STUDY AND DESIGN A STEP UP DC-DC CONVERTER FOR RENEWABLE ENERGY APPLICATION

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APPROVAL

"I hereby declare that I have read through this report entitled "STUDY AND DESIGN A STEP UP DC-DC CONVERTER FOR RENEWABLE ENERGY APPLICATION" and found that it has complies partial fulfilment for awarding the Bachelor of Electrical Engineering"

Signature : ……………………………………

Supervisor's name : ……………………………………

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DECLARATION

I declare that this report entitled "STUDY AND DESIGN A STEP UP DC-DC CONVERTER FOR RENEWABLE ENERGY APPLICATION" is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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DEDICATION

To my beloved mother and father

ACKNOWLEDGMENT

Firstly, thanks to ALLAH for giving me strength to finish my final year project 1. I like to express my special appreciation to my supervisor, Dr. Azziddin Bin Mohamad Razali for the guidance and supervision during progress of this project. I also give my appreciation to my beloved family for their supports, understanding and inspirational to complete this final year project 2. Lastly, I want to thank all my friends that help me during the working progress and a special appreciation for those that involve directly and indirectly with me to complete the project.

ABSTRACT

In this era of globalization, the used of power electronics have increase widely due to high demand and applications of technology. On the other hand, the renewable energy sources become more important to the world with the depletion supply of oil and gas, coal and others. The renewable energy such as solar energy has its own speciality and can converts to electricity with the uses of the power electronics devices. The step up DC to DC converter is one of the popular devices in recent years. The main objective of this project is to study, simulate, analyse and design a step up DC to DC converter with 12V dc supply which is from the PV panel and produces a high voltage output which in range of 600V to 700V. The high output voltage will then be connected to multilevel inverter in order to converts DC to AC voltage for the transmission grid system. The step up DC to DC converter used in this project is Full-bridge converter. The software used to design, simulate and analyse the circuit simulation model is MATLAB/Simulink software. The open loop and close loop simulation circuits have been designed in the MATLAB/Simulink software. The close loop system uses the Proportional Integral (PI) as a controller to control the duty cycle of the Metal Oxide Semiconductor Field Effect transistor (MOSFET) to get the constant output voltage.

ABSTRAK

Dalam era globalisasi ini, penggunaan kuasa elektronik meningkat secara meluas kerana permintaan yang tinggi dan penggunaan teknologi. Sebaliknya, sumber tenaga boleh diperbaharui menjadi lebih penting kepada dunia dengan bekalan minyak dan gas, arang batu dan lain-lain. Tenaga boleh diperbaharui seperti tenaga solar mempunyai keistimewaan tersendiri dan boleh ditukar kepada elektrik dengan menggunakan alat elektronik kuasa. Langkah penukar DC ke DC adalah salah satu peranti yang popular dalam beberapa tahun kebelakangan ini. Objektif utama projek ini adalah untuk mengkaji, mensimulasikan, menganalisis dan merancang langkah DC ke DC penukar dengan bekalan 12V dc yang dari panel PV dan menghasilkan output voltan tinggi yang antara 600V hingga 700V. Voltan keluaran yang tinggi akan disambungkan kepada penyongsang bertingkat untuk menukar DC ke AC voltan untuk sistem penghantaran grid. Langkah penukar DC ke DC yang digunakan dalam projek ini ialah penukar Jambatan penuh. Perisian yang digunakan untuk merekabentuk, mensimulasikan dan menganalisis model simulasi litar ialah perisian MATLAB / Simulink. Litar simulasi gelung terbuka dan litar simulasi telah direka bentuk dalam perisian MATLAB / Simulink. Sistem gelung dekat menggunakan Integral Proportional (PI) sebagai pengawal untuk mengawal kitaran tugas dari Metal Oxide Semiconductor Field Effect transistor (MOSFET) untuk mendapatkan voltan keluaran tetap.

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CHAPTER 1

INTRODUCTION

1.1 Research Background

In this era of technology, the use of power electronics in our daily life has grown drastically due to its wide range of applications. Power electronics circuit are widely used in renewable energy applications. One of the renewable energy is solar energy. Photovoltaic technology transforms the solar energy in sunlight into electrical and thermal energy. Malaysia still depends on the hydropower to generate more of its electricity.

Basically, DC-DC converter is one of the most popular power electronics circuit. A DC-DC converter converts an input dc voltage to a different dc output voltage level and it provides a regulated voltage output. A DC-DC converter also has its own disadvantages such as the electrical connection between the input and output. If the input supply is grounded, the output will be grounded as well. Therefore, a transformer can be use as a device to electrically isolate the output from the input electrically.

Transformer has two basic functions such as to provide electrical isolation and to step up or step down the voltage. Furthermore, transformer will improve design flexibility in relationship between input and output of converter with it turns ratio.

On the other hand, renewable energy resources such as solar energy will produces unregulated voltage and the DC-DC converter is used to regulate the voltage output for the load. Open loop and close loop systems are used to regulate the voltage. Open loop system produces unregulated dc output voltage. Therefore, to get a good regulated voltage, feedback controller is implemented in a close loop system. PI controller is used in DC-DC converter to regulate dc output voltage. The project designed DC-DC full-bridge converter topologies to regulate the voltage from the PV panel. A full-bridge DC-DC converter is designed in this project to step up and regulated the voltage from 12V solar panel.

1.2 Problem statement

First of all, for renewable energy such as photovoltaic (PV) system produce low voltage and unregulated voltage output and it is not suitable for dc application. Then, DC to DC full-bridge converter should be designed to surpass this problem. Therefore, this full-bridge converter mainly selected because it is needed to produce high output voltage from the low voltage input. On the other hand, in order to achieve the specification from the other part of the project, Proportional integral (PI) controller needs to be design and connects to the full-bridge converter. To design and control the PI controller is hard because it needs to fill the requirement for the chopper selected.

1.3 Objectives

The objectives of this project are:

1. To develop the simulation circuit of open loop and close loop of full-bridge converter.
2. To produce high output voltage such as 900V from 12V dc supply.
3. To develop a hardware of DC-DC converter for grid system application.

1.4 Scope of project

This project mainly focuses on analysis and development of DC-DC full-bridge converter for Grid system application. Basically, the single phase grid system requires around 340V ac voltage which is generate from the multilevel inverter. This project use PV panel as the voltage supply. Therefore, chopper is used to convert the low dc voltage to high voltage output which is 700V. The voltage requirement for multilevel inverter is around 700V. The simulation consists of designing open loop and close loop full-bridge converter in order to generate fixed output value. The simulation is performed using MATLAB/Simulink software. To develop the hardware, a microcontroller will be used to control the output voltage. Figure 1.1 shows the flow of process in this project. The focussing area for this project is in the dotted line box.

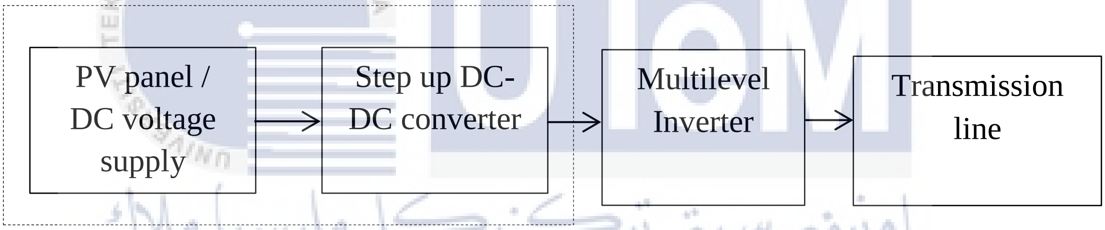

Figure 1.1: Block diagram of project

1.6 Report outline

This report consists of 5 chapters which are investigates about DC-DC full-bridge converter for PV system application.

Chapter 1 consists of the introduction of DC-DC full-bridge converter and overview of the studies. This chapter will discuss about the research background, problem statement full-bridge converter, objective and scope of project.

Chapter 2 consists of literature review about the chopper. The literature review in this chapter states the fundamental theory and basic principles of DC-DC full-bridge converter.

Chapter 3 consists of the design methodology based on fundamental theory and basic principles of the open loop and close loop DC-DC full-bridge converter. The design approach will be explained such methodology process for this project.

Chapter 4 will discuss about an early simulation result of the project which consist of open loop and close loop from the MATLAB/Simulink. The result is shown in waveform. Hardware progress will also be included.

Chapter 5 will discuss about future work and conclusion about project in this semester.

CHAPTER 2

LITERATURE REVIEW

2.1 THEORY AND BASIC PRINCIPLES

2.1.1 Solar Panel

Solar energy is one of the renewable energy that most popular usage these day because of its environment friendly (also known as eco-friendly) and does not cause air pollution or noise. Solar energy can generates electrical power besides other renewable energy such as hydroelectric and wind turbine. Solar power is crucial to human nowadays because it can be use everywhere and it is free. Furthermore, solar power is suitable usage for rural area and area that not served by the conventional grid connection. PV system has the basic element which is solar cell[1]. This solar cell converts the energy of the sunlight into electricity. It has three type of cell which are monocrystalline, polycrystalline and amorphous. There are three types of the PV power system which are stand-alone, hybrid and grid connected.

Stand-alone PV power system requires battery to meet the energy demand during low solar irradiation and night time. Hybrid power system combines multiple sources to deliver the non-intermittent electric power. Then, for grid connected system, the PV panel is connected to power conditioning and control before it connects to the grid.

2.1.2 DC-DC full-bridge converter

In power electronics field, there are various types of DC-DC converter. Each type of converter has its own specific function and application. Those types of converter can be classified to a few groups. There are DC-DC converters that are suitable to step up and step down the input voltage. Some DC-DC converters are suitable for step down voltage and also some can be used for both applications. DC to DC converter or chopper is an electronic circuit that converts fixed direct current (DC) voltage from one level variable dc output voltage. Full-bridge converter is an isolated converter. Next, full-bridge converter is mainly used in switching power supplies and suitable for high power application. Full-bridge converter consists of four switching devices.

This converter is used to improve efficiency as high as possible with smaller size[10]. As stated earlier, DC to DC converter mainly used in switch mode power supplies (SMPS), DC motor control (battery-supplied vehicles) and more other application. Full-bridge converter circuit consists of four power switch which is MOSFET, transformer, two diodes, inductor, capacitor and load resistance. Thus, full-bridge converter will step up the input dc voltage value. Full-bridge converter also can operate in high frequency.

2.1.3 DC-DC push-pull converter

Push-pull converter is an isolated DC-DC converter that can step up and step down the voltage because it has a transformer in the circuit. The difference between push-pull converter and the full-bridge converter is push-pull converter has two windings transformer in both primary and secondary side while full-bridge only has one winding at primary side and two windings at secondary side. Push-pull converter has less switching devices which is only two while full-bridge has four. However, the switching control will be difficult because both switches cannot be activated simultaneously, resulting low impedance and high shoot through current potentially damaging and destroying the switch[10].

2.1.4 DC-DC boost converter

Boost converter is a converter that operates as a step up converter. It is because the output voltage will be higher than the input voltage and it is non-isolated converter[10]. Boost converter can operate while the switch is open and closed. Literally, it can operate with two conditions. The function of DC-DC boost converter is to convert the unregulated dc input voltage to a controlled dc output voltage. The boost converter circuit consist of inductor, capacitor, one power switch which is, diode and load resistance. In boost converter circuit, the capacitor generally added to output to perform the function of reducing the voltage ripple.

2.1.5 MOSFET

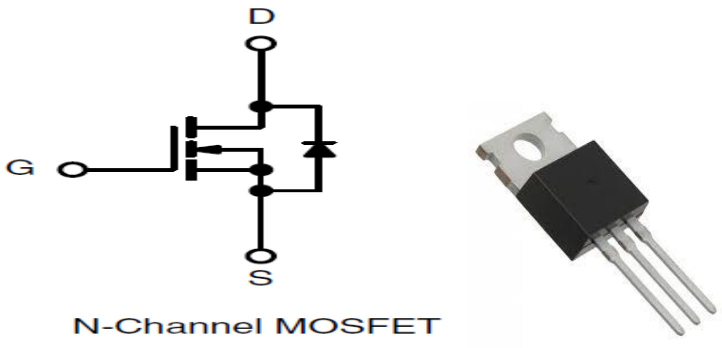

Figure 2.1: MOSFET

MOSFET or metal oxide silicon field effect transistor is a common switch and it is very fast device. The switching frequency of the MOSFET is higher than 100 kHz besides its frequency may go up to MHz range. Next, it comes up with two types which are n-channel and p-channel. It has three terminals which are drain, source and gate[2]. Furthermore, MOSFET are suitable for low voltage rather than IGBT which are suitable for high voltage application such as for multilevel inverter.

2.1.6 IGBT

IGBT or insulated gate bipolar transistor is one of the power switches that popular in electronic devices. IGBT is suitable for many applications in power electronics especially in pulse width modulation (PWM)[3]. Next, IGBT also suitable for three-phase drives requiring high dynamic range control. Then, IGBT has a very low-on state voltage drop because of its conductivity modulation and it also has low driving power with simple drive circuit.

2.1.7 High frequency transformers

High frequency transformers is a transformer that use the same basic principle as the standard transformer but it is operates at higher frequency. The high frequency transformer use frequencies from 20 kHz to 1 MHz.

The advantages of high frequency transformer is when the transformer operates at higher frequency, the size of the transformer would be small[4]. In addition, if the frequency is high, the size of transformer will be smaller in any given power rating. Therefore, with the size of the transformer is smaller, the copper wire needed is less which will reduce the losses and helps the transformer become more efficient.

2.1.8 Arduino Microcontroller

Arduino Uno is one of the most famous microcontroller boards nowadays. It is used widely by the armature and professional to design, prototype and building electronic project. Furthermore, it is simple to use as it just plug and play. The programs are easy to understand and even easy to control its input and output according to our project requirement.

The processor used in Arduino Uno is 8-bit ATmega328 processor, with a total of digital input/output pin and six analogue input pins. There are also three different timers using 16MHz crystal oscillator to generate PWM signal[11]. The timers which are Timer 0, Timer 1 and Timer 2 have its own two outputs and can be programmed to operate under different frequencies and duty cycle. Figure 2.2 shows the output pin for Timer 0 which is located on pin 5 and 6 while for Timer 1 and Timer 2 are located on pin 9, 10 and 11, 3 respectively. The block diagram and full schematic for Arduino Uno can be referred in appendix.

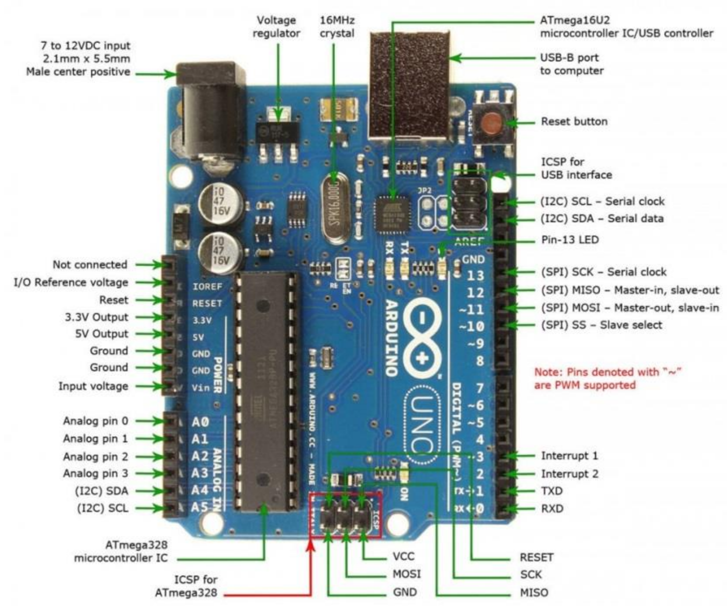

Figure 2.2: Arduino Uno Board Diagram

2.1.9 Gate Driver

Gate driver is a circuit that used to control circuit and power switch circuit. The function of gate driver is to control the desired voltage that required by the power switch circuit. In addition, it can also be used to isolate the power switch circuit such as buck converter topologies and others. Full-bridge converter also has high frequency switching devices which require four of it.

