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FACULTY OF ELECTRICAL ENGINEERING

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FINAL YEAR PROJECT II

PERFORMANCE ANALYSIS OF 100 W BOOST CONVERTER

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PERFORMANCE ANALYSIS OF 100 W BOOST CONVERTER

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A thesis submitted in fulfilment of the requirements for the degree of Bachelor of Electrical Engineering

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2014

I declare that this report entitled "Performance Analysis of 100 W Boost Converter" is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :...

Name : MOHAMAD SHAHRUL NIDZAM BIN HALIM

Date : ....

Dedicated especially in order to express my appreciation to

my supervisor, Mr. Musa Yusup Lada

my beloved father, Halim bin Ishak

my beloved mother, Noorziati binti Embi

my brothers and sisters,

my friends, lecturers

and every individual,

who have inspired me throughout this long road no visible end.

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ABSTRACT

DC-DC converters are widely used in regulated switch mode DC power supplies. The input of these converters is an unregulated DC voltage and therefore it will fluctuate due to the disturbances in the system. The output voltage regulation in DC-DC converter is achieved by constantly adjusting the amount of energy absorbed from the source and that injected into the load, which is in turn controlled by the relative durations of the absorption and injection intervals. The objectives of this project are to design a DC-DC boost converter and to make the hardware implementation of the circuit. This system utilized basic open-loop and closed-loop control configurations of the boost converter. The parameter of component values for hardware design can be obtained through some calculation from the theoretical formulae and analysis on MATLAB Simulink software. The methodology of designing the hardware circuit is presented in details. All the simulation results will be verified by the hardware design. The process involved are simulating the boost converter circuit, designing the circuit layout, making the printed circuit board (PCB), testing the PCB board, analysing the data on hardware and drawing conclusion. Hardware implementations have been done in order to verify the operation of the boost converter. From this project, the output voltage obtained in hardware is slightly different compared to the simulation due to some unresolved issues. Other than that, the acceptable results are valid for PWM and gate driver. The efficiency of the boost converter is almost to 1 which is close to the ideal when tested with load variation.

ABSTRAK

Penukar DC-DC digunakan secara meluas dalam mod suis terkawal bekalankuasa DC. Input penukar ini adalah voltan DC yang tidak dikawal dan oleh itu ia akan naik turun disebabkan oleh gangguan dalam sistem. Peraturan voltan keluaran di penukar DC-DC dicapai dengan sentiasa menyesuaikan jumlah tenaga yang diserap dari sumber dan yang disuntik ke dalam beban, seterusnya dikawal oleh tempoh masa relative penyerapan dan suntikan selang. Objektif projek ini adalah untuk mereka bentuk penukar rangsangan DC-DC dan membuat pelaksanaan perkakasan litar. Sistem ini digunakan untuk konfigurasi asas penukar rangsangan kawalan gelung terbuka dan kawalan gelung tertutup. Nilai-nilai parameter komponen untuk reka bentuk perkakasan boleh didapati melalui beberapa pengiraan daripada formula teori dan analisis pada perisian MATLAB Simulink. Metodologi mereka bentuk litar perkakasan dibentangkan secara terperinci. Semua keputusan simulasi akan disahkan oleh reka bentuk perkakasan. Proses ini terlibat secara simulasi rangsangan penukar litar, mereka bentuk susun atur litar, membuat papan litar bercetak (PCB), menguji papan PCB, menganalisis data pada perkakasan dan membuat keputusan. Pelaksanaan perkakasan telah dilakukan untuk mengesahkan operasi rangsangan penukar. Daripada projek ini, voltan output yang didapati dalam perkakasan adalah sedikit berbeza berbanding simulasi kerana beberapa isu-isu yang tidak dapat diselesaikan. Selain daripada itu, keputusan yang boleh diterima adalah sah untuk PWM dan pemandu pintu. Kecekapan rangsangan penukar adalah hampir kepada 1 yang berhampiran dengan ideal apabila diuji dengan perubahan beban.

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LIST OF ABBREVIATIONS

A	-	Ampere
C	-	Capacitor
D	-	Duty Ratio
DC	-	Direct Current
f	-	Frequency
Hz	-	Hertz
IC	-	Integrated Circuit
L	-	Inductor
PCB	-	Printed Circuit Board
PWM	-	Pulse Width Modulation
R	-	Resistor
T	-	Time
V	-	Voltage
V_L	-	Voltage Inductor
V_O	-	Voltage Output
V_S	-	Voltage Source
µF	-	Micro Farad
µH	-	Micro Henry

Ω	-	Ohm
DC-DC	-	Direct Current to Direct Current
MOSFET	-	Metal-Oxide-Semiconductor Field-Effect-Transistor
CMC	-	Current Mode Control
VMC	-	Voltage Mode Control
PV	-	Photovoltaic

CHAPTER 1

INTRODUCTION

1.1 Background

Converters required power electronic circuit in order to match the voltage and current requirements of the load to those of the source. Converters are classified by the relationship between input and output [1].

DC-DC converters are used to convert the unregulated DC input to a controlled DC output with a desired voltage output. It is classified as a regulator and it is useful when a load requires a specified DC voltage or current but the source is at a different or unregulated DC value. It is used widely in DC motor drive application and it provides smooth acceleration control, high efficiency and fast dynamic response [2].

Control system has been designed in order to compensate any disturbance or error in the converter system. Control design for any system involves a mathematical description of the relation among inputs to the process, state variables, and output. These control parameters will be presented in the form of mathematical equations which describe behaviour of the system called as model of the system.

The advantages and primary reasons of building control system are to get power amplification, remote control, convenience of input form and compensation for disturbance [3].

1.2 Problem Statement

DC-DC boost converter also known as a regulator is a design of power electronics which capable to regulate unregulated DC input to a desired voltage output. There are two basic configurations applied in boost converter system, namely open-loop and closed-loop respectively. Open-loop system is simpler manual modelling where as closed-loop system is automatic control system modelling. The DC-DC boost converter needs four external components: inductor, electronic switch, and diode and output capacitor.

The converter operates in two different modes depending on its energy storage capacity and the relative length of the switching period. These two operating modes are known as the discontinuous conduction mode (DCM) and continuous conduction mode (CCM). If the energy storage capacity of the converter is too small or the switching period is relatively too long, then the converter would transmit all the stored energy to the load before the next cycle begins.

Therefore, the boost converter circuit undergo debugging, testing the parameters and collecting data for the implementation of hardware circuit. This hardware is designed using OrCAD software to make the hardware more convenient and efficient.

1.3 Project Objectives

There are four objectives to be covered in this project:

1. To model the open-loop and closed-loop boost converter.
2. To design the hardware of open-loop and closed-loop boost converter.
3. To develop calculations for determining relative circuit parameters for the design of boost converter.
4. To verify the performance of open-loop and closed-loop boost converter.

1.4 Scope of the Project

The scope of this project is to create a boost converter in continuous current mode (CCM) by applying the theoretical concepts and the simulation designs into hardware implementation. The basic theoretical about fundamental behaviour of boost converter, pulse width modulation and gate driver been studied in order to achieve the objectives of this project. In this project, MOSFET power switch will be used as a switching device. The simulation of DC-DC boost converter will be simulated by using MATLAB Simulink software to analyze the optimum performance characteristics of the boost converter. The PCB of boost converter circuit will be designed using OrCAD software.

1.5 Report Outlines

This report is organized in five chapters; **Chapter 1** offers a preface about power electronic converters focusing on boost converter. Besides, the objectives, problem statement and scope of the project are also addressed.

Chapter 2 provides the discussion based on theories and literature reviews that have been done Then, the basic knowledge to the specific converter that is the boost converter been introduced. The theoretical analysis of the boost converter describes in detail in order to understand all the important parameters related to the system.

Chapter 3 explains on the methods implement to carry out the analysis of the boost converter. The introduction of flowchart, milestones and Gantt chart make ease the sequence of the project operation. Other than that, the simulation approach and hardware implementation are stated in this chapter. The boost converter will be tested in open-loop system and closed-loop system. The simulation is verified under MATLAB Simulink environment, while the hardware implementation describes the design procedures of PCB circuit.

Chapter 4 represents the design analysis of boost converter using the simulation and hardware implementation approaches. The experimental results and analysis for boost converter in open loop and closed loop system are also included in this part.

Chapter 5 concludes the overall achievement of the boost converter project. This chapter conclude all the data that been gathered and collected. A summary is reviewed to finalize the outcome of the project.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter review the existing project created to get an idea about the boost converter by following conception, specification and any information that related to the project. In later of this chapter, some review about the proposed design of boost converter to fulfil this project will be reported.

2.2 Converters

Converters serve as an interface between the source and load as shown in Figure 2.1. It convert one type or level of a voltage or current waveform to another and classified by the relationship between input signal and output signal as shown in Table 2.1 [12].

