\psPICE\inverter2.sch

**** FOURIER ANALYSIS TEMPERATURE = 27.000 DEG C

****

FOURIER COMPONENTS OF TRANSIENT RESPONSE V($N_0011)

DC COMPONENT = -8.560374E+00

HARMONIC NO	FREQUENCY (HZ)	FOURIER COMPONENT	NORMALIZED COMPONENT	PHASE (DEG)	NORMALIZED PHASE (DEG)
1	5.000E+01	2.708E+02	1.000E+00	6.679E+01	0.000E+00
2	1.000E+02	7.512E+00	2.774E-02	-1.390E+02	-2.725E+02
3	1.500E+02	9.028E+01	3.334E-01	-1.617E+02	-3.621E+02
4	2.000E+02	7.407E+00	2.735E-02	-3.899E+00	-2.711E+02
5	2.500E+02	5.398E+01	1.993E-01	-2.988E+01	-3.639E+02
6	3.000E+02	7.564E+00	2.793E-02	1.301E+02	-2.707E+02
7	3.500E+02	3.847E+01	1.421E-01	1.020E+02	-3.656E+02
8	4.000E+02	7.637E+00	2.820E-02	-9.700E+01	-6.314E+02
9	4.500E+02	2.978E+01	1.100E-01	-1.264E+02	-7.276E+02
10	5.000E+02	7.730E+00	2.855E-02	3.643E+01	-6.315E+02
11	5.500E+02	2.416E+01	8.921E-02	5.054E+00	-7.297E+02
12	6.000E+02	7.898E+00	2.917E-02	1.692E+02	-6.323E+02

13	6.500E+02	2.027E+01	7.485E-02	1.363E+02	-7.320E+02
14	7.000E+02	8.007E+00	2.957E-02	-5.837E+01	-9.935E+02
15	7.500E+02	1.732E+01	6.396E-02	-9.283E+01	-1.095E+03
16	8.000E+02	8.154E+00	3.011E-02	7.412E+01	-9.946E+02
17	8.500E+02	1.500E+01	5.541E-02	3.789E+01	-1.098E+03
18	9.000E+02	8.308E+00	3.068E-02	-1.540E+02	-1.356E+03
19	9.500E+02	1.315E+01	4.856E-02	1.682E+02	-1.101E+03
20	1.000E+03	8.416E+00	3.108E-02	-2.225E+01	-1.358E+03
21	1.050E+03	1.155E+01	4.266E-02	-6.201E+01	-1.465E+03
22	1.100E+03	8.549E+00	3.157E-02	1.093E+02	-1.360E+03
23	1.150E+03	1.020E+01	3.765E-02	6.754E+01	-1.469E+03
24	1.200E+03	8.652E+00	3.195E-02	-1.196E+02	-1.723E+03
25	1.250E+03	9.017E+00	3.330E-02	-1.636E+02	-1.833E+03

TOTAL HARMONIC DISTORTION = 4.701631E+01 PERCENT

JOB CONCLUDED

TOTAL JOB TIME 1.64

**** 06/11/16 17:31:00 *********** Evaluation PSpice (Nov 1999) **************

* C:\Users\user\Documents\Documents\psPICE\inverter2.sch

**** FOURIER ANALYSIS TEMPERATURE = 27.000
DEG C

****
*****

FOURIER COMPONENTS OF TRANSIENT RESPONSE I(R_R6)

DC COMPONENT = 7.332074E-04

HARMONIC FREQUENCY FOURIER NORMALIZED PHASE
NORMALIZED
NO (HZ) COMPONENT COMPONENT (DEG)

PHASE (DEG)

1	5.000E+01	2.256E-02	1.000E+00	-1.158E+02	0.000E+00
2	1.000E+02	6.011E-04	2.664E-02	3.583E+01	2.674E+02
3	1.500E+02	7.525E-03	3.335E-01	1.055E+01	3.579E+02
4	2.000E+02	5.913E-04	2.621E-02	1.657E+02	6.288E+02
5	2.500E+02	4.501E-03	1.995E-01	1.372E+02	7.161E+02
6	3.000E+02	6.035E-04	2.675E-02	-6.527E+01	6.294E+02
7	3.500E+02	3.208E-03	1.422E-01	-9.603E+01	7.144E+02
8	4.000E+02	6.110E-04	2.708E-02	6.249E+01	9.888E+02
9	4.500E+02	2.487E-03	1.102E-01	3.041E+01	1.072E+03
10	5.000E+02	6.171E-04	2.735E-02	-1.693E+02	9.886E+02
11	5.500E+02	2.019E-03	8.948E-02	1.568E+02	1.430E+03
12	6.000E+02	6.310E-04	2.796E-02	-4.145E+01	1.348E+03
13	6.500E+02	1.696E-03	7.515E-02	-7.706E+01	1.428E+03
14	7.000E+02	6.411E-04	2.841E-02	8.578E+01	1.707E+03
15	7.500E+02	1.453E-03	6.440E-02	4.870E+01	1.785E+03
16	8.000E+02	6.516E-04	2.888E-02	-1.468E+02	1.706E+03
17	8.500E+02	1.261E-03	5.587E-02	1.743E+02	2.143E+03
18	9.000E+02	6.653E-04	2.949E-02	-1.994E+01	2.064E+03
19	9.500E+02	1.108E-03	4.909E-02	-6.041E+01	2.139E+03
20	1.000E+03	6.750E-04	2.992E-02	1.066E+02	2.422E+03
21	1.050E+03	9.777E-04	4.333E-02	6.436E+01	2.496E+03
22	1.100E+03	6.849E-04	3.036E-02	-1.269E+02	2.420E+03
23	1.150E+03	8.650E-04	3.834E-02	-1.711E+02	2.492E+03
24	1.200E+03	6.953E-04	3.082E-02	-7.602E-01	2.778E+03
25	1.250E+03	7.690E-04	3.408E-02	-4.710E+01	2.847E+03

TOTAL HARMONIC DISTORTION = 4.699533E+01 PERCENT

JOB CONCLUDED

TOTAL JOB TIME 1.84