2.1.10 Pulse Width Modulation (PWM)

PWM is a modulation technique that produces pulse width signal that required the power switch to turn on and off. The signal produced by sawtooth waveform and reference voltage waveform is compared using comparator to get PWM output waveform. Next, duty cycle a ratio between turn on time of pulse and period of the pulse based on frequency designed. The duty cycle can be controlled with varying the reference voltage.

Therefore, when the reference voltage waveform is higher than sawtooth waveform, the output is high. Then, if the sawtooth waveform is higher than reference voltage waveform, the output is low. When the output is high, power switch will turn on and switch off when output is low.

2.2 PREVIOUS RELATED WORK

2.2.1 Analysis of Full-Bridge DC-DC Converter in Power System[5].

This paper presents a full-bridge converter which is used in green power application that involved high power and high voltage in power system. Next, it proposed the full-bridge converter with uncontrolled rectifier that uses three different operating modes which are discontinuous current mode (DCM), continuous current mode (CCM) and border mode.

Figure 2.4 shows the operating principle which is phase-shift control. The method proposed in this paper is phase-shift control method and the full-bridge converter is controlled by phase-shift algorithm.

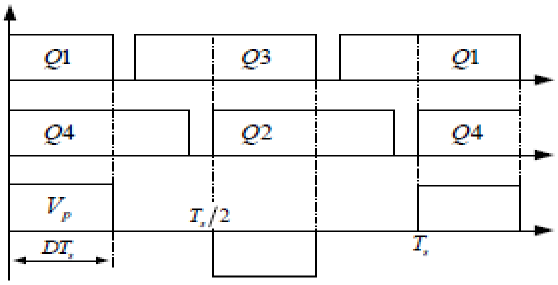

Figure 2.3: Switching state

The waveform labelled ‘Q’ represents the IGBTs in the circuit. IGBT Q1 and Q3 take turns to be switched on which are similar to IGBT Q2 and Q4[5]. However, IGBT Q1 and Q4 cannot be turned on at the same time. It must be a time delay between those power switches. Figure 2.5 shows the equivalent circuit of the full-bridge converter.

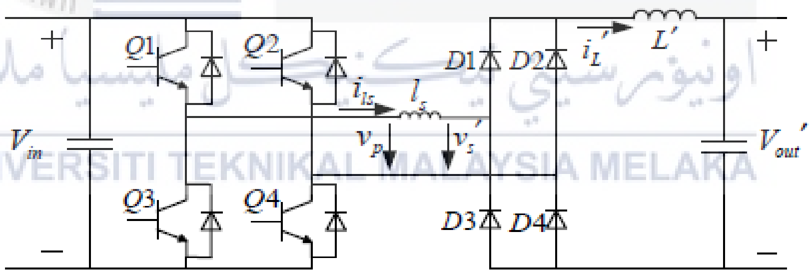

Figure 2.5: Equivalent circuit

The steady state operation with continuous current mode will be determined if the inductor current, I_L is always above zero. When the output inductor current is not good enough to keep the i_{ls} and i_L in continuous state and those current become zero at period of time each half cycle, the converter will be considered as in discontinuous current mode. Lastly, the border mode occurs between the continuous and discontinuous mode and the current i_{ls} and i_L only touches zero for a single moment in the half cycle.

2.2.2 IGBT OR MOSFET [9].

This paper discuss about the advantages and disadvantages of IGBT and MOSFET. It also discussed on how to choose the power switches between IGBT and MOSFET based on the application requirement. Next, the paper explains about the design similarities among those two power switches. Based on this paper, the different between IGBT and MOSFET is the voltage breakdown of IGBT is higher than the MOSFET which IGBT is above 1000V while MOSFET below 250V. The IGBT and MOSFET are selected based on application-specific and cost, size, thermal and speed requirement.

Table 2.1 shows the condition of IGBT and MOSFET that are preferred based on frequency, duty cycle, application, output power and the load.

Condition	IGBT	MOSFET
Duty cycle	Low duty cycle	High duty cycle
Output power	>5 kW output power	<500 W output power
Frequency	Low frequency (<20 kHz)	High frequency (>2000 kHz)
Load	Narrow or small line	Wide line
Application	High voltage application (>1000V)	Low voltage application (<250V)

Therefore, it can be conclude that IGBT and MOSFET are chosen based on application requirement and the selection between IGBT and MOSFET depend on specification of the application such as the frequency needed.

2.2.3 Design and Implementation of Full-Bridge DC-DC Converter for Photovoltaic Application[6].

This article explained about the selection of the component to design and develop a full-bridge DC-DC converter which more to the hardware implementation. Moreover, the simulation circuit is developed by using the MATLAB SimPowerSystem toolbox. The hardware development is more to prototype. Figure 2.7 shows the full-bridge DC-DC converter circuit.

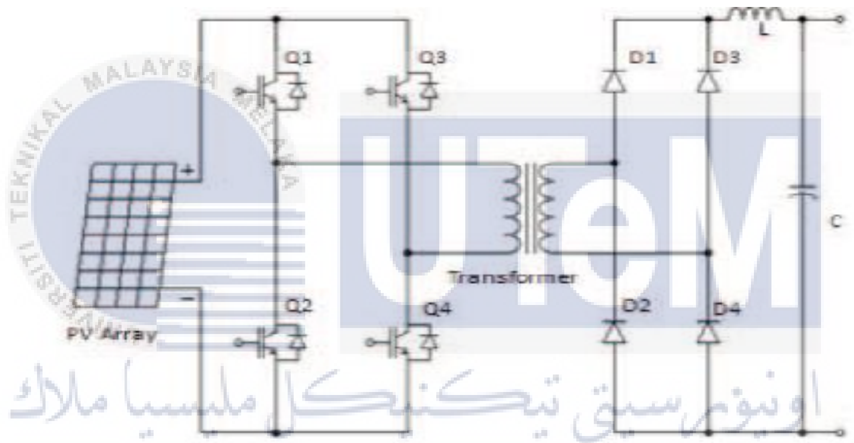

Figure 2.5: Full-bridge DC-DC converter

The prototype developed uses IGBTs FGA 15N120 as the power switches from the Fairchild Semiconductor. These IGBT selected based on its current handling capacity, operating frequency and voltage sustainability. Next, transformer and manufacturing is selected based on high power and high frequency. The transformer used in the project is MnZn P type core for 25 kHz frequency and 5 Kw power. The transformer design specification is shown in table 2.2.

Table 2.2: Transformer design specification

Core geometry	EE42
Wire gauge	22
Primary turns	108 turns
Secondary turns	108 turns
Calculated output power	2807 W
Calculated input power	3150 W

The PV input voltage is 19.94V while converter output voltage is 18.72V with duty cycle 50% and 3 kHz frequency. The prototype developed is tested in the laboratory and its efficiency is about 94%.

CHAPTER 3

DEVELOPMENT OF FULL-BRIDGE CONVERTER FOR PHOTOVOLTAIC APPLICATION

3.1 Introduction

This chapter will present about the methodology used for the project. The project is divided to two phase which are the simulation process of the DC-DC full-bridge converter and hardware development. The simulation process consists of open loop and close loop which are with and without feedback controller. The flow chart on figure 3.1 on and Gantt chart of table 3.1 and table 3.2 presents the detailed research activities.

3.1.1 Flow Chart

The flow chart methodology for Final Year Project 1 (FYP1) and Final Year Project 2 (FYP2) is shown in Figure 3.1. Methodology in FYP 1 is the selection of project title and conducting research about the project by reading journal, paper and reference books. The project starts with the study of full-bridge converter topology and the power switch operation. Next, the project continues with choosing the related software to design the simulation circuit for the full-bridge converter.

The MATLAB/Simulink is used to design the circuit of the open loop and close loop of the full-bridge converter. The simulation analysis is repeated if the result is different compared to calculation result. When the simulation is successful, the data is recorded.

The simulation circuit is now used to design the hardware circuit. FYP 2 starts with research on the components that will be used for the project. The research is carried by reading the journal, internet browsing, paper, reference book and others. Then, the type and the value of the components are selected based on the research. There are some components need to be designed for the converter circuit such as the high frequency transformer and inductor.

The hardware circuit is designed and tested on the breadboard. The device used to observe the result of PWM output, voltage and current on breadboard is oscilloscope. The troubleshoot option will be done if the output result is failed. The gate driver circuit also need to be designed in order to complete the project. Arduino Uno is selected as the microcontroller of the project which requires coding to be built.

This project is done with testing and observing of the Full-bridge converter circuit output on the oscilloscope. The data is analysed and recorded when the project is succeed. Lastly, the data is compared with the simulation result and the calculation result.

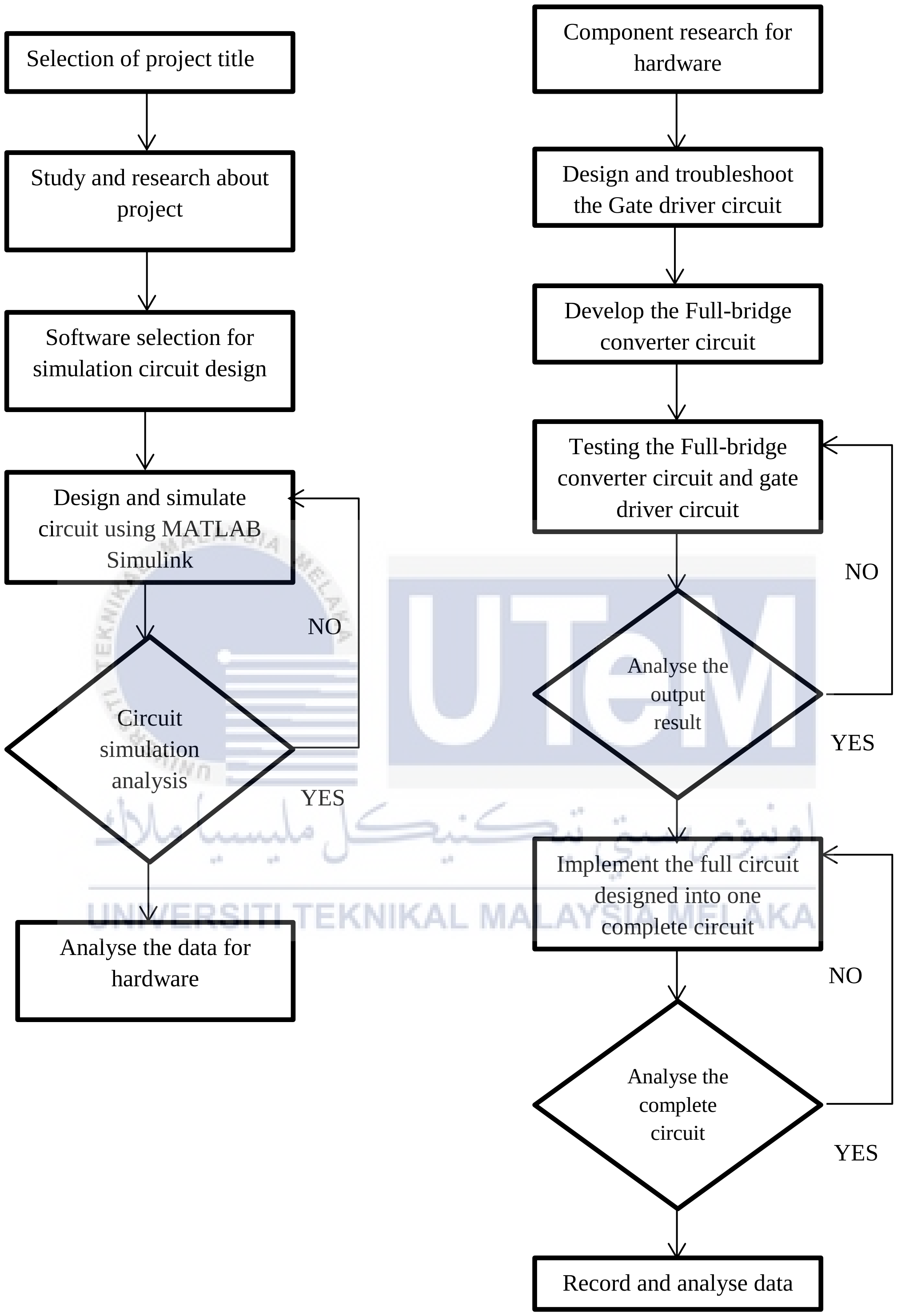

Figure 3.1: Flow chart

3.1.2 Gantt Chart

Table 3.1 and Table 3.2 show the Gantt chart for the activity in Final Year Project 1 and 2.

Table 3.1: Gantt chart of Final Year Project 1

TASK/ WEEK	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Research and study on DC to DC full-bridge converter														
Design and develop simulation of full bridge converter														
Analyse the simulation of full bridge converter														
Drafting the report														
Presentation														
Prepare the full report														
Submit full report														

Table 3.2: Gantt chart of Final Year Project 2

TASK/ WEEK	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Research and study on components used for full-bridge DC to DC converter	■	■	■												
Design and develop hardware full-bridge converter			■	■	■	■									
Testing and analyse the design of full bridge converter							■	■	■	■					
Drafting the report								■	■	■	■				
Prepare the full report										■	■	■	■		
Submit full report														■	
Presentation															■

3.2 Simulation approach

The open loop and close loop circuit of the full bridge converter are designed with the use of MATLAB/Simulink software. The MATLAB/Simulink software is able to design and simulate circuit according to designer requirement. Furthermore, it can design the controller circuit such as PI and PID controller circuit. Voltage and current can be measured using voltage and current measurement besides output waveform can be measured using the scope.

The full-bridge converter is designed based on voltage required by the multilevel inverter. The input supply which is from the PV panel is 12V. The simulation circuit of the full-bridge converter use DC supply which is also 12V. Then, the voltage is step up to 600V-700V through the step up transformer in the full-bridge converter. The parameter of the converter is calculated according to the full-bridge converter topology. The output voltage ripple is limited to 1% only. The switching frequency used in this simulation circuit is 10 kHz with the 0.45 duty cycle assumption.