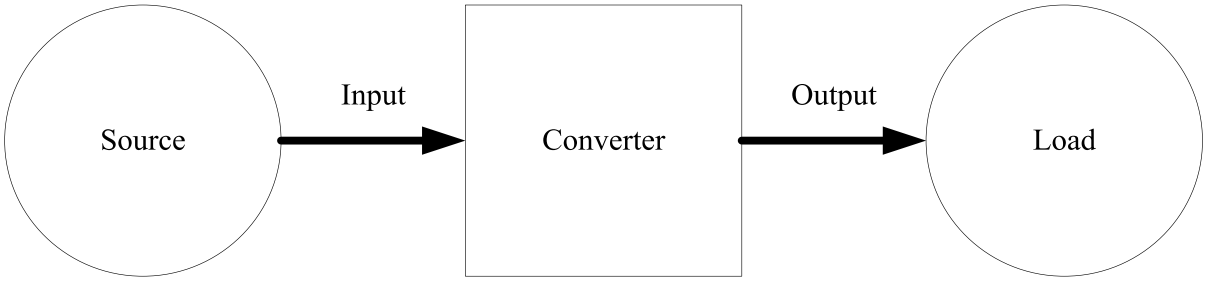


Figure 2.1: Basic converter system [12].

Converter circuits capable to operate in different mode, depending on electronic circuit used, high frequency switching semiconductor and applied control system. Thus, converters are capable to operate in multiple stages in a process with different type of converter involves in Figure 2.2 [12].

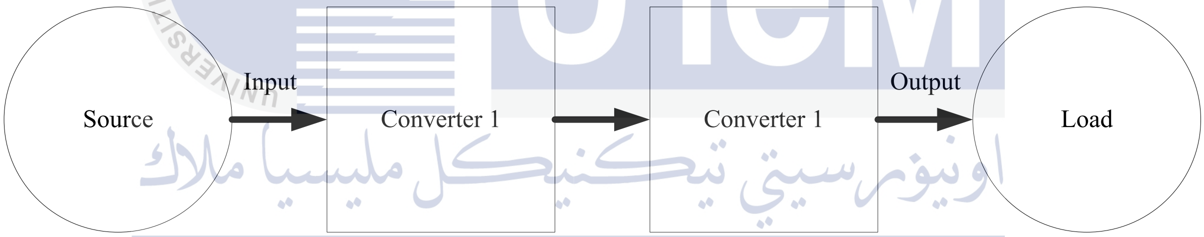


Figure 2.2: Two converters are used in a multistep process [12].

Table 2.1: Classification of converters [12].

Type of converter	Functions
AC input/DC output	The AC/DC converter that produces a DC output from an AC input. It classified as a rectifier.
DC input/AC output	The DC/AC converter that produces a AC output from a DC input. It classified as a inverter.
DC input/DC output	The DC/DC converter that produces a DC output from a DC input. It classified as a regulator.

AC input/AC output	The AC/AC converter that produces a AC output from an AC input. It used to change the level and/or frequency of an AC signal.

2.3 DC-DC Converter

DC-DC converters are used to convert the unregulated DC input to a controlled DC output at a desired voltage output. It is classified as a regulator and it is useful when load requires a specified DC voltage or current but the source input is at a different or unregulated DC value [12]. Generally, DC-DC converter block diagram is shown in Figure 2.3.

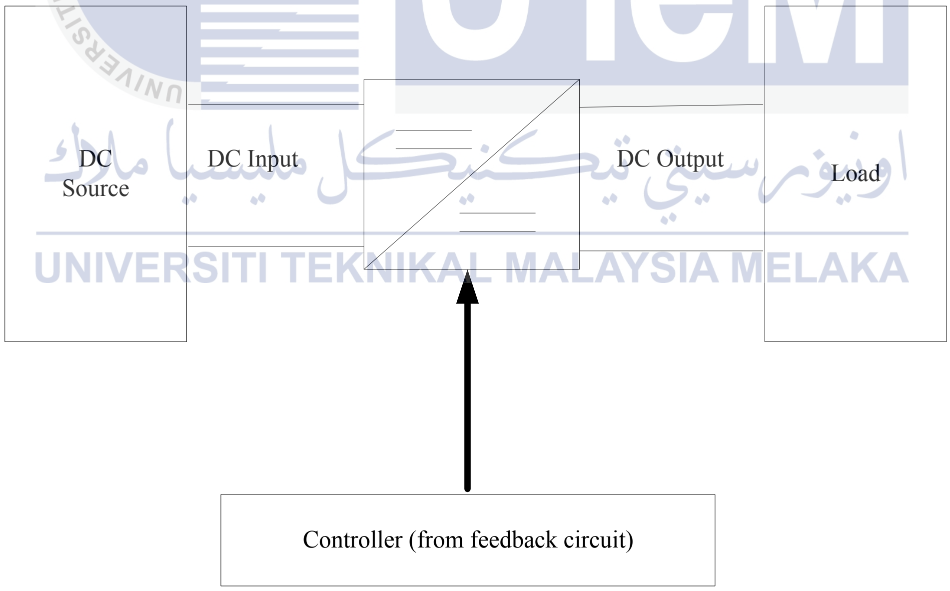


Figure 2.3: General DC-DC converter block diagram [12].

DC-DC converters include buck converters, boost converters, buck-boost converters, Ćuk converters and full-bridge converters [9]. Switched DC-DC converters offer a method to increase or decrease an output voltage depend on application or system.

DC-DC converters operate in two modes according to the inductor current. The inductor current fluctuates but never goes down to zero is called Continuous Conduction Mode (CCM), while Discontinuous Conduction Mode (DCM) happens when the inductor current fluctuates and goes down to zero at or before the end of each cycle [12].

Energy is periodically stored into and released from a magnetic field in an inductor. This is applied to control the output voltage so that the output remains constant even though the input voltages keep changing. There are two categories of DC-DC converters that are non-isolated DC-DC converter (Buck, Boost and Buck-Boost) and isolated DC-DC converter (Flyback, Forward, Push-Pull, Full-Bridge and Half-Bridge) [12].

Non-isolated DC-DC converter is used when the input of converter is often an unregulated DC voltage, which is obtained by rectifying the line voltage. Therefore, it will vary due to the changes in the line voltage magnitude. Switched-mode DC-DC converters are used to convert the unregulated DC input to a controlled DC output at a desired voltage level.

Isolated DC-DC converter, full-bridge converter and half-bridge converter are derived from the step-down converter. Flyback converter is derived from the buck-boost converter. Forward converter and push-pull converter are derived from the step-down converter with isolation [12].

2.3.1 DC-DC Converter Switching

There are two switching condition that need to be applied, that is when ON and OFF states as shown in Figure 2.4.

When ON state, the output voltage is the same as the input voltage and the voltage across the switch is 0V.

When OFF state, the output voltage = 0V and the current through the switch = 0A. In ideal condition, power loss = 0W since the output power equal to the input power.

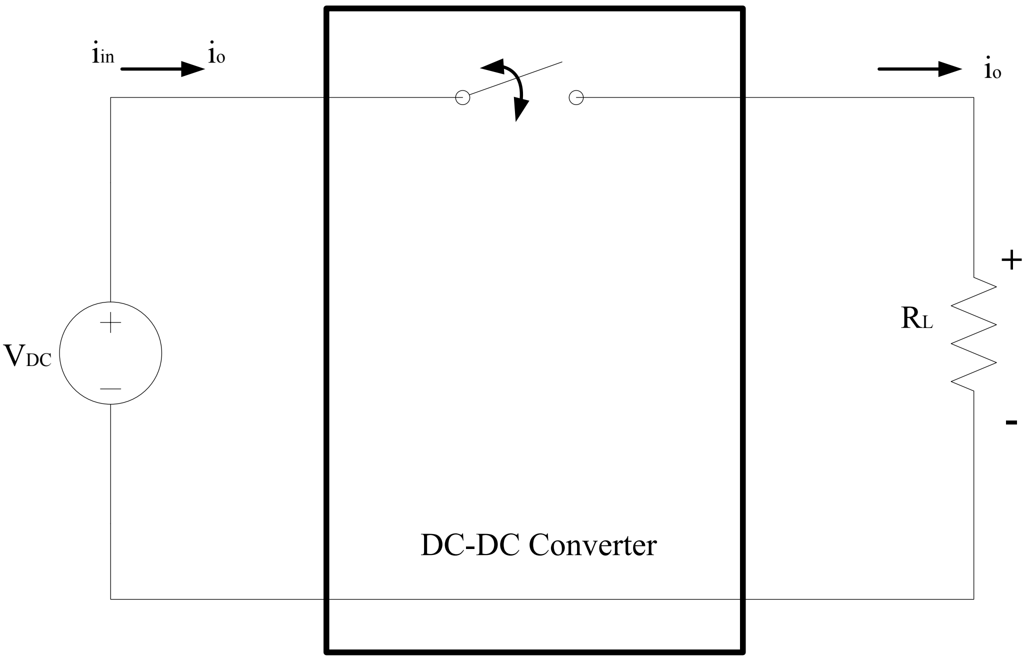


Figure 2.4: Switching ON and OFF of DC-DC converter [12].

ON and OFF states resulting in pulse as shown in Figure 2.5 where the switching period, *T*, is a one full cycle (360°) of a waveform ranging from t_{ON} to t_{OFF} pulse.