1. Power and output voltage

   Power, P = 50W   Voltage, V= 700V

2. Find the value resistor

   Load resistor, R = $\frac{(V_{out})^2}{P}$ = $\frac{700^2}{50}$ = 9800 ohm   (3.1)

3. Find the value of secondary turns, N_S.

   The number of primary turns selected, N_p = 25 turns

   From equation; $V_{out} = 2V_S\left(\frac{N_s}{N_p}\right)D$ (3.2)

$$700 = 2(12)\frac{N_S}{25}(0.45)$$

$$N_s = 1620 \text{ turns}$$

4. Find the period, T

$$T = \frac{1}{fs} = \frac{1}{10000} = 1 \times 10^{-4} \quad (3.3)$$

5. Find the value of inductor, L_X

Assume the value change of inductor current, $\Delta I_{Lx} = 0$

From the equation, $$0 = \frac{Vo}{R} - \left(\frac{Vo\ (0.5-D)T}{L_X}\right) \quad (3.5)$$

$$0 = \frac{700}{9800} - \left(\frac{700\ (0.5-0.45)0.0001}{L_X}\right)$$

$$\frac{900}{2700} = \left(\frac{0.018}{L_X}\right)$$

$$L_X = 49\ mH$$

6. Find the value of the capacitor, C with the output voltage ripple 1%

From the equation, $$C = \frac{1-2D}{32 L_x r\ f^2} \quad (3.4)$$

$$C = \left(\frac{1-2(0.45)}{32(0.049)(0.01)\ (10000)^2}\right)$$

$$C = 65\ nF$$

Table 3.3: Calculation parameter

	Parameter	Value
1.	Vin	12V
2.	Vout	700V
3.	Duty cycle	0.45
4.	Capacitor, C	65 nF
5.	Voltage ripple	0.01
6.	Load resistance	9.8 $kohm$
7.	Inductor, Lx	49 mH

3.3 Design Full-bridge Converter Simulation Circuit

Full-bridge DC-DC converter can operates at two modes which are continuous current mode (CCM) and discontinuous current modes (DCM). Continuous current mode is applied for getting an efficient power conversion while discontinuous current mode is applied at stand by application. At CCM condition, the inductor current will not reach zero during switching operation. The CCM mode operation is applied at open loop and close loop system of full-bridge converter of this project.

3.3.1 Basic operation of full-bridge converter

The full-bridge converter has almost the same principles operation as push-pull converter and half bridge converter but the unique features of this converter is it has four power switches to operate. Firstly, if we assume the transformer is ideal, the full-bridge converter has switch pair (Sw_1, Sw_2) and (Sw_3, Sw_4)which can alternate closing. In addition, if one pair is conducted, the other pair will be in off stated. The voltage across the transformer primary is positive V_s if the Sw_1 and Sw_2 are closed while the primary voltage across the transformer is negative -V_s when Sw_3 and Sw_4 are closed. The full-bridge converter can reduce voltage stress across an open switch when the input voltage is high. Figure 3.2 shows the full-bridge converter.

3.3.2 Open loop Full-bridge Converter

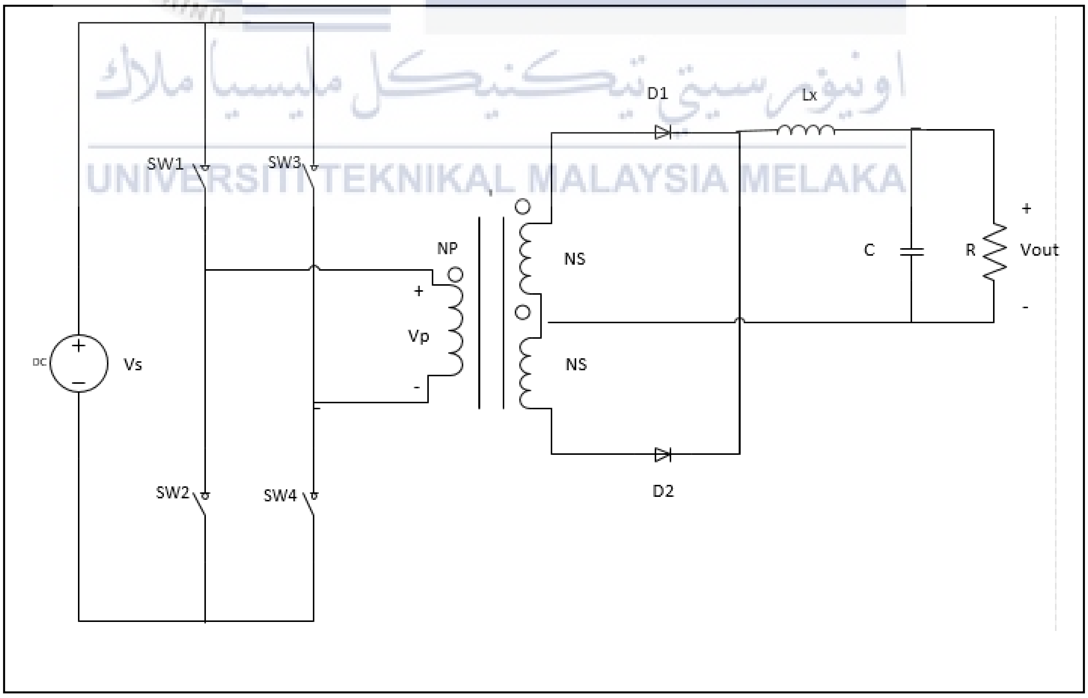

Figure 3.2: Open loop Full-bridge converter

Figure 3.2 shows the schematic diagram of open loop full-bridge converter to step up the input voltage. The basic operation of the full-bridge converter is involving two switching devices at one time for one half cycle of the control waveform. The other two switching devices will be operated after the half cycle completed. Open loop is referred to non-feedback system and it is a continuous control type system and it has no effect on the control action of the input signal. The circuit diagram uses four switching devices which are MOSFETs and other components such as diodes, inductor, capacitor, resistor and DC voltage source. The value of the duty cycle used in the circuit diagram is 0.45 which below than 0.5 based on the topology of full-bridge converter. PV solar panel will act as the input voltage source. The DC voltage from the PV solar panel is set to 12V and will be step up to range of 600V-700V. The circuit in figure 3.2 is constructed using MATLAB/Simulink software.

3.3.2 Close loop Full-bridge Converter

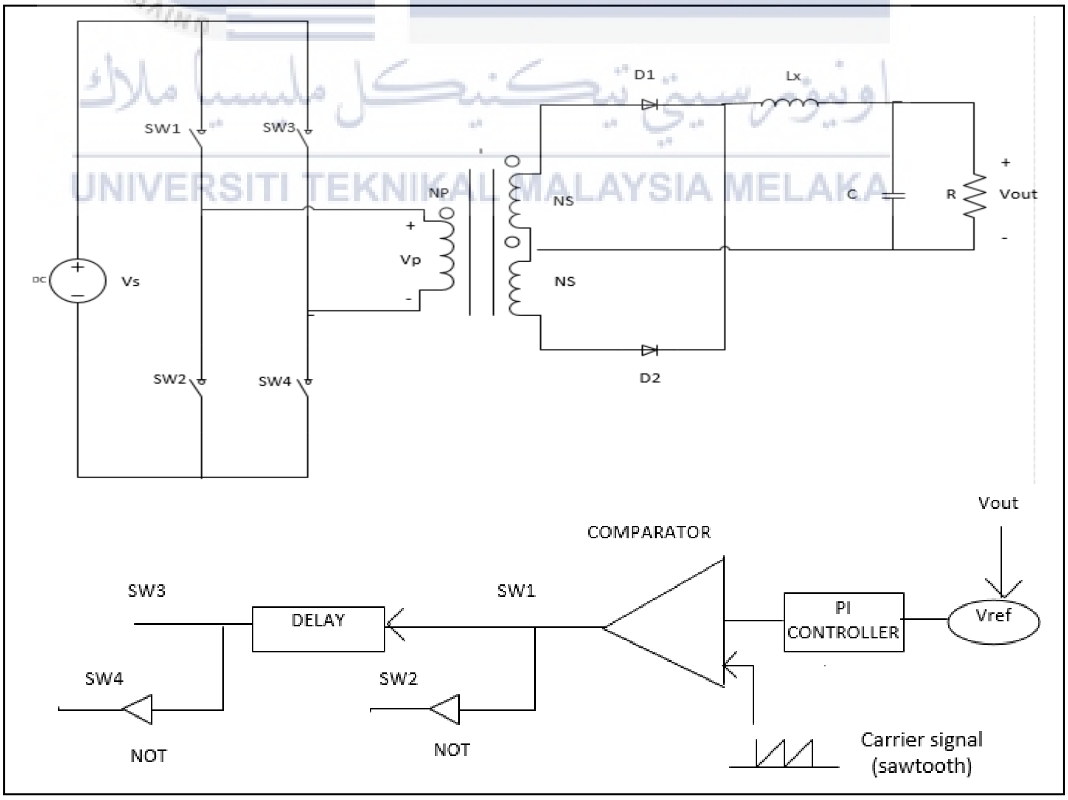

Figure 3.3: Block diagram of close loop control full-bridge converter

Close loop full-bridge converter is designed to maintain the output voltage required by the load. All the parameter used to design the close loop system is the same as the open loop. Close loop system consists of feedback controller which used to maintain the output voltage produce from the input. In order to produce fixed output voltage, Proportional Integral (PI) controller is used in the circuit diagram. The voltage reference in the diagram is 650V which in range of desired output voltage. Capacitance value in the circuit will minimize the voltage output ripple at output voltage. The proportional (P) value is 0.01 while the integral (I) value is 100 which greater than proportional value. The reason PI controller used in this project is because PI controller is the most simplest and effective compared to other controller.

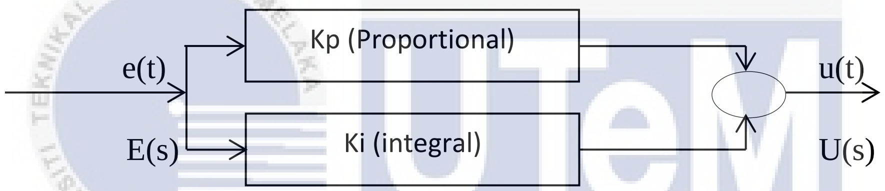

Figure 3.4: Block diagram of PI controller

The basic form of PI controller is

$$U(t) = K_P \left[e(t) + \frac{1}{T_i} \int_0^t e(\tau) d(\tau) \right]$$

Those u(t) and e(t) denote control and the error signal respectively, K_p and K_i are the parameter to be tuned.

3.4 Hardware approach

This section will discuss in detail about the hardware implementation in the project. Moreover, the implementation of Arduino Uno microcontroller to generate the switching pulse also will be discussed in this section. Figure 3.5 shows the block diagram that represents the main components of the proposed DC-DC full-bridge converter. The parameter of components use such as inductor, capacitor and resistor may different from the calculation and simulation because of hardware implementation and to get the best output result. Therefore, each of the block function and purpose will be discussed and thoroughly in detail in next section.

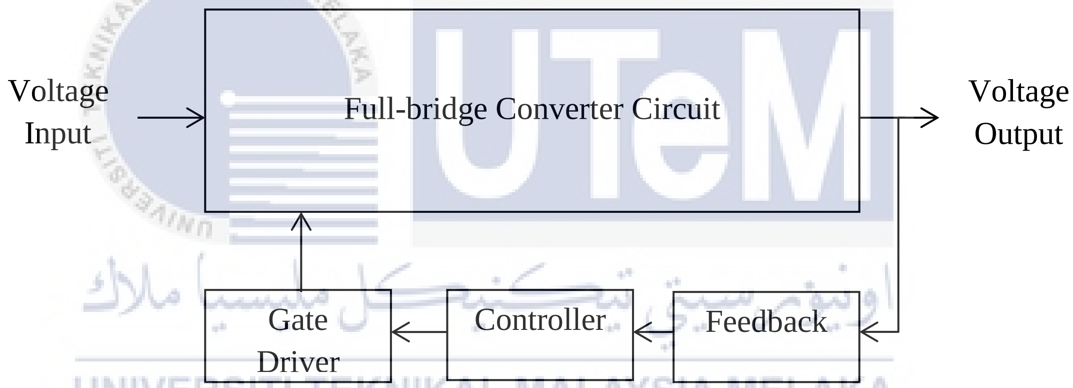

Figure 3.5: Block Diagram for the Full-bridge converter circuit

3.4.1 Controller

Controller is like a brain for the project. The aim for this project is to generate pulse for the switching devices which is MOSFET. Arduino Uno is chosen from the other microcontroller to carry the task because of its capability to generate switching frequency up to 8 MHz. Figure 3.4 shows the Arduino controller input and output circuit schematic connection used in this project. The output pins used on the Arduino board are Pin D13, D8, D12 and D7 to sense the input voltage. Pin D13 and D8 are paired and generate the same pulse while pin D12 will generate the other same pulse with pin D7. The input is connected to the board via the USB cable.

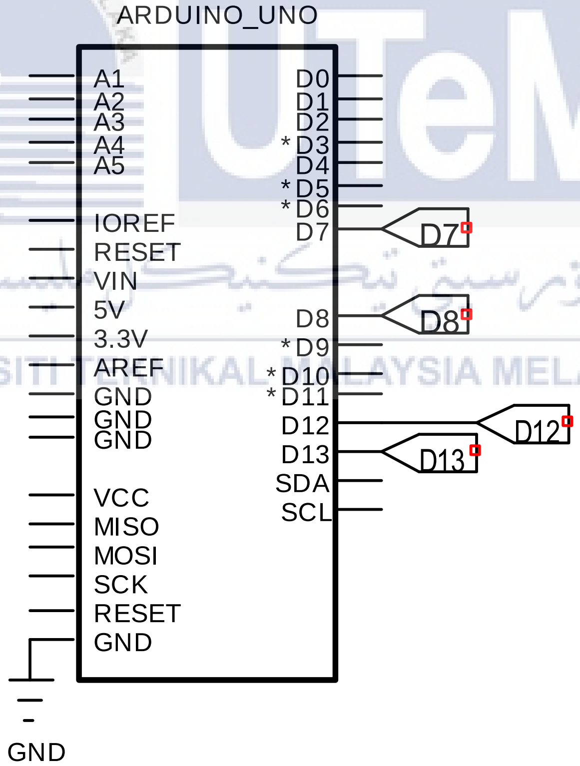

Figure 3.6: Arduino Uno circuit schematic

3.4.2 Gate Driver Circuit

Gate driver used in this project is to provide required voltage that need by power switches to turn on. There are two gate driver used in this project because one gate driver only can control two MOSFETs. Therefore to control 4 MOSFETs, 2 gate drivers will be used. Besides that, it is used to provide isolation between the controller circuit and converter circuit. The PCB's layout and the schematic circuit diagram of the gate driver are shown in Appendix A. The input ports that receive the pulse generation from the microcontroller are IN1 and IN3 in both gate drivers.

The other input ports which are EN1 and EN3 are used to receive 5 volts supply from DC source. However, the IN2 and IN4 cannot be used because those input ports are used for other option. Figure 3.7 shows the input ports of the gate driver.