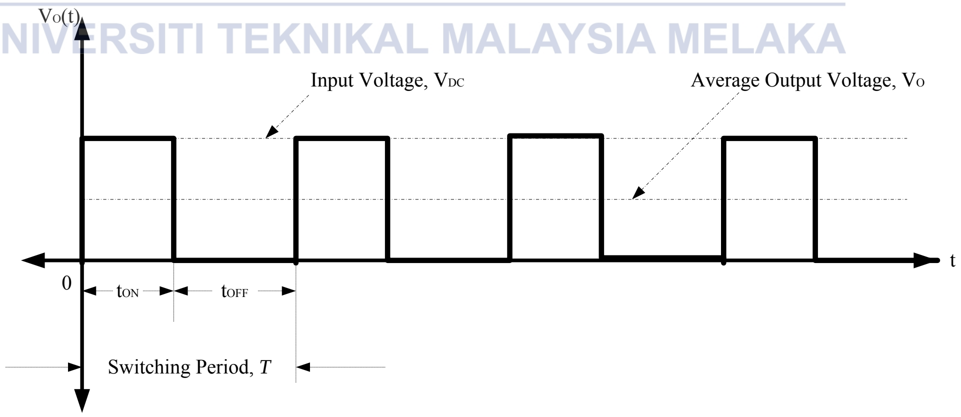


Figure 2.5: t_{ON} and t_{OFF} pulse [12].

Thus, duty ratio, D, which depends on t_{ON} and range of duty ratio is $0 < D < 1$. If switching frequency, f_s, is given,

$$D = \frac{t_{on}}{t_{on}+t_{off}} = \frac{t_{on}}{T} = t_{on}fs \qquad (2\text{-}1)$$

Average DC output voltage,

$$\bar{V_0} = \frac{1}{T}\int_0^T v_o(t)dt = \frac{1}{T}\int_0^{DT} V_i\, dt = ViD \qquad (2\text{-}2)$$

There are two modes of operation in DC-DC converters based on inductor current, i_L,

i) Continuous Conduction Mode (CCM), when $i_L > 0$.
ii) Discontinuous Conduction Mode (DCM) when i_L goes to 0 and stays at 0 for some time.

Figure 2.6: Continuous Conduction Mode [12].

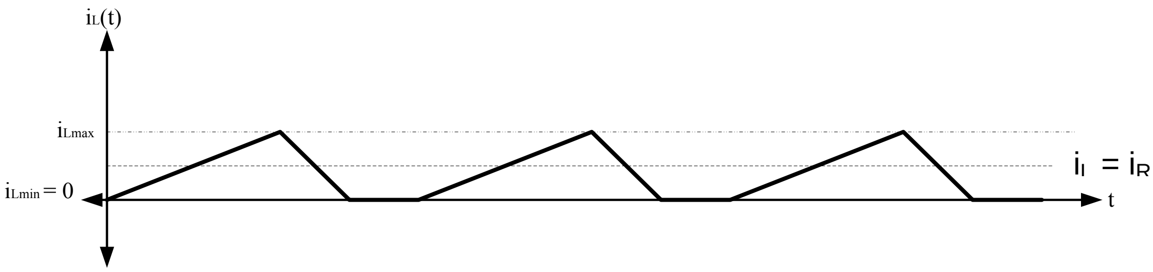


Figure 2.7: Discontinuous Conduction Mode [12].

In steady state and periodic operation, inductor charges and discharges with V_{avg} DC voltage across inductor in one period = 0. Thus, inductor looks like a short circuit as shown in Figure 2.8.

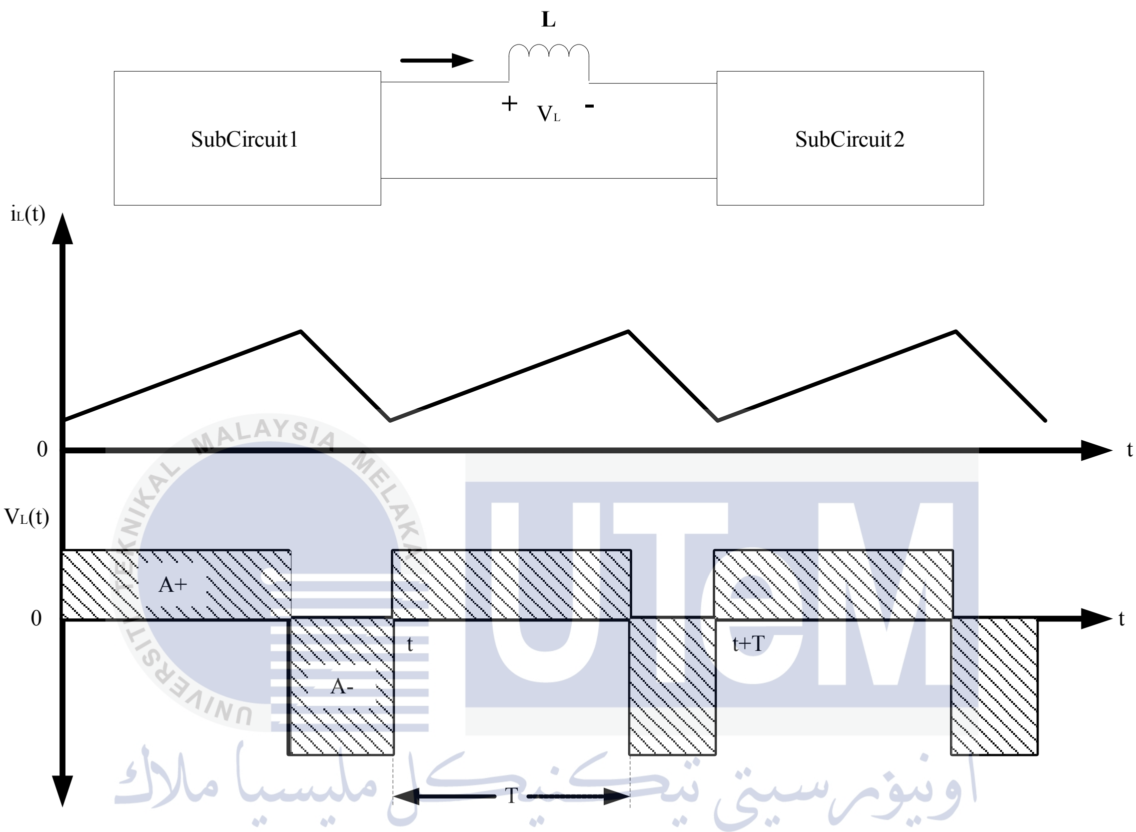


Figure 2.8: i_L: and V_L when inductor looks like short circuit [12].

The advantage of CCM over DCM by using the DC conversion ratio is independent of the load, which makes DC analysis of converters operating in CCM easier. While operating in DCM, the output voltage depends on the load and the duty ratio of the switch, which makes DC analysis of converters operating in DCM more complicated. Also, to deliver the same power in DCM as in CCM, the peak currents are higher, resulting in greater losses in the conduction paths leads to reduced efficiency and higher peak current can also cause switch stress and greater input and output current ripple that adversely affects noise issues [16].

2.4 Analysis of Boost Converter

Boost converter or step-up converter, is switching DC-DC converter that produces an output voltage greater than the source voltage. Boost converter consists of a prime component that will build in the converter such as diode, inductor, capacitor, resistor, power MOSFET and PWM controller.

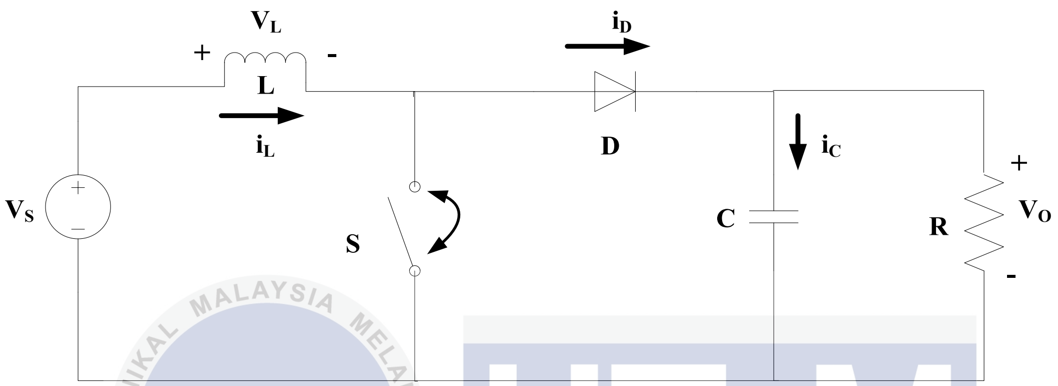


Figure 2.9: The boost converter [5].

A basic boost configuration is depicted in Figure 2.9. Assuming that the switch (transistor) has been open for a long time and the components are ideal, the voltage across the capacitor is equal to the input voltage.

2.4.1 Charge Phase

Figure 2.10 shows the charge phase. When the switch is closed, the input voltage is flowing across the inductor. The diode prevents the capacitor from discharging to ground. It causes the diode to be reverse-biased. The current across the inductor rises linearly with time rate due to the rate of change of current is a constant. The current across the inductor increases and the energy stored in the inductor builds up [5].