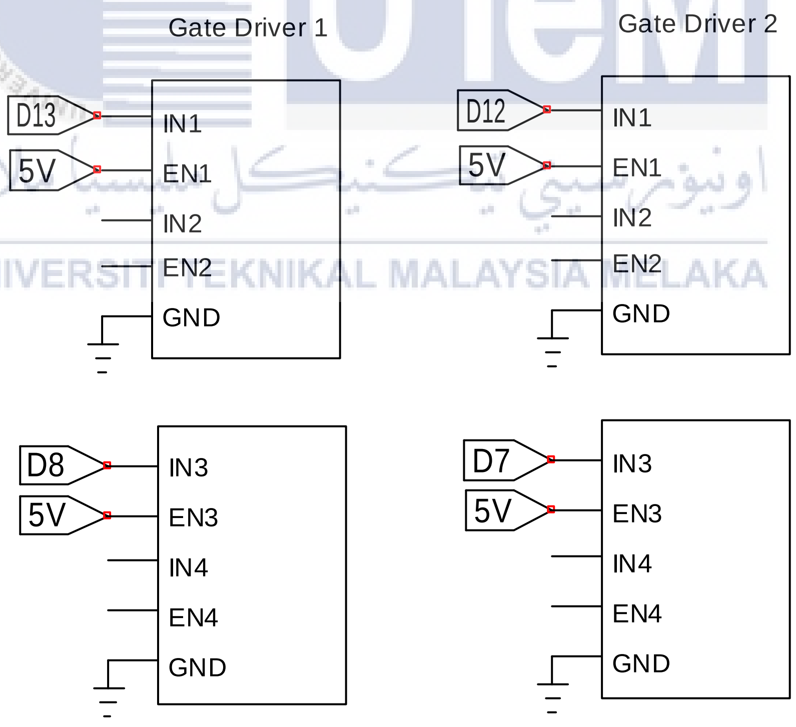

Figure 3.7: Input ports of the gate driver

Figure 3.8 shows the output ports of the gate driver. Each output G and S will be connected to the gate port and source port of the MOSFET. Therefore, G1 and S1 will be connected to MOSFET 1 while G3 and S3 will be connected to MOSFET 3 in full-bridge converter circuit. On the other hand, G2 S2 and G4 S4 output ports will not be used because the ports are compliment to G1 S1 and G3 S3 respectively. Those output ports are on the first gate driver while the second gate driver will use the same method and will be connected to MOSFET 4 and MOSFET 2. Moreover, the input ports of the second gate driver will be the same as the first one.

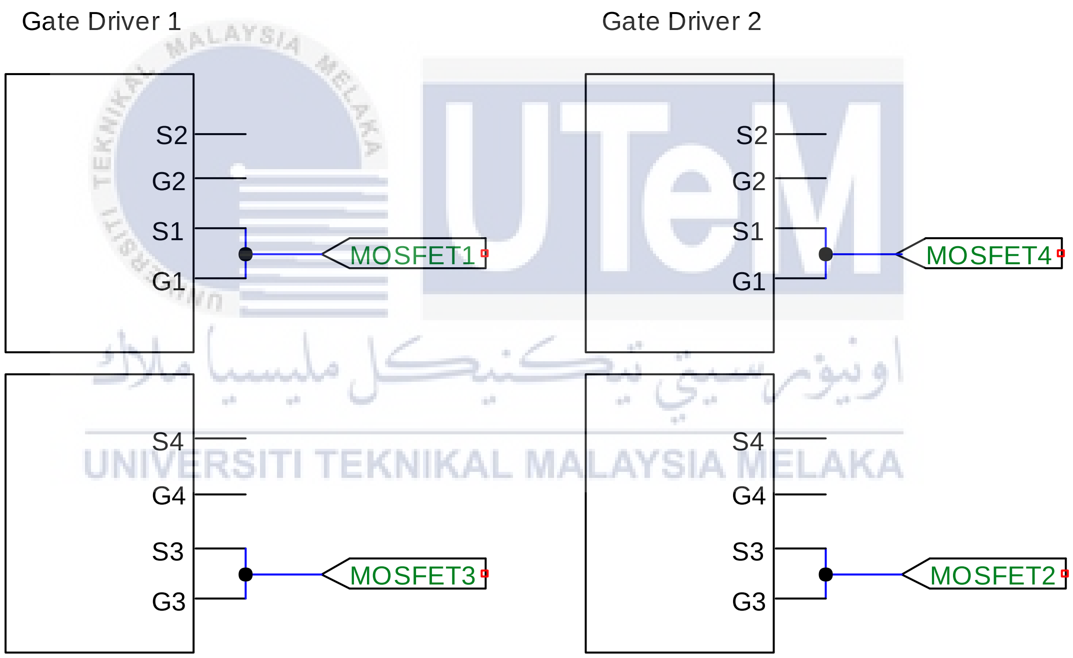

Figure 3.8: Output ports of the gate driver

3.4.3 Full-bridge Converter Circuit

The Full-bridge converter circuit is drive by the PWM signal through the gate driver at the gate of the MOSFETs. Figure 3.9 shows the full-bridge converter circuit that are connected to gate driver output ports. The converter circuit will receive supply 12V from DC source which is solar panel. The converter circuit consist of the full-bridge components such as inductor, capacitor, resistor, high frequency transformer and MOSFETs. The full-bridge converter circuit is mainly to step up low voltage to high voltage level.

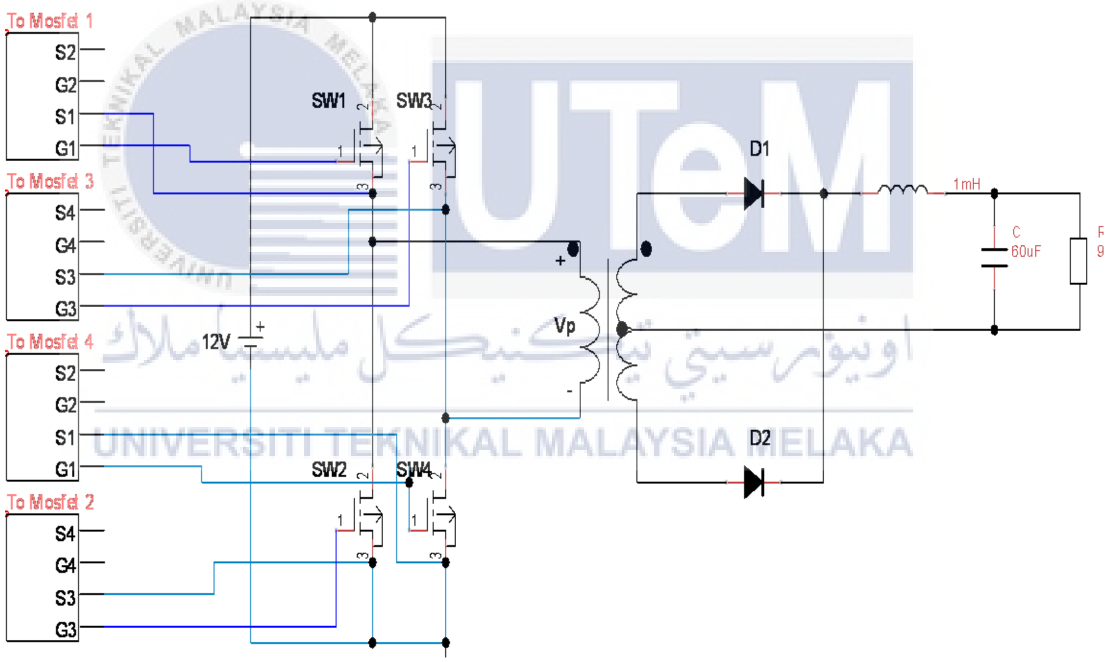

Figure 3.9: Full-bridge converter circuit

3.4.3.1 Inductor and Capacitor

Capacitor and inductor are passive components that plays important role in the full-bridge converter circuit. Capacitor is use for limiting the output voltage ripple while inductor is use to reduce the current ripple and it provide the continuous output current for the converter circuit. The capacitor value used in the hardware setup is 56uF. Voltage rating for the capacitor is 500V because of the high voltage consumed of the circuit.

Inductor value used in the project is 1.5mH and it is designed by using toroid core. The diameter of coil chosen for designing the toroid core based on the calculation from web ferrite toroid online calculator. Table 3.4 shows the value of inductor and capacitor. Based on the research, to implement the hardware, the value of capacitor and inductor can be lower than the calculated value.

The inner diameter of the toroid core is 2.3mm while inner diameter of the toroid core is 1.4mm. The height of the toroid core is 0.5mm and its magnetic permeability is around 3000. Therefore, the diameter of coil chosen is 0.32mm. The result for number of turns of winding is around 83 turns. Figure 3.10 shows the online calculator result. The link used to access the online calculator is https://coil32.net/online-calculators/ferrite-torroid-calculator.html and there are varieties of calculator to calculate different types of coil and inductor. The value of inductor designed is measured by inductor equipment is shown on Figure 3.11.

Table 3.4: Calculated and chosen value of capacitor and inductor

Calculated value	**Chosen value**
Capacitor = 65 nF	Capacitor = 56nF
Inductor = 49 mH	Inductor = 1.5 mH

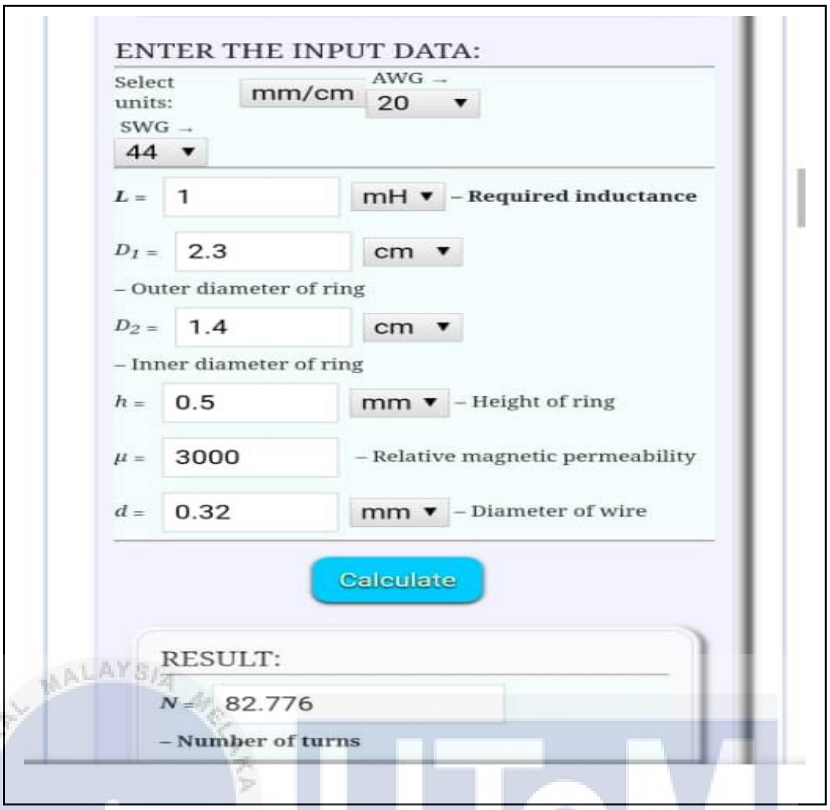

Figure 3.10: Toroid core inductor calculator

Figure 3.11: Inductor value

Figure 3.12: Inductor design

3.4.3.2 High frequency transformer

High frequency transformer is a transformer that use the same basic principle as the standard transformer but it is operates at higher frequency. The full-bridge converter circuit requires a transformer to operate. Therefore, a step up transformer is designed based on the calculation. The full-bridge converter topology from equation (3.2) is used to calculate the number of turns and resulting 1620 turns for a secondary turns.

The primary turns chosen for the transformer is 25 turns. In addition, the full-bridge topology has two windings at the secondary turns of the transformer. Therefore, the 1620 turns must divides into two resulting 810 turns for each winding.

The diameter of wire for the transformer coil at the first winding is 0.8mm while at the second and third winding the diameter of wire chosen is 0.45mm. Figure 3.13 shows the transformer designed.

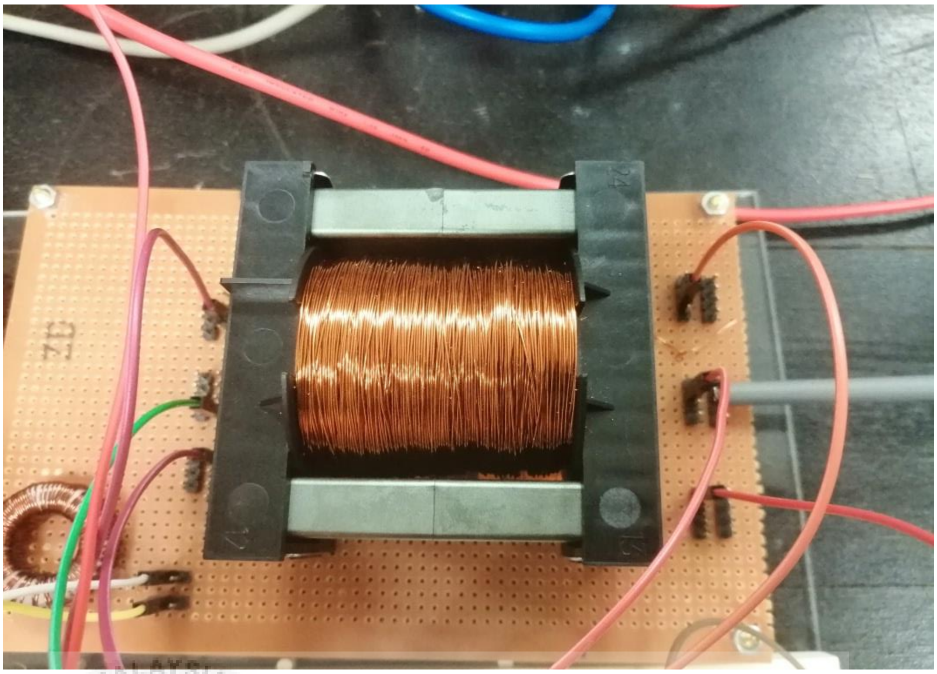

Figure 3.13: Transformer designed

3.4.3.3 Power switch

N-type Power MOSFET as shown in Figure 3.14 below is selected as the power switch for the high side switching of the proposed converter circuit. There are 4 MOSFETs in the full-bridge converter circuit according to the topology. The positive input supply will be connected to the drain port of the MOSFET 1 and MOSFET 3 while the negative input supply will be connected to source port of the MOSFET 2 and MOSFET 4.

The MOSFET is selected as the power switching devices because of it high frequency switching capability and gate driver requirement. Suitable MOSFET is chosen based on its Vdss rating which must exceed the voltage. As stated earlier, the positive side of primary winding will be connected to source port of the MOSFET 1 and the negative side of the primary winding will connect to drain port of the MOSFET 4.

Moreover, the MOSFET can reduce the switching losses and improved efficiency in high frequency application. The datasheet of MOSFET IRF840 is shown in Appendix B.

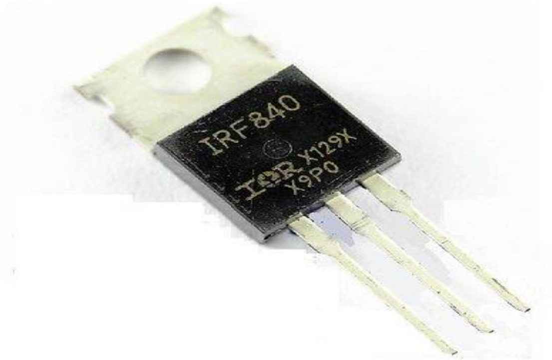

Figure 3.14: MOSFET IRF840

3.4.3.4 Diode

In the application of the power circuit, the international rectifier HFA08TB60 diode is chosen because of its fast recovery. The diode is shown in figure 3.15. This diode is suitable for the use of high speed, high efficiency, power supplies and power conversion system. It has very high voltage rating which is 600V. The advantages of this diode make it is the most suitable diode to be used in the full-bridge converter circuit. The datasheet of HFA08TB60 diode can be referred in Appendix C.

Figure 3.15: Diode HFA08TB60

3.5 Hardware setup

The project is mainly setup according to the topology of full-bridge converter and block diagram of the converter circuit on Figure 3.5. The full-bridge converter circuit is connected and tested on a breadboard. Based on the circuit designed, the power supply of 12V is connected at the input terminal which is at drain port of MOSFET 1 and source port of MOSFET 2. The output pins used from the Arduino Uno are pin 7,8,12 and 13 and then connected to gate driver input port as shown in Figure 3.7. The Arduino Uno is connected to the laptop using USB cable connection in order to upload the program code. The program codes will be discussed later in Chapter 4. Moreover, the USB connection is also act as the power supply for the Arduino board.

Basically, the input supply for the converter circuit is obtained from the solar panel but because of some issues and difficulties, only DC supply is used to provide input voltage to the circuit. The oscilloscope is used in order to obtain the output waveform by connecting the probe to the output pin. Figure 3.16 shows the full setup for the hardware project.

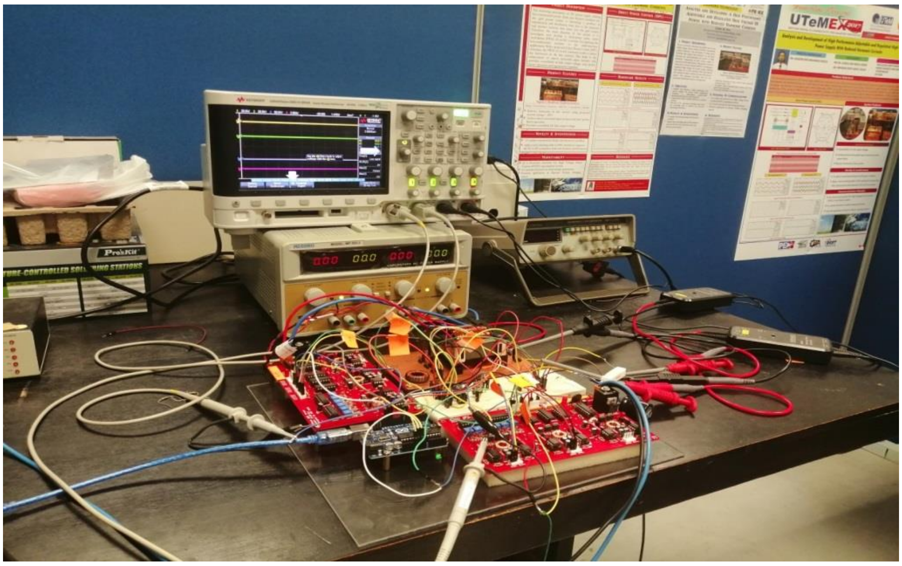

Figure 3.16: Hardware setup

CHAPTER 4

RESULT AND DISCUSSION

4.1 Simulation result

The result consists of the circuit design, simulation of open loop and close loop full-bridge converter and data analysis. The open loop and close loop full-bridge converter simulation circuit is analysed with steady state analysis. The result obtained is voltage output waveform, inductor current waveform, switching waveform, the primary and secondary transformer voltage waveform of open loop and close loop full-bridge converter. The result is analysed and compared with calculation result.

4.2 Switching state of circuit simulation model

Figure 4.1 shows the switching waveform of the MOSFETs in the circuit simulation model. In the simulation model, the full-bridge converter has its switch pairs which are MOSFET 1 with MOSFET 4 and MOSFET 2 with MOSFET 3. When the MOSFET 1 and 4 are closed, the MOSFET 2 and 3 will open. Then, when MOSFET 2 and 3 are closed, MOSFET 1 and 4 will open.

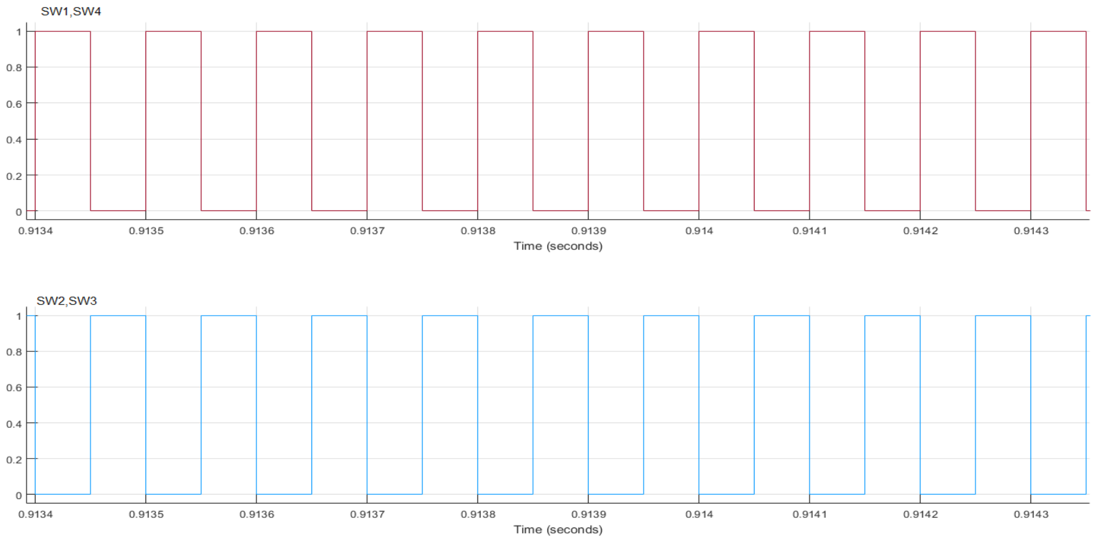

Figure 4.1: Switching waveform of MOSFETs pair

The first graph shows the MOSFET 1 and 4 pairs and the second graph shows the MOSFET 2 and 3 pairs. The slope is existed in the second graph because of the transport delay block. There is a time delay created between each pair to operate which are $50\mu s$.

From the equation, $$T_S = \frac{1}{2f} \quad (4.1)$$

$$= \frac{1}{2(10000)} = 50\mu s$$

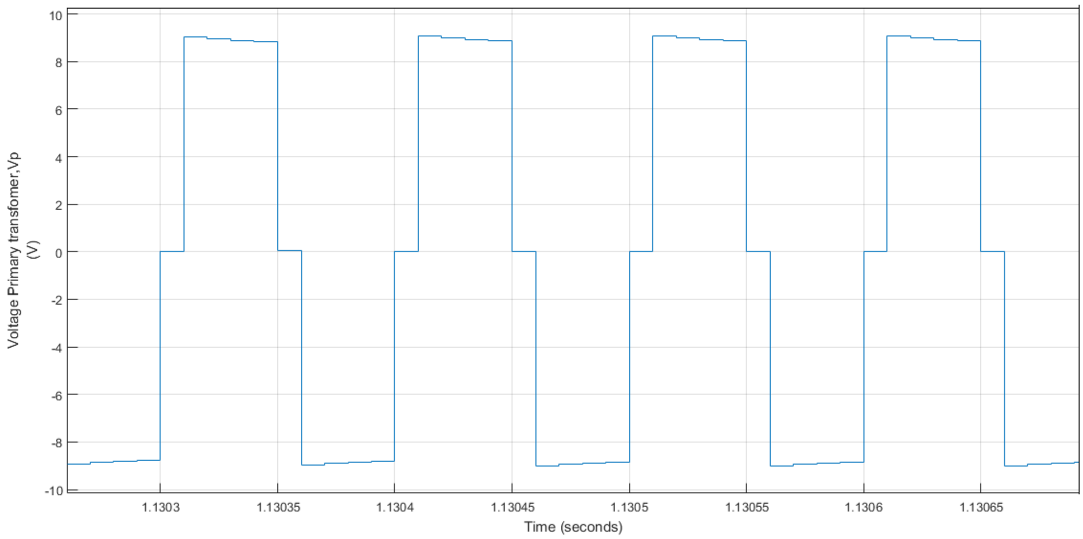

Figure 4.2: Voltage across the primary transformer

Figure 4.2 shows the voltage across the primary transformer waveform. When the MOSFET 1 and 4 operates the voltage across the primary transformer will be V_P. Then, when MOSFET 2 and 3 operates the voltage across the primary transformer is $-V_P$. The delay for switching pair to operate will give the voltage, V_P equal to 0. Apparently, the result of switching waveform in both open loop and close loop are the same because in PI controller in the close loop does not affect the switching state.

4.3 Open loop Full-bridge Converter

Figure 4.3 shows the circuit simulation model of the open loop full-bridge converter. The repeating sequence block is used to generate output waveform with 10 kHz switching frequency and 0.45 duty cycle. The input and output voltage is measured by voltage measurement while inductor current is measured by using current measurement. Transport delay block is used to create a delay between SW1, SW4 and SW2, SW3 for the switching frequency. The waveform of the simulation is observed by using scope.

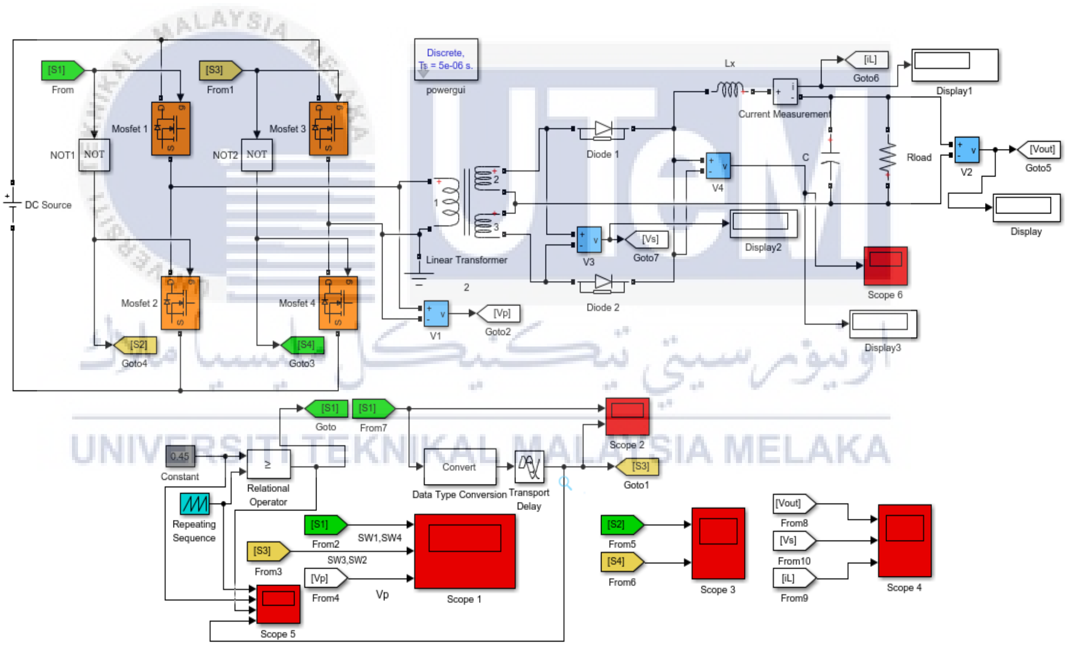

Figure 4.3: Circuit simulation model Full-bridge converter

4.3.1 Steady state analysis of open loop full-bridge converter

Steady state analysis is measured with fixed value of parameter as the simulation approach. The result of the analysis is output voltage waveform, inductor current, primary and secondary transformer voltage.

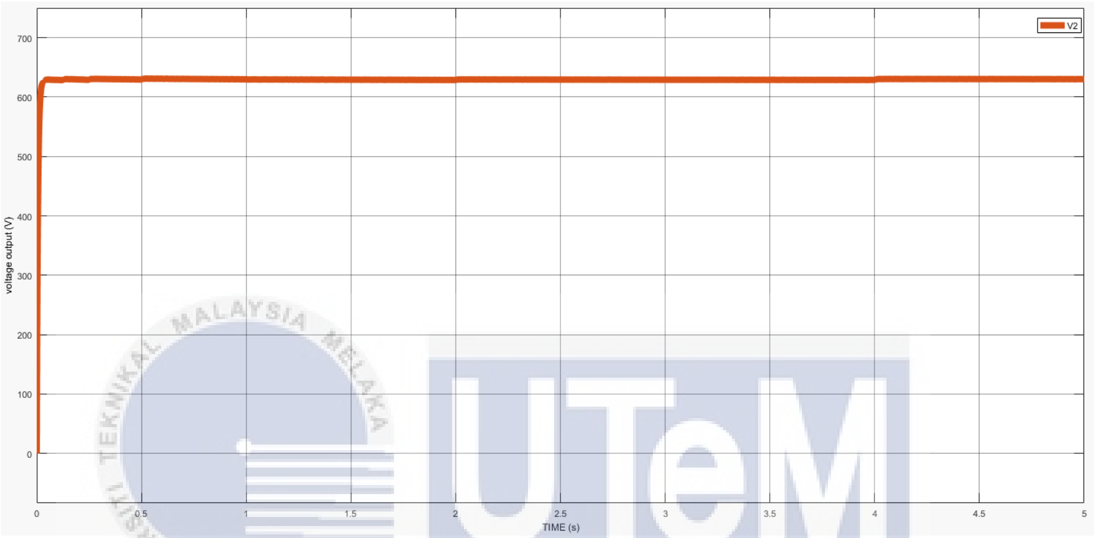

Figure 4.4: Output voltage waveform

Figure 4.4 shows the output voltage waveform at the load. The output voltage value shown in the graph is varies between 638V to 655V which in range of the required output voltage.

Figure 4.5 shows output inductor current which is 0.054 A at peak value. The output current waveform is produced in continuous current mode because the value of the output current never fall to zero and fulfil the requirement of the design of full-bridge converter in CCM.

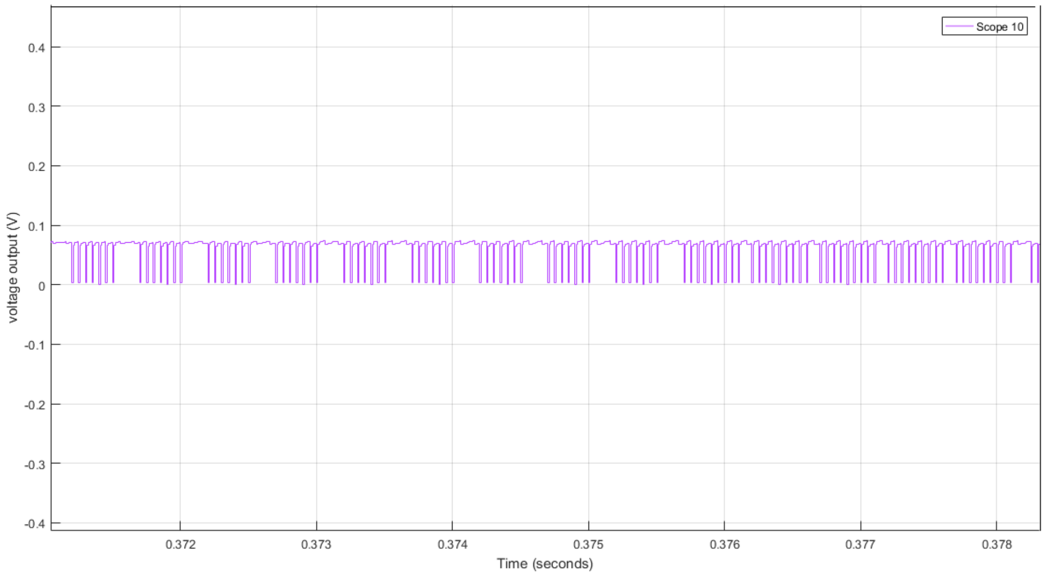

Figure 4.5: Output inductor current waveform

Table 4.1 shows the parameter used in the simulation model of the full-bridge converter.

	Open loop Full-bridge converter	
	Parameter	**Value**
1.	Vin	12V
2.	Vout	638V-655V
3.	Duty cycle	0.45
4.	Inductor current	0.054A
5.	Voltage ripple	0.01
6.	Load resistance	9.8 *kohm*

4.4 Dynamic analysis open loop full-bridge converter

Dynamic analysis of open loop converter is analysed in two conditions which are voltage fixed while duty cycle varied and voltage varied while duty cycle is fixed. The purpose of the analysis is to control the output voltage by variable duty ratio and voltage input of full-bridge converter.