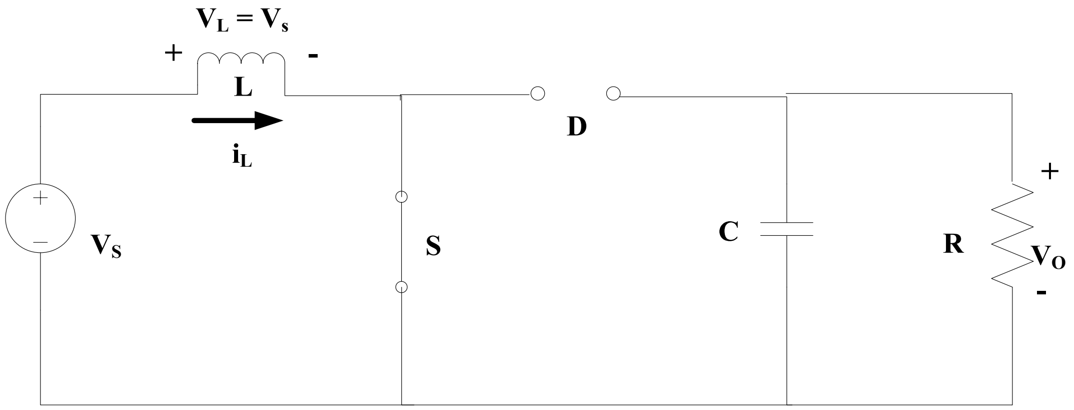


Figure 2.10: Boost converter charge phase [5].

Kirchoff"s voltage law around the path containing the source input, inductor and closed switch is:

$$v_L = V_S = L\frac{di_L}{dt} \qquad \text{or} \qquad \frac{di_L}{dt} = \frac{V_S}{L} \tag{2-3}$$

The change in inductor current is computed from:

$$\frac{\Delta i_L}{\Delta t} = \frac{\Delta i_L}{\mathrm{DT}} = \frac{V_S}{L} \tag{2-4}$$

Therefore, Δi_L for the switch closed is:

$$(\Delta i_L)_{\text{closed}} = \frac{V_S DT}{L} \tag{2.5}$$

2.4.2 Discharge Phase

Figure 2.11 shows the discharge phase. When the switch is opened, the voltage across the inductor is changing to maintain current flow. The inductor is discharging its energy and the polarity of inductor voltage is such that its terminal connected to the diode is positive with respect to its other terminal connected to the source. So, the diode becomes forward-biased to provide a path for inductor current. Now the capacitor voltage is higher than the source voltage. The inductor receives energy when the switch is closed and transfers it to the output when the switch is open. When the capacitor is relatively large, V_{out} remains relatively constant during the second half of the cycle [5].

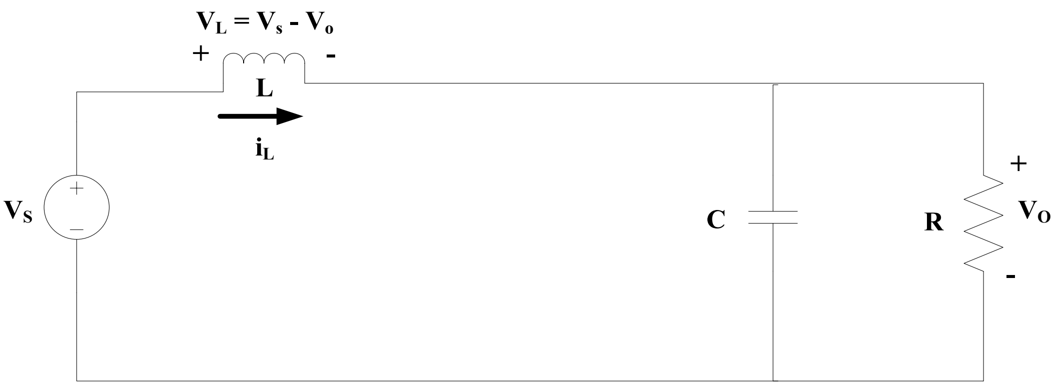


Figure 2.11: Boost converter discharge phase [5].

Assuming that the output voltage V_o is a constant, the voltage across the inductor is:

$$v_L = V_s - V_o = L\frac{di_L}{dt} \tag{2-6}$$

$$\frac{di_L}{dt} = \frac{V_S - V_O}{L} \tag{2-7}$$

The change in inductor current while the switch is open is:

$$\frac{\Delta i_L}{\Delta t} = \frac{\Delta i_L}{(1-\mathrm{D})\mathrm{T}} = \frac{V_S - V_O}{L} \tag{2-8}$$

Therefore, Δi_L for the switch opened is:

$$(\Delta i_L)_{\text{opened}} = \frac{(V_S - V_O)(1-\mathrm{D})\mathrm{T}}{L} \tag{2-9}$$

2.4.3 Inductor Voltage and Inductor Current Waveforms

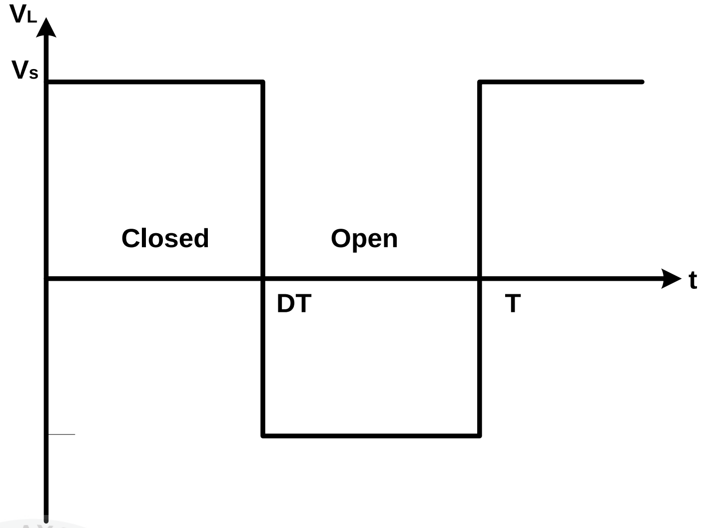


Figure 2.12: Boost converter inductor voltage [1].

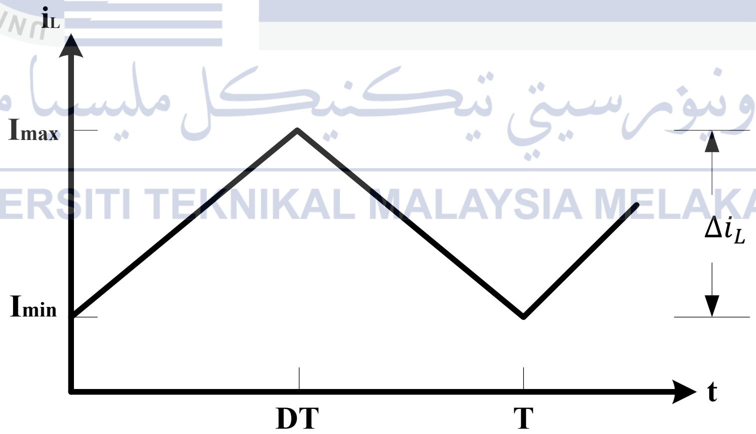


Figure 2.13: Boost converter inductor current [1].

2.4.4 Determination of Minimum Inductor Value

For steady-state operation, the net change in inductor current must be zero. Using Equations (2-5) and (2-9):

$$(\Delta i_L)_{\text{closed}} + (\Delta i_L)_{\text{opened}} = 0 \tag{2-10}$$

$$\frac{V_S DT}{L} + \frac{(V_S - V_O)(1-\mathrm{D})\mathrm{T}}{L} = 0 \tag{2-11}$$

Therefore, the output voltage V_o is:

$$V_o = \frac{V_S}{(1-D)} \tag{2-12}$$

The average current in the inductor is determined by recognizing that the average power supplied by the source must be the same as the average power absorbed by the load resistor. The output power P_o is:

$$P_o = \frac{{V_o}^2}{R} = V_o I_o \tag{2-13}$$

and input power is $V_s I_S = V_S I_L$. By applying input and output powers with Equation (2-12), the average inductor current I_L can be expressed as:

$$I_L = \frac{V_S}{(1-D)^2 R} = \frac{{V_O}^2}{V_S R} = \frac{V_O I_O}{V_S} \tag{2-14}$$

Maximum and minimum inductor currents are determined by using the average value and the change in current from Equation (2-5):

$$I_{\max} = I_L + \frac{\Delta i_L}{2} = \frac{V_S}{(1-D)^2 R} + \frac{V_S DT}{2L} \tag{2-15}$$

$$I_{\min} = I_L - \frac{\Delta i_L}{2} = \frac{V_S}{(1-D)^2 R} - \frac{V_S DT}{2L} \tag{2-16}$$

Assume that the inductor current is continuous, meaning that it is always positive. The condition necessary for continuous inductor current is $I_{\min}$ to be positive.

$$I_{\min} = 0 = \frac{V_S D}{2Lf} \tag{2-17}$$

The minimum combination of inductance and switching frequency for continuous current in the boost converter is

$$L_{\min} = \frac{D(1-D)^2 R}{2f} \tag{2-18}$$

Therefore, a boost converter designed for continuous-current operation will have an inductor value greater than $L_{\min}$. Typical value of design inductor is ten times value of the minimum inductor, $L_{\min}$.