4.4.1 Analysis of fixed voltage and varied duty cycle

The purpose of this analysis is to control the output voltage based on changing the duty cycle of the open loop full-bridge converter circuit by using the same parameters as steady state analysis except the duty cycle.

Table 4.2 shows the analysis result by varying the duty cycle from 0.2 to 0.8. Based on the table 4.2, the simulation is different with calculation because open loop of full-bridge converter simulation circuit regulates poor output voltage.

Table 4.2: Output voltage when duty varied

Duty cycle	**Voltage Output (V) calculation**	**Voltage Output (V) simulation**
0.2	311.04	560.5
0.4	622.08	650.4
0.5	777.60	670.8
0.6	933.12	750.3
0.8	1244.16	792.4

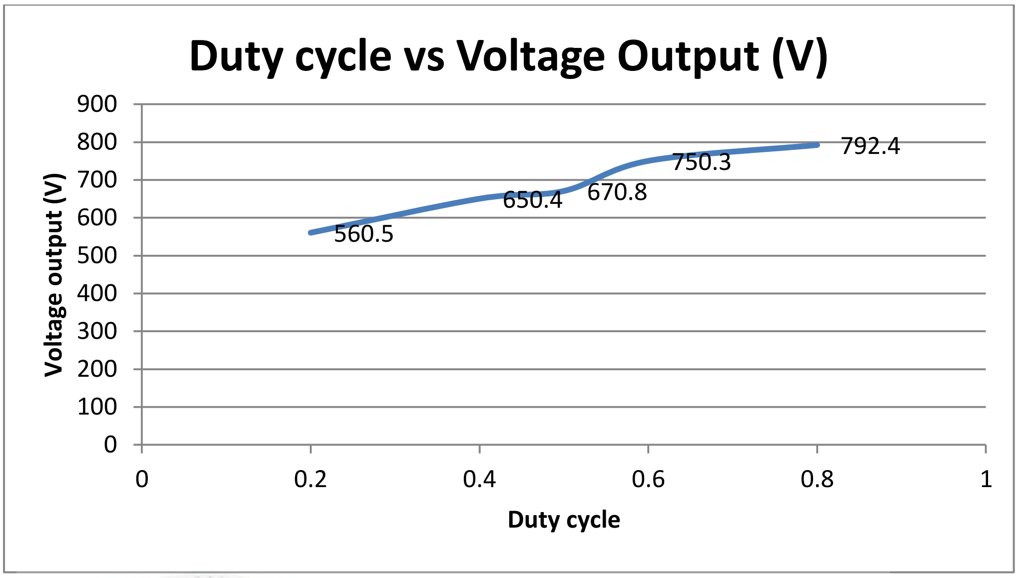

Figure 4.6: Duty cycle against voltage output when voltage input fixed

Figure 4.6 shows the graph of duty cycle and voltage output. Based on the graph, when the duty cycle increases, the output voltage also increases. The graph shows the output voltage increase linearly by the duty cycle. Therefore, when the used of high duty cycle, the open loop full-bridge converter circuit step up higher output voltage.

Based on the analysis, the output voltage of the open loop full-bridge converter circuit can be controlled by varying the duty cycle.

4.4.2 Analysis of fixed duty cycle and varied input voltage

The purpose of this analysis is to analyse the output voltage by varying the input voltage of the open loop full-bridge converter. The parameter used is the same as the steady state analysis except the input voltage.

Table 4.3 shows the voltage output results when duty cycle is set to 0.45 and input voltage is varied between 12V to 60V the result of the analysis is compared with the calculation result. Therefore, based on the result the open loop full-bridge converter produce poor output voltage which not same as the calculation value.

Figure 4.7 shows the graph of voltage input and output. The output voltage is directly proportional to the input voltage and linearly increases. Therefore, it concludes that the output voltage can be controlled by varying the input voltage.

Table 4.3: Output voltage when input voltage varied

Voltage input (V)	Voltage Output (V) calculation	Voltage Output (V) simulation
12	700	664
24	1400	1336
36	2100	2012
48	2800	2678
60	3500	3342

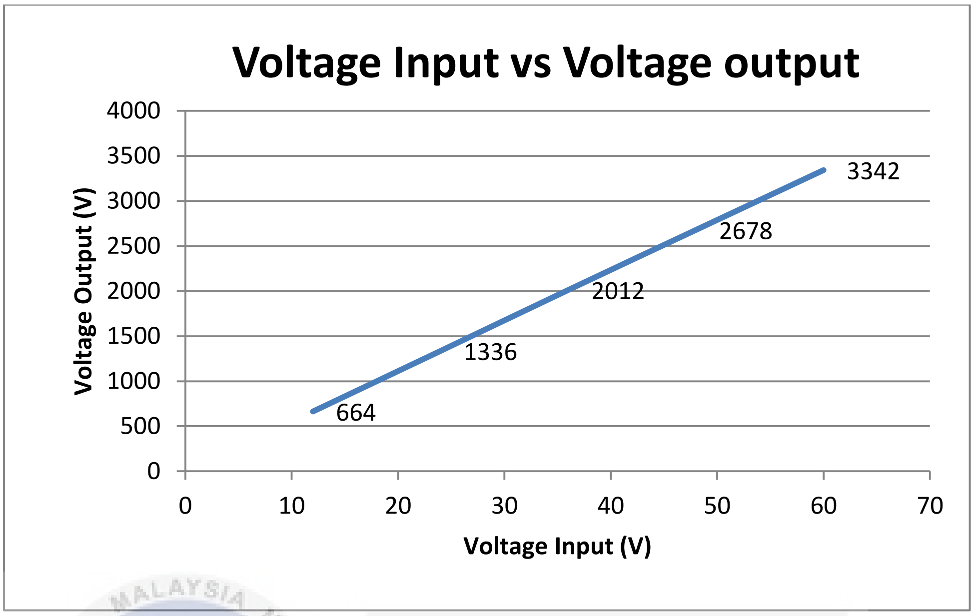

Figure 4.7: Voltage input against voltage output when duty cycle is fixed

4.5 Close loop Full-bridge Converter

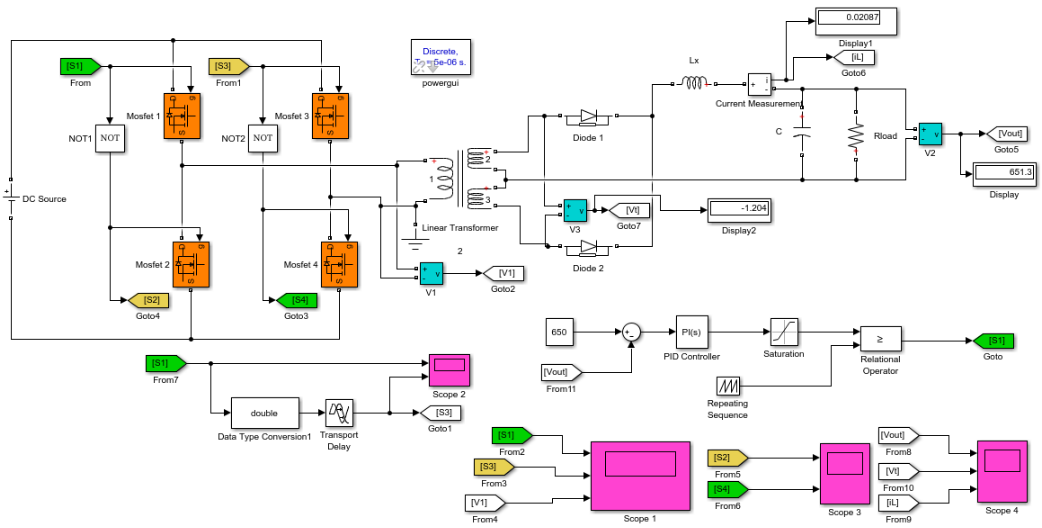

Figure 4.8: Close loop full-bridge converter

Figure 4.8 shows the full schematic diagram of the close loop full-bridge converter which is designed in the MATLAB/Simulink software. The circuit simulation model uses PI controller to regulate a constant output voltage that required by the load. The simulation model uses 650V as the voltage reference, Vref. Next, the PI controller in the circuit of close loop full-bridge converter has the parameter value of Kp and Ki which are assumed to get the desired output voltage. The value of Kp and Ki are assumed as 0.01 and 100 respectively

4.5.1 Steady state analysis close loop full-bridge converter

The close loop simulation circuit is analysed in steady state at fixed parameters. The purpose of the analysis to get the constant output voltage based on designed parameters.

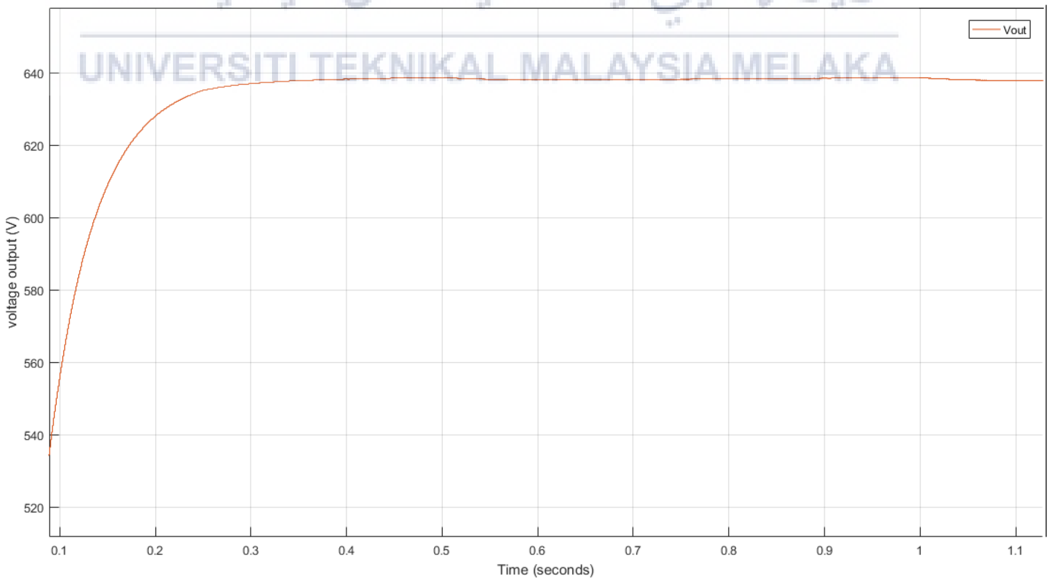

Figure 4.9: Close loop output voltage waveform

Figure 4.9 shows the output voltage waveform of close loop full-bridge converter. The feedback controller shows it operates when the waveform produces good regulated voltage. The value of the output voltage is varies between 648V and 652V which more stable than the open loop system.

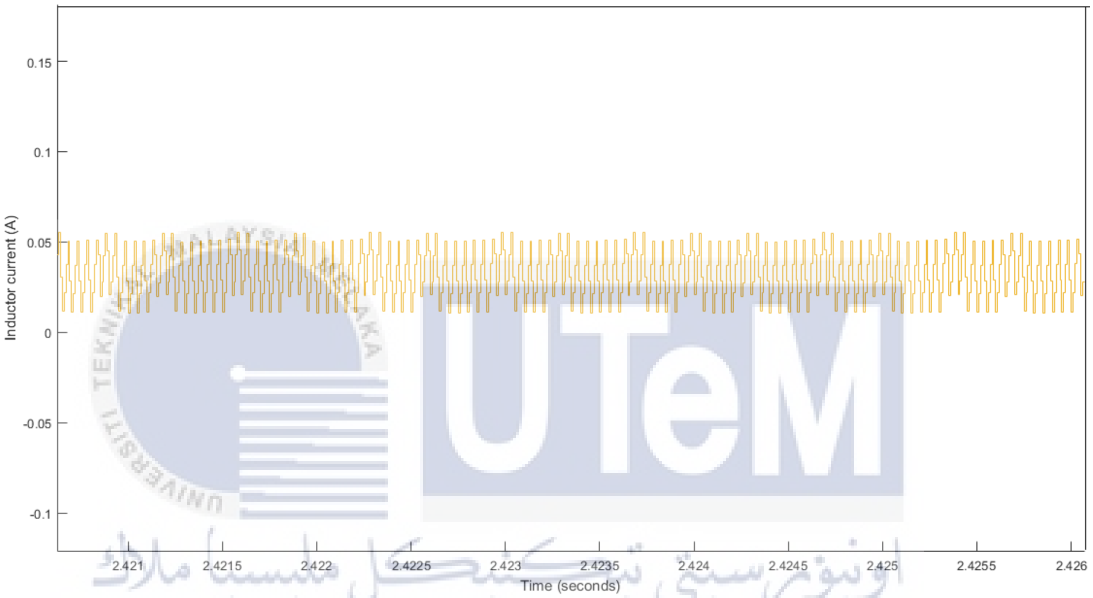

Figure 4.10: Output inductor current waveform

Figure 4.10 shows the output inductor current waveform which at peak value 0.02A.

4.6 Dynamic analysis close loop full-bridge converter

Dynamic analysis close loop full-bridge converter is analysed into two conditions. First condition is value of voltage output and voltage reference is fixed while load varies or load variation. Next, value of voltage input and load fixed while voltage reference varies.

4.6.1 Load Variation

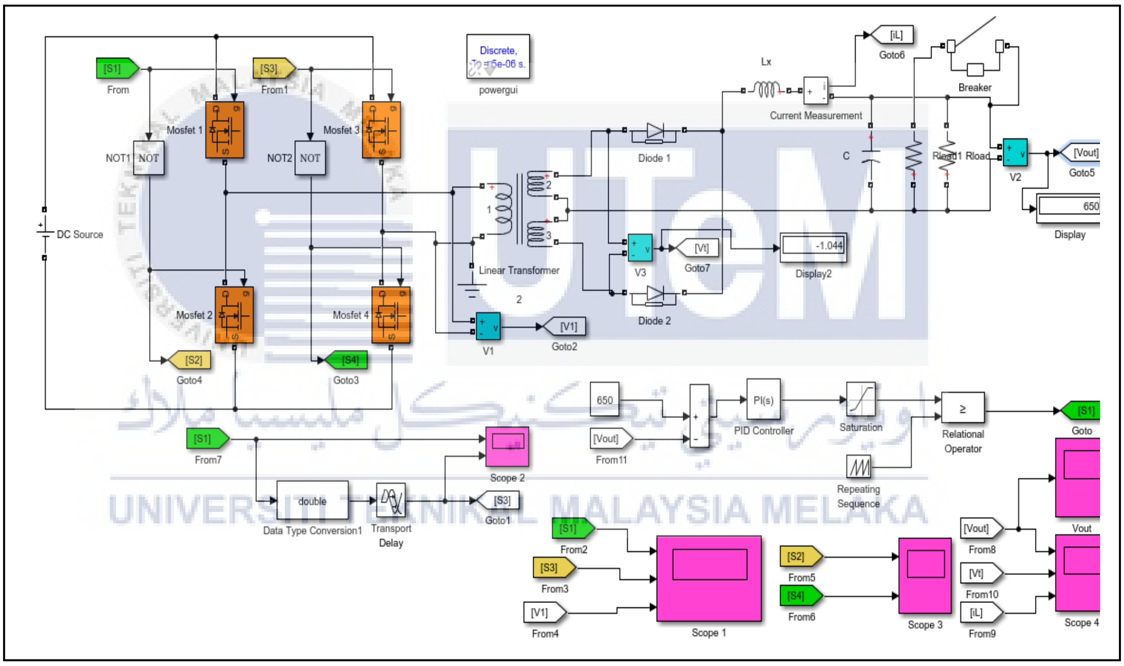

Figure 4.11: Close loop full-bridge converter with breaker

Figure 4.11 shows the close loop full-bridge converter with breaker for analysis when load is varies. The function of breaker as a switching to open or closed the additional circuit load. Based on figure 4.11, the value load of R and R1 is 10kΩ. When the breaker is open, the load is 10kΩ and varied to 5kΩ after the breaker is closed due to load has become parallel.

Figure 4.12 shows the output voltage waveform when load changes. Based on the output voltage waveform at Figure 4.12, the switch is open between 0.95 to 1 second and transient between switch open and closed caused the voltage drop to 650V. The output voltage remains constant when the load change between 10kΩ and 5 kΩ because of PI controller has regulates the voltage. Therefore, PI controller is successfully designed to regulate the output voltage.

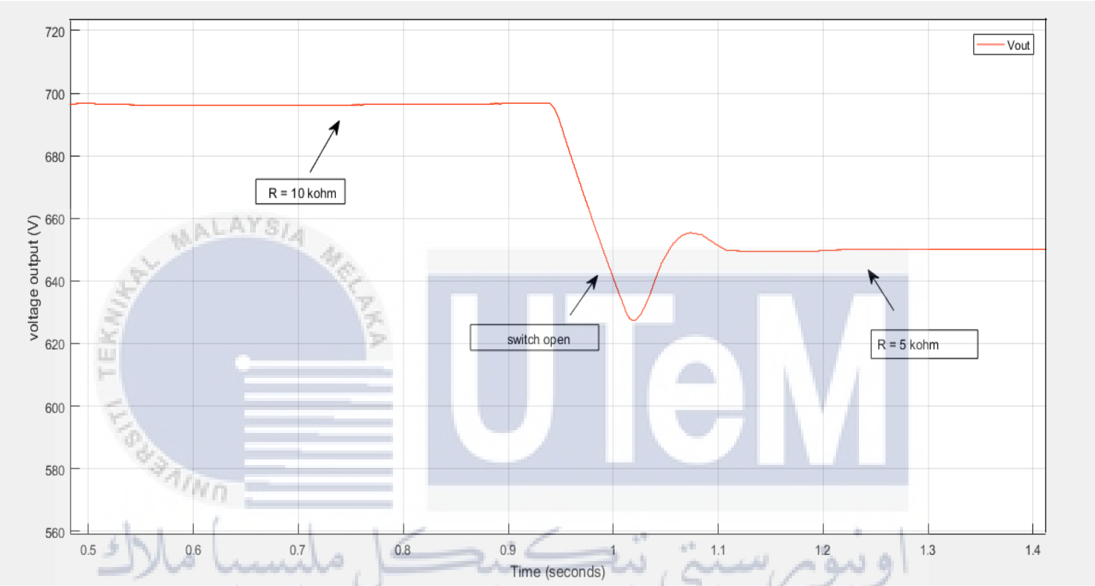

Figure 4.12: output voltage waveform when load varies

4.6.2 Voltage input and load fixed while voltage reference varied

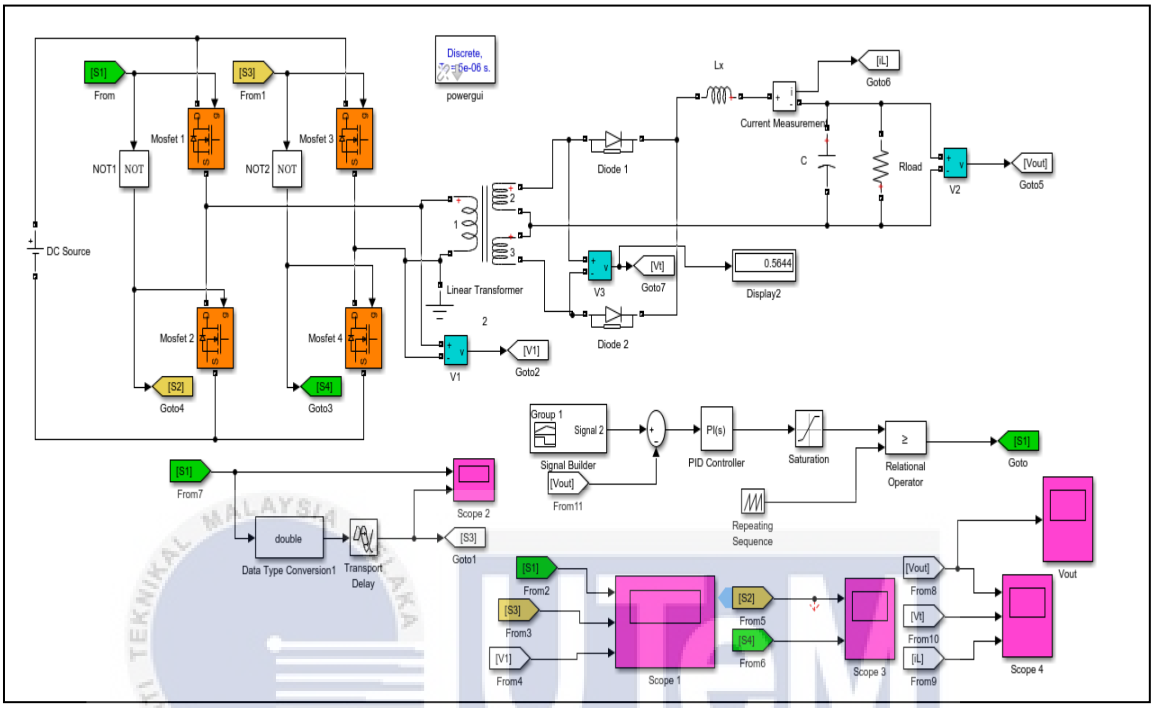

Figure 4.13: Close loop full-bridge converter with signal builder

Figure 4.13 shows the close loop full-bridge converter circuit with used of signal builder as voltage reference. The function of signal builder is to create voltage reference at 270V and 670V. Based on the Figure 4.14 the output waveform always followed the voltage reference. When the waveform followed the reference voltage, it shows that the PI controller is working and the design for the PI controller is successful. Therefore, PI controller successful to regulate the output voltage.

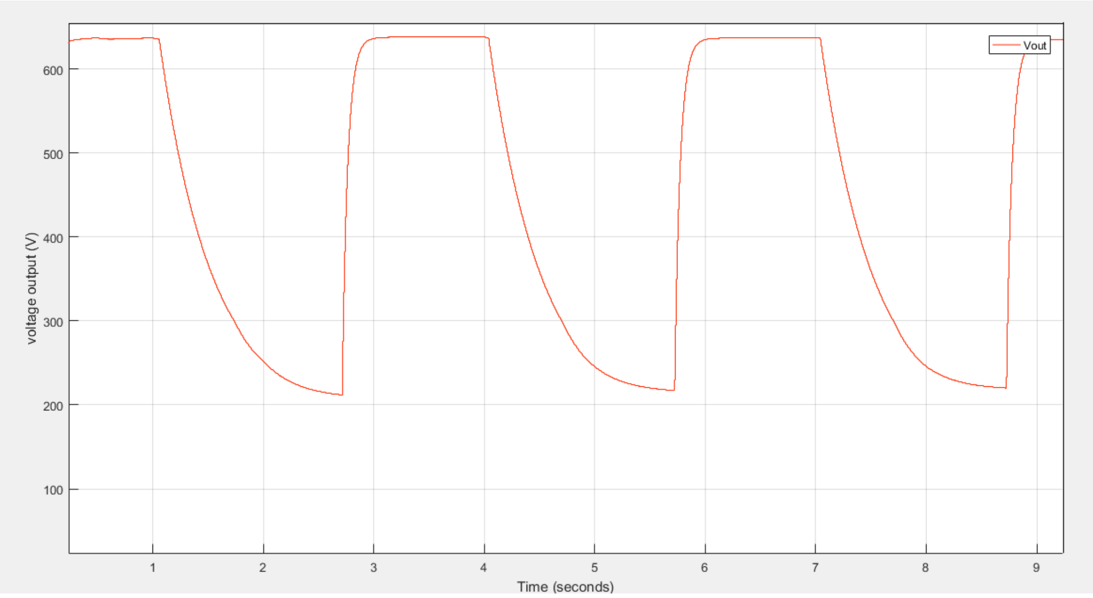

Figure 4.14: Reference Output voltage

4.7 Hardware result

The hardware results of this project are designed of the full-bridge converter, construction of the circuit, gate driver result analysis, microcontroller result analysis for the open loop converter circuit. The analysis result is output waveform of PWM, output voltage, switching pulse waveform and transformer analysis. The analysis result is then compared with simulation and calculation result.

4.8 Transformer design

The design of the transformer has been discussed earlier in chapter 3. The transformer itself is been tested before it is applied to the converter circuit. The high frequency transformer was tested by using the function generator. The function generator injects 2 kHz of sine wave frequency to the transformer by connecting each of the positive and negative part of the winding with the function generator. The waveform is shown in Figure 4.15. The green waveform represents the first winding while the yellow and blue waveforms represent secondary and third winding respectively.

Then, the transformer is tested with 10 kHz of frequency. The first and secondary winding pins are connected to the oscilloscope by using probe. Figure 4.16 shows the waveforms of the transformer when it is observed by using oscilloscope. Green waveform represents the primary transformer while the yellow waveform represents the secondary winding of the transformer. Only second winding is observed because the lack of probe cable. The value of the output voltage is higher when frequency used is high. Figure 4.12 shows that when the frequency increases, the output voltage will increase.

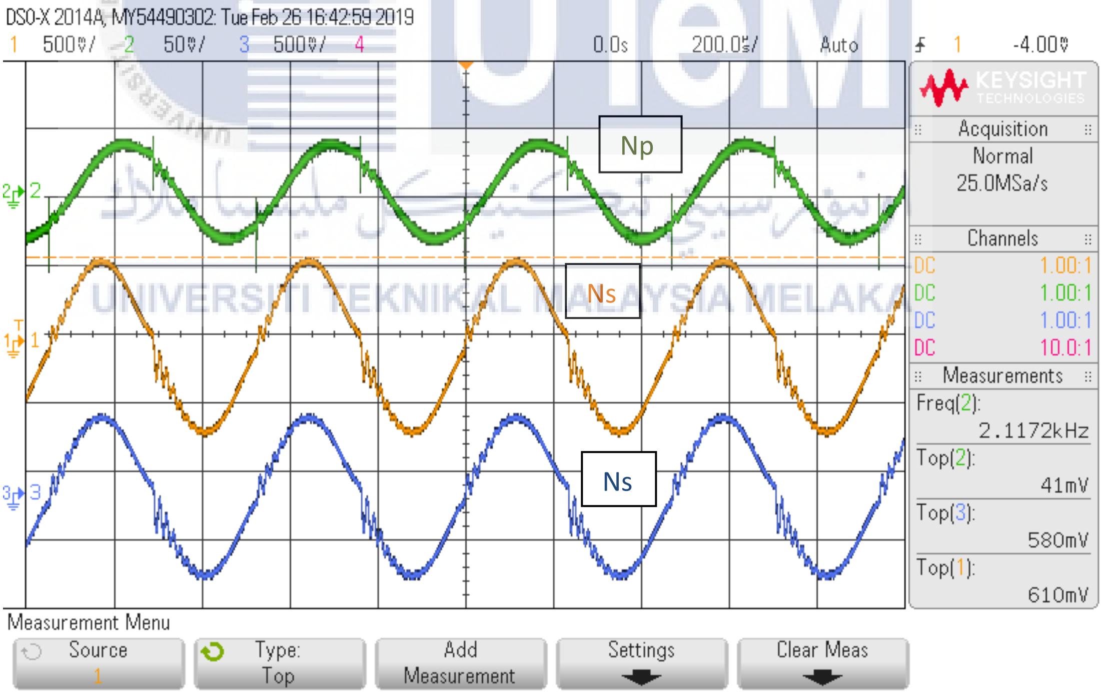

Figure 4.15: Transformer winding waveforms

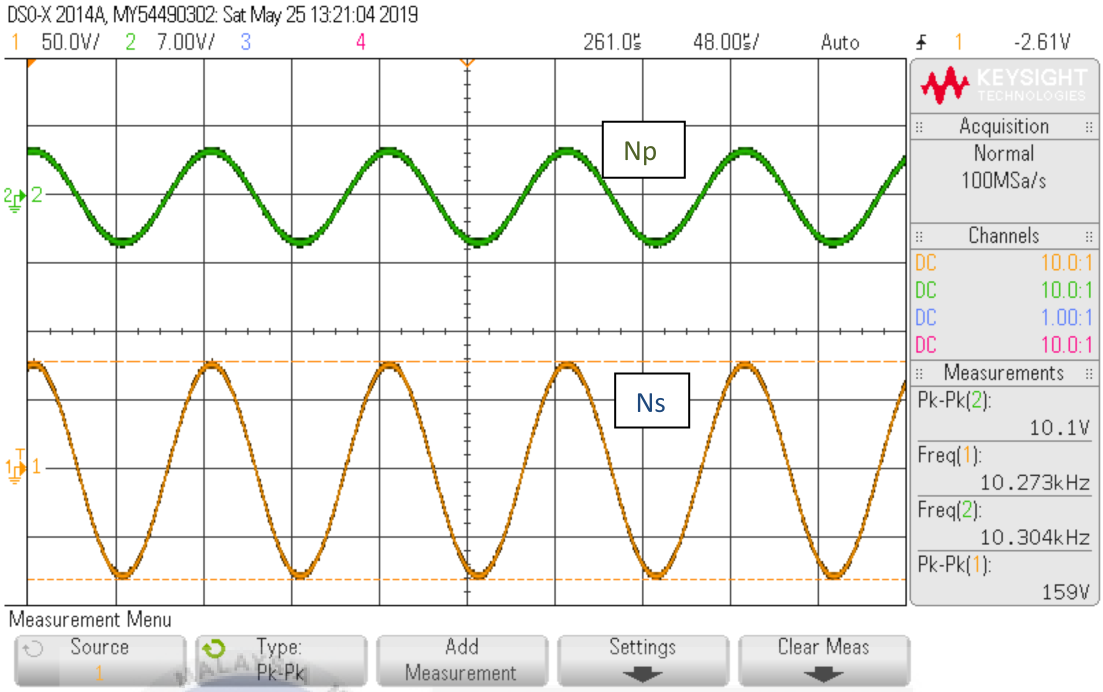

Figure 4.16: Primary and secondary winding waveforms

4.9 Open loop hardware design of the full-bridge converter

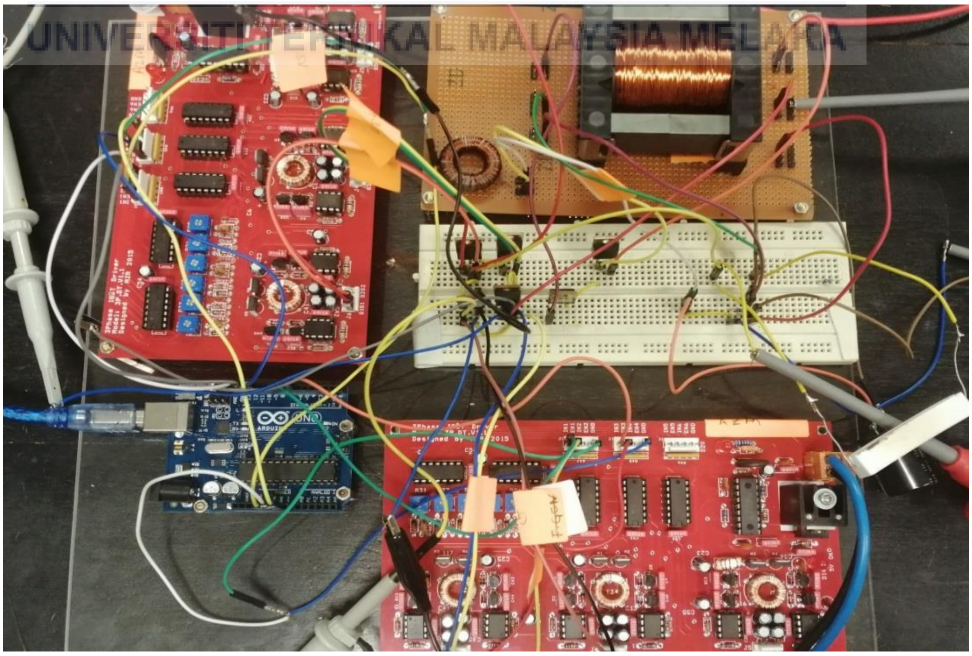

Figure 4.17: Hardware of open loop full-bridge converter

Figure 4.17 shows the hardware of the open loop full-bridge converter consist of the Arduino Uno microcontroller, gate driver circuit and the converter itself. The 12V DC supply connected to the input of full-bridge converter circuit and two boards of the gate driver. The Arduino Uno board get the input supply from the laptop via USB cable.