2.4.5 Diode Current and Capacitor Current Waveforms

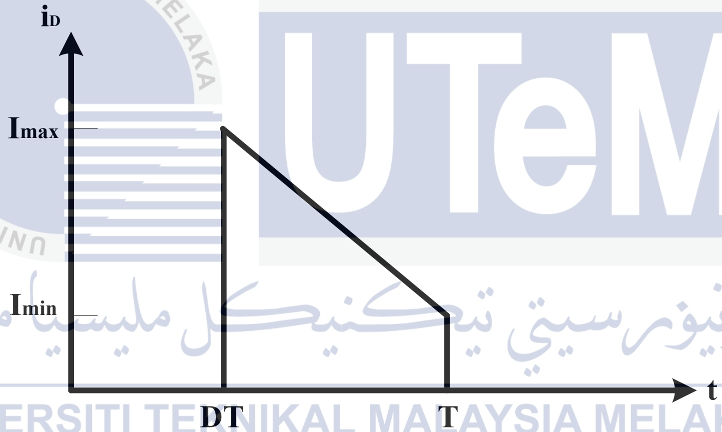


Figure 2.14: Boost converter diode current [1].

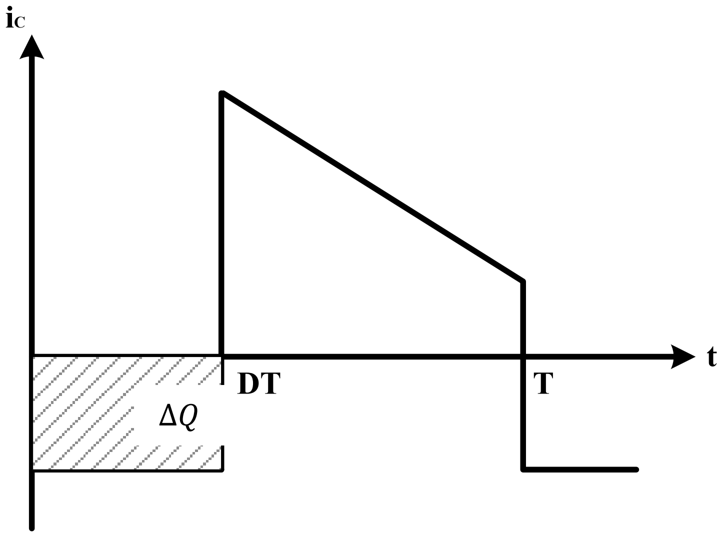


Figure 2.15: Boost converter capacitor current [1].

2.4.6 Determination of Output Voltage Ripple

In practice, a finite capacitance will result in some fluctuation in output voltage, or ripple. The peak-to-peak output voltage ripple can be calculated from the capacitor current waveform as shown in Fig. 2.1.6. The change in capacitor charge can be calculated from:

$$|\Delta Q| = \left(\frac{V_o}{R}\right)DT = C\Delta V_o \tag{2-19}$$

An expression for ripple voltage is then:

$$\frac{\Delta V_o}{V_o} = \frac{D}{RCf} \tag{2-20}$$

Expressing capacitance in terms of output voltage ripple yields

$$C = \frac{D}{R(\Delta V_o/V_o)f} \tag{2-21}$$

2.5 PWM Control Techniques

Pulse-width modulation (PWM) is a modulation technique that conforms the width of the pulse or the pulse duration [4]. Its main use is to allow the control of the power supplied to electrical devices. The average value of voltage and current fed to the load is controlled by turning the switch between supply and load ON and OFF at a fast pace. The longer the switch is ON compared to the OFF periods, the higher the power supplied to the load. The PWM switching frequency has to be much faster than what would affect the load. The term duty ratio describes the proportion of „on‟ time to the regular interval or „period‟ of time, A low duty ratio corresponds to low power because the power is OFF for most of the time.

The main advantage of PWM is the power loss in the switching devices is very low. When a switch is OFF, there is practically no current. When a switch is ON, there is almost no voltage drop across the switch. Power loss, the product of voltage and current is close to zero. PWM also works well with digital controls. Because of their ON/OFF nature, PWM can easily set the needed digital controls.

The common PWM control method is shown in Figure 2.16. This method takes a sample of the output voltage and subtracts this from a reference voltage to establish a small error signal, V_{ERROR}. This error signal is compared to an oscillator ramp signal. The comparator outputs PWM that operates the power switch. When the circuit output voltage changes, V_{ERROR} also changes and thus causes the comparator threshold to change. This duty ratio change then moves the output voltage to reduce the error signal to zero, thus completing the control loop.

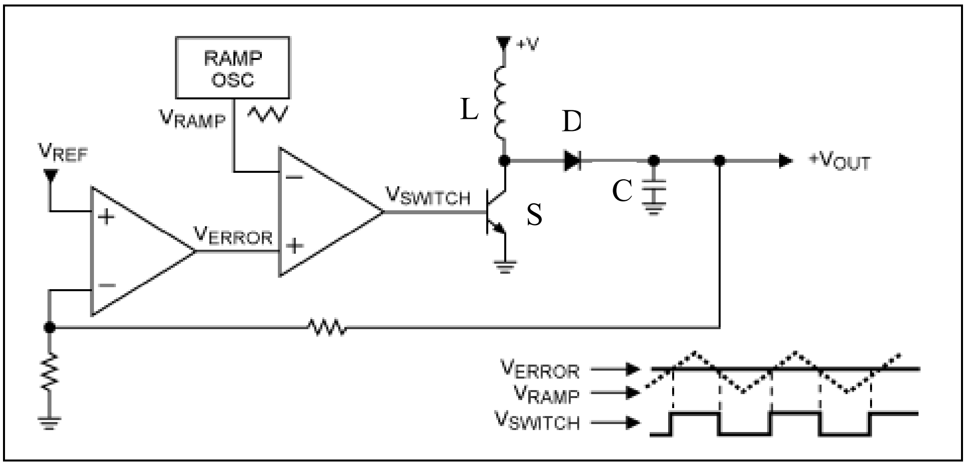


Figure 2.16: Varying error signal generates a pulse-width-modulated switch signal.

There are two methods for controlling the feedback loop and regulation characteristics of a switching DC-DC power converter that are Voltage Mode Control (VMC) and Current Mode Control (CMC) [16].

2.5.1 Voltage Mode Control

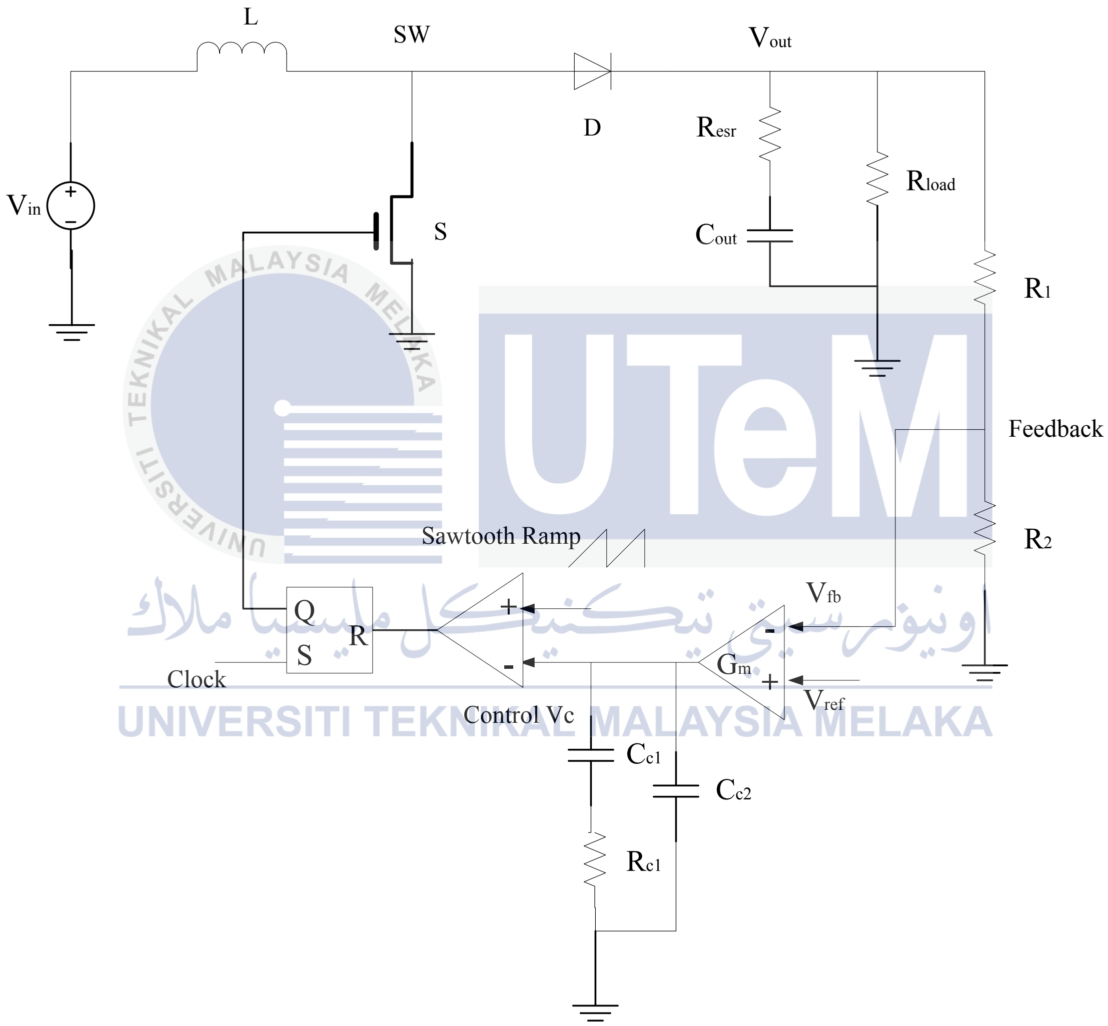


Figure 2.17: Control circuit of the boost converter with VMC [16].