4.10 Microcontroller

The Arduino Uno microcontroller is using Arduino software to generate PWM output waveform at pin 7,8,12 and 13. Figure 4.18 shows the code program which to control the switching pulses of the output pins. The code designed mainly purpose to generate output pulse that similar to topology of the full-bridge converter.

```


// the setup routine runs ones you press reset:
void setup() {
  // initialize the digital pin as an output.
  pinMode(13,OUTPUT);
  pinMode(12,OUTPUT);
  pinMode(8,OUTPUT);
  pinMode(7,OUTPUT);
}

void loop() {
digitalWrite(13,HIGH);  // HIGH is the voltage level
digitalWrite(8,HIGH);  // HIGH is the voltage level
delay(1.5);  // delay
digitalWrite(13,LOW);  //  by making the voltage LOW
digitalWrite(8,LOW);  //  by making the voltage LOW
delay(1);  // delay


digitalWrite(12,HIGH);  // HIGH is the voltage level
digitalWrite(7,HIGH);  // HIGH is the voltage level
delay(1.5);  // delay
digitalWrite(12,LOW);  // making the voltage LOW
digitalWrite(7,LOW);  // making the voltage LOW
delay(1);  // delay
```


Figure 4.18: Main coding program

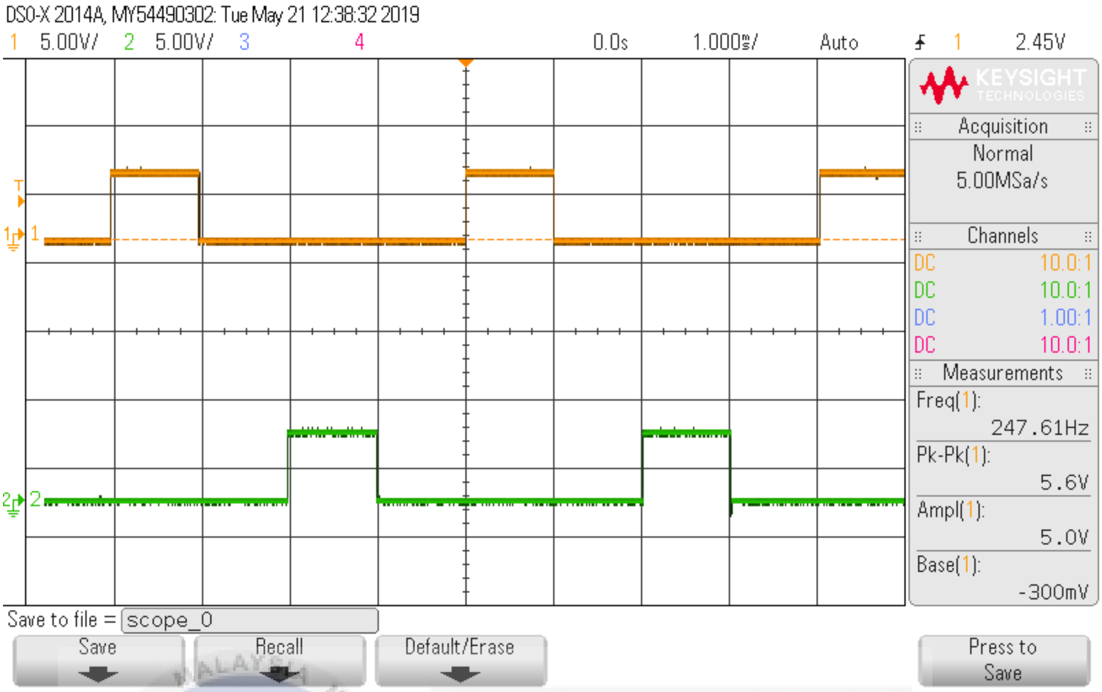

Figure 4.19: Output waveform for Arduino Uno output pins

Figure 4.19 shows the output waveform from the Arduino Uno output pins. The yellow waveform represents the switching state of the output for pin 8 and 13 which will be the pulse for MOSFET 1 and MOSFET 4. The green waveform represents the switching state of the output for pin 7 and 12 which will be the pulse for MOSFET 3 and MOSFET 2. Based on the topology, when the MOSFET 1 and 4 is in the on state, the MOSFET 3 and 2 will be in off state and there is a delay for the MOSFET 3 and 2 to be turned on. The circuit is tested with low frequency which generated from the Arduino. Only low frequency can be used because of some error through the coding program.

4.11 Open loop PWM waveform gate driver circuit.

The gate driver output waveform supposed to be same with the controller output waveform. In this project, there are two gate driver used to generate switching pulse to the MOSFETs. Each gate driver will provide output pulse for 2 MOSFETs. Figure 4.20 shows the output PWM waveforms of the 4 MOSFETs. The yellow and green waveform represents the pulse for MOSFET 1 and 4 while the red and blue waveform represents the pulse for the MOSFET 3 and 2. Each gate driver need to apply 12V DC supply in order for the gate driver to operate.

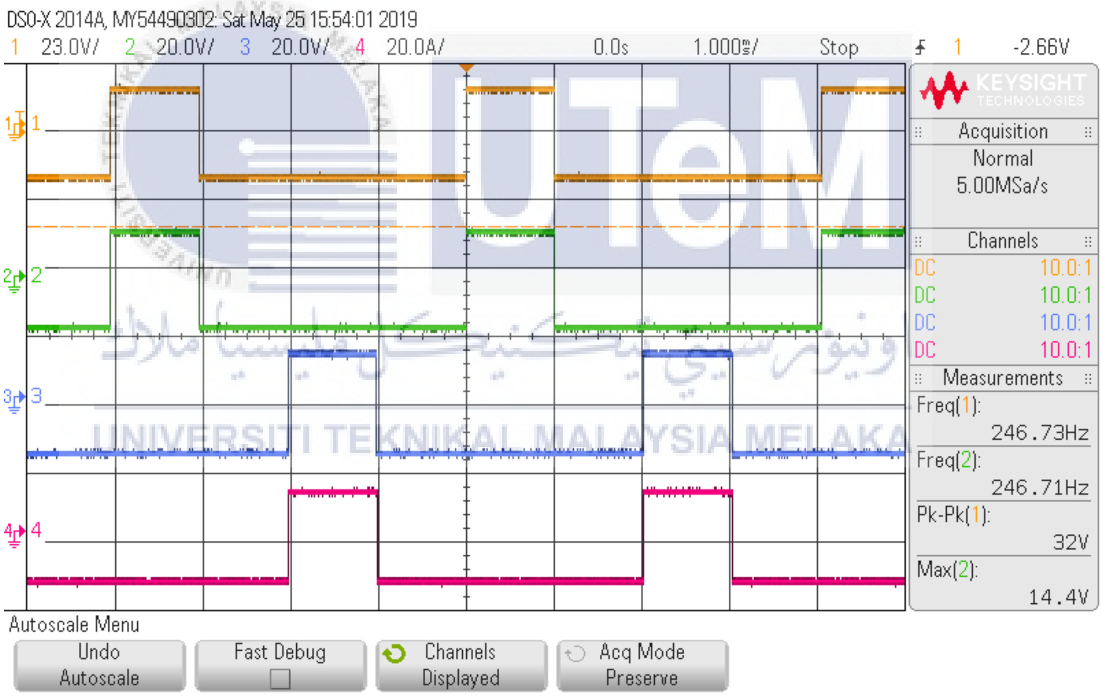

Figure 4.20: PWM waveform of gate driver

4.12 Open loop full-bridge converter analysis

The full-bridge converter circuit in this project is control by microcontroller of Arduino Uno. The open loop circuit of the full-bridge converter is analyse using oscilloscope KEYSIGHT Technology and high voltage isolating probe. The high voltage isolating probe is used instead of the normal probe because of the high voltage output which exceeds 400V. The switching PWM output waveform is generate by the microcontroller and drive by the two gate drivers. The analysis result is compared with simulation and calculation result.

4.13 Steady state analysis of open loop full-bridge converter hardware

Steady state analysis of the hardware full-bridge converter is analysed with fixed value of parameters as the hardware approach. Figure 4.21 shows the waveform of switching state, output waveform and voltage across the primary winding of the transformer. The yellow and green waveform represents the switching pulse of the MOSFETs. The red waveform shows the voltage across the primary winding of the transformer which resulting the same waveform from the topology of full-bridge converter.

On the other hand, the output voltage waveform is exactly will get the DC straight line. By using the high voltage isolating probe, the aspect ratio of the voltage measured is 1:50 which means the output voltage displayed on the oscilloscope will be multiplied with 50. The voltage is 8V and the exact voltage output is around 400V. The open loop hardware result is not achieved the requirement which is around 650V voltage output. This is because of the frequency generated is only 248Hz. If the frequency used is high, the voltage output will increase higher.

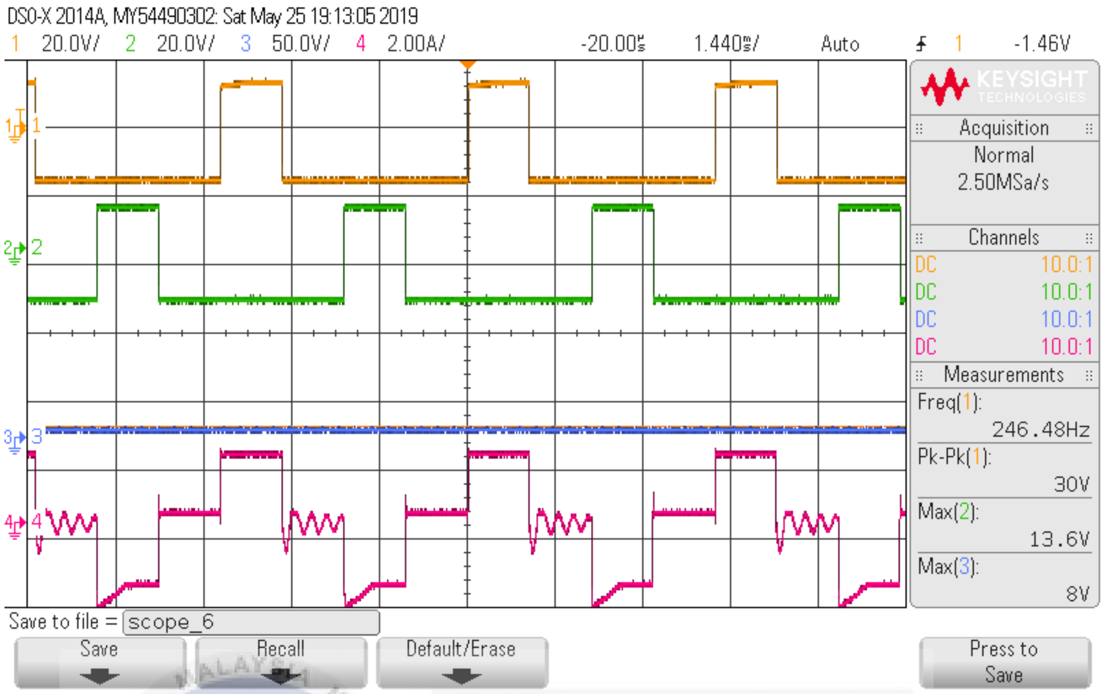

Figure 4.21: Output voltage waveforms

Table 4.4 shows the result between hardware and simulation circuit of the open loop full-bridge converter circuit. Based on table, the voltage output from the hardware and simulation is different and also the parameter of the inductor, capacitor and resistor used is smaller than the calculated value.

Table 4.4: Comparison between calculation and simulation of open loop full-bridge converter circuit

Open loop Full-bridge converter			
	Parameters	**Hardware**	**Simulation**
1	Vin	12V	12V
2	Vout	400V	650V
3	Inductance, L	1 mH	1 mH
4	Capacitance, C	56 µF	65 µF
5	Load resistance, R	10 kΩ	10 kΩ

4.14 Close loop hardware of full-bridge converter

Basically, the hardware circuit for the open loop of the converter is same as the close loop which generated by the controller circuit and drive by the gate driver circuit. The feedback result of the close loop full-bridge converter is not successfully designed due to limited time for developing the hardware.

There is a factor that caused the close loop full-bridge converter not successfully designed. There were some issues regarding the microcontroller. At first, this hardware project is planned to use XMC4700 relax lite kit as the microcontroller but the software for the XMC4700 relax lite kit is quite difficult to use and there is no reference to study about the software. Therefore, Arduino Uno is selected as a backup microcontroller to continue the project for the last 3 weeks before the dateline.

CHAPTER 5

CONCLUSION

5.1 Conclusion

As for the conclusion, all objectives of this project are achieved except to design, construct and analyse the hardware circuit of the close loop full-bridge converter circuit. The circuit simulation model of this project is done by using MATLAB/Simulink software. The parameter used in this project is calculated based on theory of full-bridge converter topology. The PI controller used in the close loop system is to regulate he variable input voltage at constant output voltage.

Based on analysis result on the hardware of full-bridge converter, the result is slightly different with the calculation due to losses happened. Besides that, the output voltage from the simulation of full-bridge converter circuit can be controlled by varies the voltage input and duty cycle.

Lastly, from the simulation analysis, this project is categorized as successful to generate voltage in range of 600V to 700V to the multilevel inverter for grid system application. In addition, from hardware analysis, the project is nearly successful as the output voltage is around 400V and it may needs some improvement based on the components used.

5.2 Recommendation

The recommendation of this project is student can improve this project with the successful design of the hardware of close loop full-bridge converter. The close loop full-bridge converter can regulate better output voltage and increase the efficiency.

Besides that, this project can improve with the uses of XMC4700 relax lite kit microcontroller. The implementation of microcontroller XMC4700 relax lite kit maybe challenging but it is good for further research. Lastly, the hardware of the full-bridge converter circuit can be designed by using Printed Circuit Board (PCB) to look more systematic.

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