The block diagram of a VMC boost converter is illustrated in Figure 2.17. The converter output voltage is monitored through a voltage divider. The voltage at feedback is compared to the reference voltage by the error amplifier to create an error current through the transconductance of the error amplifier. After going through the compensation impedance, the error current is converted to control voltage and is connected to the Pulse Width Modulator (PWM) that drives the MOSFET.

In voltage-mode control, this control voltage is compared with a saw tooth ramp. When the converter output voltage changes, the control voltage V_c also changes and thus causes the duty ratio of the power switch to change. The higher the error voltage, the longer is the duty cycle. This change of duty ratio adjusts the output voltage to reduce to error signal to zero [16]. The Control signal V_c, switch current and duty ratio waveforms are given in Figure 2.18.

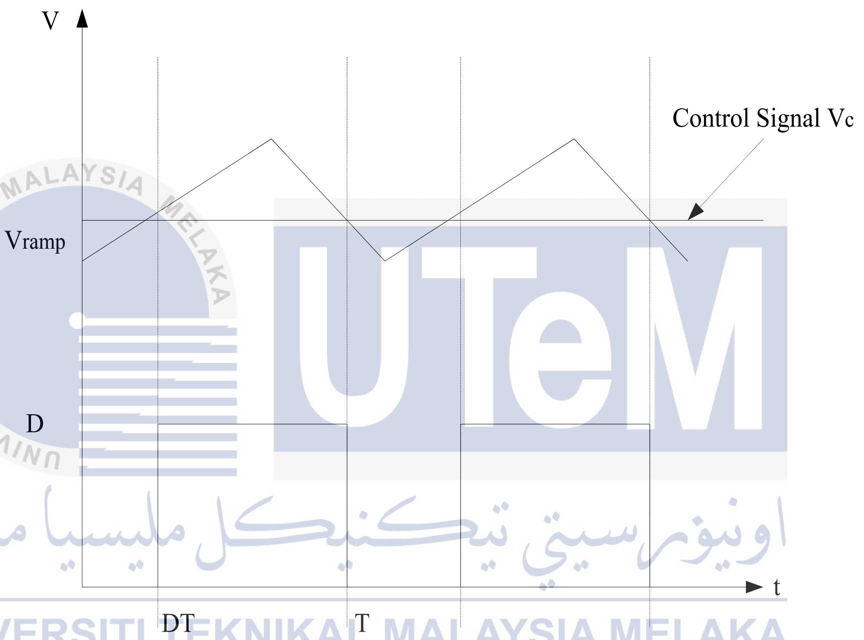


Figure 2.18: Switch current, control signal and duty ratio D of VMC [16].

The advantage of Voltage Mode Control is the output voltage is the control endpoint which is conceptually easier to understand than current mode control. Other than that, the sensing voltages are easy. Typically a resistor divider scales the output voltage to a value that is read by an ADC (Analog-to-Digital Converter), or is presented to an analog comparator. So, VMC is less noise, less power loss, less cost and more resolution than CMC. Lastly, the VMC only needs to monitor the output voltage so only one feedback is required, thus simplifying the design of the converter [17].

The disadvantage of Voltage Mode Control is it does not provide cycle by cycle control current through the transistor. This lack makes transformer flux balancing more difficult. Next, the output voltage is measured on the output capacitor which makes quick detection of input voltage or output changes difficult. The two pole filter off in the feedback path further slows the system response to change [17].

2.5.2 Current Mode Control

Another control scheme which has wide application in industry is Current Mode Control (CMC) in which the converter output voltage is controlled by the inductor current.

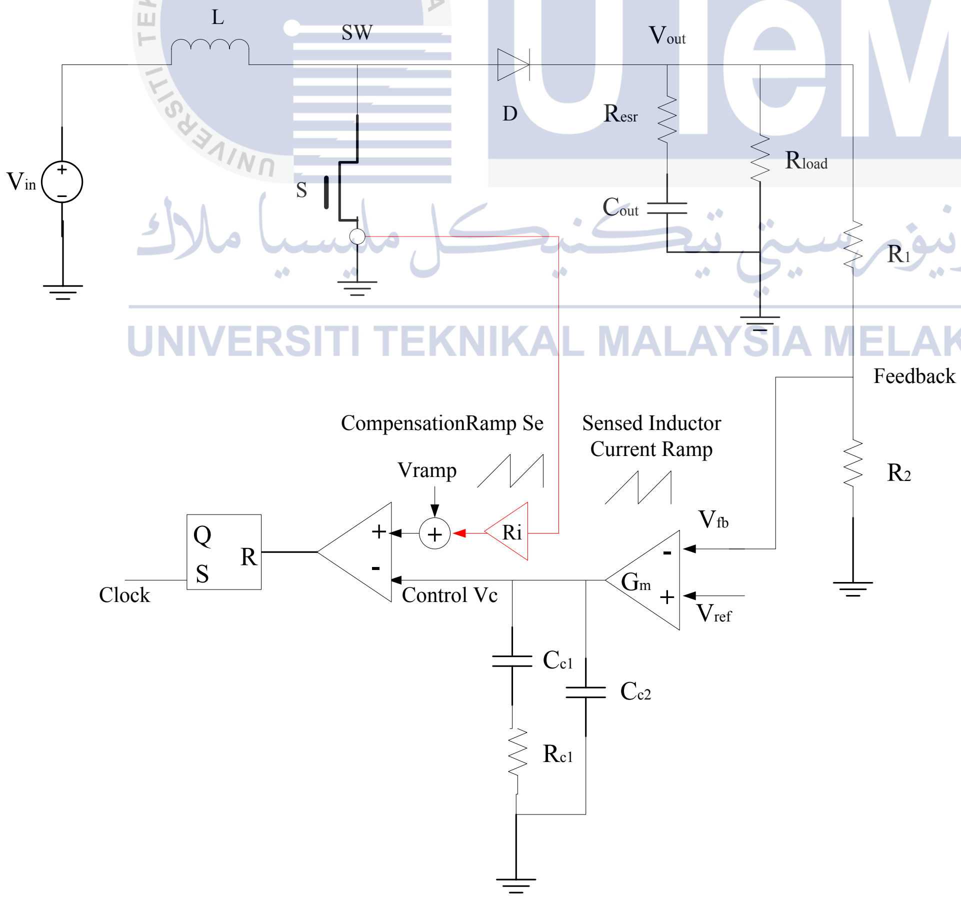


Figure 2.19: Control circuit of the boost converter with CMC [16].

The structure of a boost converter with current mode control is illustrated in Figure 2.19. The current feedback is the additional path which is different from the basic control block diagram of boost converter with voltage mode control. Rather than using a sawtooth ramp to control the duty ratio of the converter used in Voltage Control Mode, the current mode control regulates the peak of the inductor current with a control signal V_c.

At the beginning of the duty cycle *DT*, a clock pulse initiates the switching period, the MOSFET is turned on. While the transistor conducts, its current is equal to the inductor current which ramps up with a positive slope V_{in}/L. The switch current is measured and converted to a voltage using current sensor resistor. When the sum of the saw tooth ramp V_{ramp} and sensed voltage are greater than the control voltage, the controller turns the transistor switch OFF, and the inductor current decreases till next switching cycle. The duty ratio of the PWM modulator is thus adjusted to provide the necessary load current at the desired output voltage [16]. The Switch current, control signal and duty ratio *D* of the CMC is illustrated in Figure 2.20.

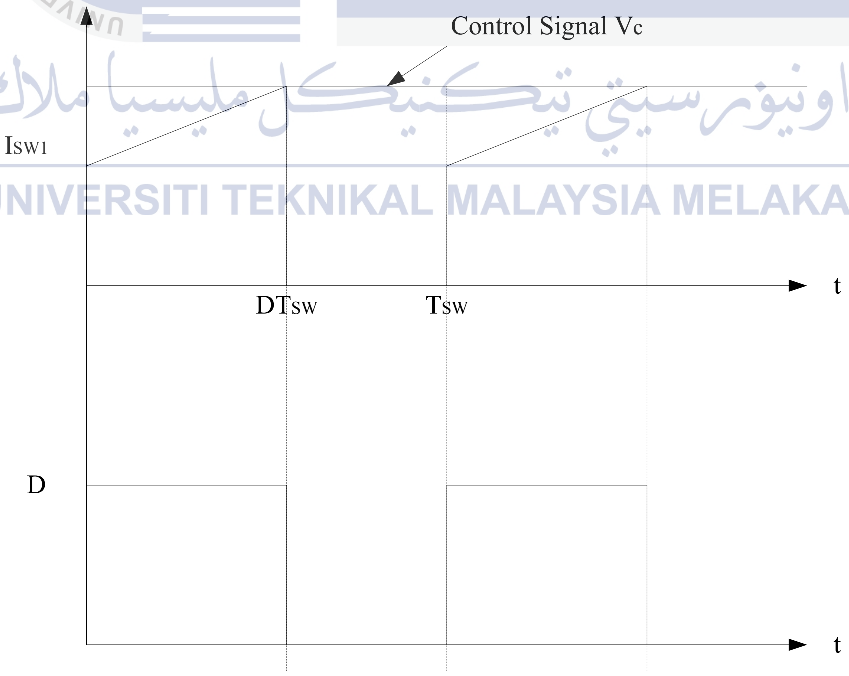


Figure 2.20: Switch current, control signal and duty ratio D of the CMC [16].

The advantage of CMC is it has faster output response than voltage mode because the current in the inductor is controlled instead of the output voltage which is measured on the output capacitor. Voltage mode is a two pole feedback loop while current mode is a one pole feedback loop. The single pole of a current mode control loop requires less high frequency roll-off to maintain loop stability. Besides, the inductor current responds directly with changes in input and output voltages. CMC provides better response to input and output voltage variations because the current changes are sensed directly. Lastly, CMC provides inherent current limiting on a cycle by cycle basis. Current limiting improves system reliability in response to current transients [17].

The disadvantage of CMC is it requires two feedback paths, increasing the system complexity and cost. Furthermore, the wide input voltage range creates design issues because large variations in PWM duty ratios are required, and exceeding 50% duty ratio introduces issues compensation. The slope compensation decreases the peak current limit as the duty ratio increases. The reduction in peak currents is designed to maintain the same average currents with increasing duty cycles. Last but not least, output current loads that vary over large ranges are also difficult for CMC to handle because the light load results in very small current measurement signals. The current measurement signals become buried in the noise [17].

2.6 MOSFET Gate Driver

Metal-Oxide-Semiconductor Field-Effect-Transistor (MOSFET) is a voltage controlled device. It is used to amplify or switch the electronic signal. The characteristic of the MOSFETs is shown in Figure 2.21. Power MOSFET is the enhancement type device compares to other types. The device will turn on if given the sufficient large voltage. The small voltage will across between drain region and source region. The advantage of this type of MOSFET is it will rapid sourcing and draining current due to the high speed switching. MOSFET also can operate up to 100 kHz range. A gate driver is used to amplify the PWM output voltage. The PWM will indicate the capability of speed switching.

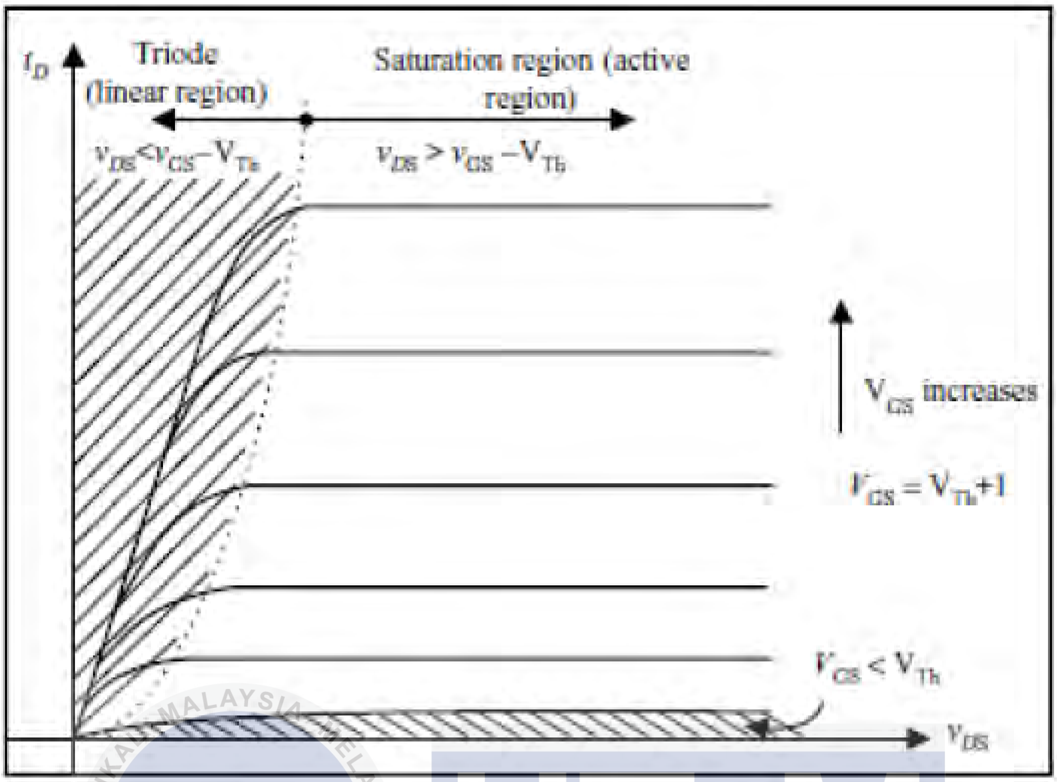


Figure 2.21: I-V MOSFET characteristics.

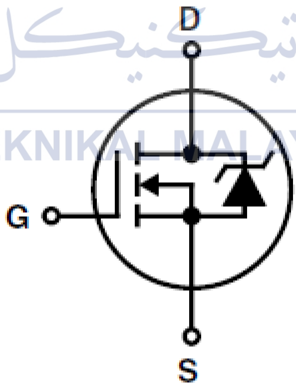


Figure 2.22: N-Channel Power MOSFET symbol.

2.7 Related Previous Works

Kapat et al. [11] stated that new formulation of a PID controller is introduced to replace the output voltage derivative with information about the capacitor current, thus reducing noise injection. This formulation preserves the fundamental principle of a PID controller and incorporates a load current feed-forward as well as inductor current dynamics. The proposed formulation preserves the basic principle of a PID controller and formulation of a conventional PID controller is introduced to replace the output voltage derivative with information about the capacitor current, thus reducing noise injection. However, the derivative gain never changes even at switching transition. Therefore, impulse noise injection due the derivative term of a conventional PID control is avoided using the proposed PID formulation.

Next, Libau [12] points about DC-DC boost converter and Hybrid Posicast controller were developed and simulated using MATLAB Simulink software. DC-DC boost converter has a very high overshoot and a very high settling time which produce oscillated output response. Hybrid Posicast controller is used in order to regulate the output voltage to a desire value. Hybrid Posicast controller operated within the feedback loop of the system. This DC-DC boost converter using Posicast Controller has an excellent performance to overcome unregulated input voltage, eliminate overshoot and minimize the settling time. But, the transfer function of DC-DC Boost Converter needed to derive using Control System elements and lots of calculation need to carry out to obtain the results.

Other than that, Aripin [5] proposed a technique for designing the controller of boost converter. From this technique, a simple converter‟s transfer function is obtained to be used in controller design. The designed controller should provide a good line and load regulation toward closed-loop converter. The advantage of this technique is the modeling and simulation of boost converter is executed using applications such as Simulink MATLAB and OrCAD. The weak point of this technique is the analysis of boost converter only focuses on closed-loop circuit by applying averaging and linearization technique to determine the transfer function.

Lastly, Hasaneen et al. [6] described a design and simulation of DC/DC boost converter. The equations of boost converter are analyzes and the design components and simulation of boost converter are proposed. The work is applied to photovoltaic system for tracking the point of maximum point. The design and simulation of DC/DC boost converter is done to operate in PV system. The parameters been proposed for all operating condition. However, the system has a nonlinear dynamic behavior as it works in switch-mode. It is exposed to significant variations which may take this system away from nominal conditions, due to changes on the load or on the line voltage at the input.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter review the procedures needed to be executed in order to achieve the objectives of the project. The design procedures of simulation and hardware implementation are discussed.

3.2 Project Methodology

Upon the completion of this project, several processes had been designed according to the sequence. All the procedures conducted throughout the project are discussed in detail with the help of flowchart, milestone and Gantt chart.

3.2.1 Flowchart

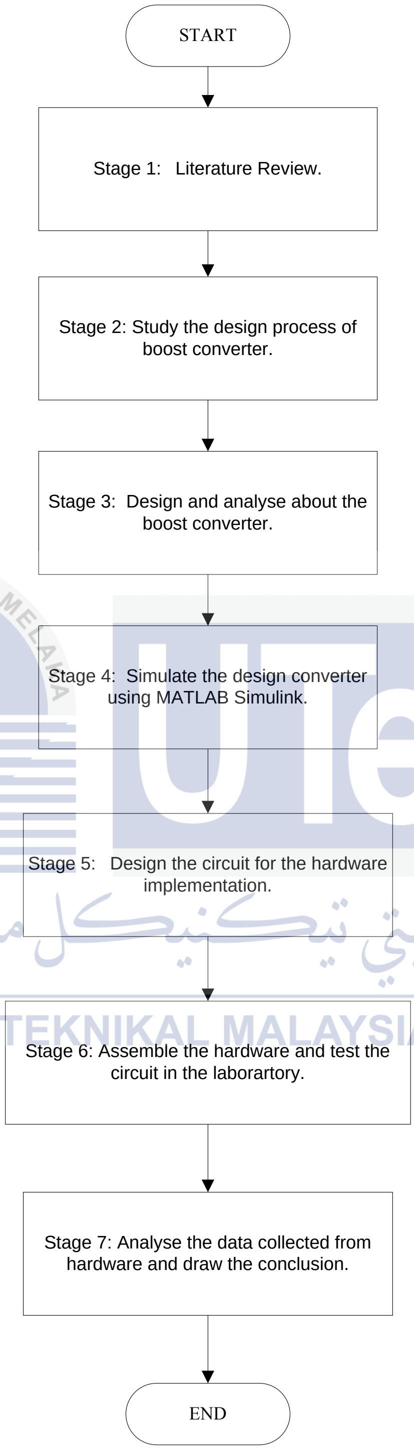


Figure 3.1: Operation flowchart.

Figure 3.1 shows the process sequence conducted upon completion of this project based on the flowchart design. The literature reviews on boost converter was conducted on the first semester by gathering all the detailed information from journals, books and internet. Next, the simulations using MATLAB Simulink are carried out to verify the calculated components using the formulae stated in Chapter 2. The boost converter must be in CCM operation. After that, the hardware of the boost converter was designed using OrCAD software to get the PCB layout. The designed circuit is assembled on the PCB. The hardware is firstly tested to check whether the circuit is functioning or not. If the circuit is not functioning, the troubleshooting process is done to solve the problem. Furthermore, the PWM was tested on Arduino Uno. The step continued with the hardware implementation and some data analysis on the hardware. The last step is drawing the conclusion based on the progress of the project.

3.2.2 Milestones

The methodology is divided into several important phases to systemize the operation sequence.

Phase 1: Detailed study about DC-DC boost converter.

1) Study the concept of boost converter.
2) Study the effect of Pulse Width Modulation (PWM) switching method to operate on boost converter.

Phase 2: Simulate the feedback loop of DC-DC boost converter.

1) Design the open-loop and closed-loop systems for boost converter.
2) Analyse the data from the simulation results.

Phase 3: Gather and collect the data based on the requirements.

1) Collect the data obtained from the simulation of MATLAB Simulink.
2) Collect the data obtained from the hardware of boost converter.
3) Gantt chart of project.

4) Milestone and date.

Milestone 1: Finding and researching on DC-DC boost converter.

Milestone 2: Simulating the DC-DC boost converter schemes.

Milestone 3: Analyzing the data from the simulation results.

Milestone 4: Implementations of DC-DC boost converter hardware.

Milestone 5: Validating the data obtained from hardware testing.

Milestone 6: Writing report.

3.2.3 Gantt Chart

Table 3.1: Gantt chart of project methodology.

Milestone	**Year**	**2013**				**2014**				
	Task	**9**	**10**	**11**	**12**	**1**	**2**	**3**	**4**	**5**
1	**Milestone 1**: Finding and researching on DC-DC boost converter.									
2	**Milestone 2**: Simulating the DC-DC boost converter schemes.									
3	**Milestone 3**: Analyzing the data from the simulation results.									
4	**Milestone 4**: Implementations of DC-DC boost converter hardware.									
5	**Milestone 5**: Validating the data obtained from hardware testing.									
6	**Milestone 6**: Writing report.									

Table 3.1 shows the chart of activities conducted according to the month upon completion of this research. The research starts on September 2013. For the first three months, the project is focused on the research of DC-DC boost converter that consists of its topologies and control schemes. Two months are provided to conduct the simulation of both open-loop and closed-loop boost converters. At the same time, the results from the simulation process are validated. After the simulations are completed, the hardware is implemented and the time allocated for this process is approximately four months. Next, three months duration times are used to do the analysis on data obtained during simulations and hardware design. The report writing is proceeding throughout the project duration process.

3.3 Feedback Loop Technique Used

There are two major feedback loop schemes in DC-DC boost converter system. In this project, MATLAB Simulink model is used for the analysis of DC-DC boost converter using open-loop and closed-loop control schemes. The boost converter involves the switching converter that operates by periodically opening and closing an electronic switch.

Next, the simulation of control schemes of DC-DC boost converter will be compared. All the data obtained from the simulation results been analyzed to estimate the performance analysis. The important parameters are shown to study the difference of performance between open-loop control system and closed-loop control system.

Lastly, the finalized values of parameters will be implemented in hardware design. The hardware consists of open-loop and closed-loop systems for variable PWM controller. This variable PWM controller applies Arduino programming in the circuit.

3.4 Designed Parameter System Results

This section will discuss about the design parameter system involving the calculation and MATLAB simulation block diagram.

3.4.1 Calculation Analysis

The values of parameter for DC-DC boost converter by using both open-loop and closed-loop control systems are calculated. The parameters of the designed DC-DC boost converter circuit are shown in Table 3.2.

Table 3.2: The parameters of DC-DC boost converter.

Input voltage, V_s	5 V – 8 V
Output voltage, V_o	24V
Rated output power, P	100 W
Output voltage ripple,$\Delta V_o/V_o$	Less than 0.2 %
Switching frequency, f	50 kHz

For V_s = 5 V;

First, find the value of duty ratio D from Equation (2-3),

$$V_o = \frac{V_S}{(1-D)} \quad => D = 1 - \frac{V_s}{V_o} = 1 - \frac{(5\,V)}{(24\,V)} = 0.79$$

Next, determine the inductance value, L from Equation (2-8),

$$L_{\min} = \frac{D(1-D)^2 R}{2f} = \frac{0.79(1-0.79)^2(75)}{2(50\,kHz)} = 26\,\mu H$$

For Continuous Current Mode (CCM), the inductance value must be at least 25 % larger than minimum inductance, $L_{\min}$. Therefore;

$$1.25L_{\min} = 1.25(26\ \mu H) = 33\ \mu H$$

The inductance chosen for the circuit is 100 μH.

Assume the circuit is in Continuous Conduction Mode (CCM).

By using Equations (2.5), (2.6) and (2.7),

$$I_L = \frac{V_S}{(1-D)^2 R} = \frac{(5\ V)}{(1-0.79)^2(75\ \Omega)} = 1.51\ \text{A}$$

$$I_{max} = \frac{V_s}{(1-D)^2 R} + \frac{V_S DT}{2L} = \frac{(5\ V)}{(1-0.79)^2(75\ \Omega)} + \frac{(5\ V)(0.79)(1/50\ kHz)}{2(100\ \mu H)} = 1.91\ \text{A}$$

$$I_{min} = \frac{V_S}{(1-D)^2 R} - \frac{V_S DT}{2L} = \frac{(5\ V)}{(1-0.79)^2(75\ \Omega)} - \frac{(5\ V)(0.79)(1/50\ kHz)}{2(100\ \mu H)} = 1.11\ \text{A}$$

Therefore, the minimum capacitance required to limit the output ripple voltage to 0.2 percent is determined from Equation (2-20) and Equation (2-21),

$$C = \frac{D}{R(\Delta V_O / V_O)f} = \frac{(0.79)}{(75\ \Omega)\ (0.002)(50\ kHz)} = 105\ \mu F$$

The capacitance chosen for the circuit is 100 μF.

$$\frac{\Delta V_O}{V_O} = \frac{D}{RCf} = \frac{0.79}{(75\ \Omega)(100\ \mu F)(50\ kHz)} = 0.002 \text{ @ } 0.2\ \%\ \text{(appropriate value)}$$

For V_s = 8 V;

First, find the value of duty ratio *D* from Equation (2-3),

$$V_o = \frac{V_S}{(1-D)} \Rightarrow D = 1 - \frac{V_S}{V_O} = 1 - \frac{(8\ V)}{(24\ V)} = 0.67$$

Next, determine the inductance value, *L* from Equation (2-8),

$$L_{\min} = \frac{D(1-D)^2 R}{2f} = \frac{0.67(1-0.67)^2(75)}{2(50\ kHz)} \approx 55\ \mu H$$

For Continuous Current Mode (CCM), the inductance value must be at least 25 % larger than minimum inductance, $L_{\min}$. Therefore;

$1.25L_{\min}$= $1.25(55\ \mu H)$ = $69\ \mu H$

The inductance chosen for the circuit is $100\ \mu H$.

Assume the circuit is in Continuous Conduction Mode (CCM).

By using Equations (2.5), (2.6) and (2.7),

$$I_L = \frac{V_S}{(1-D)^2 R} = \frac{(8\ V)}{(1-0.67)^2(75\ \Omega)} = 0.98\ \text{A}$$

$$I_{max} = \frac{V_S}{(1-D)^2 R} + \frac{V_S DT}{2L} = \frac{(8\ V)}{(1-0.67)^2(75\ \Omega)} + \frac{(8\ V)(0.67)(1/50\ kHz)}{2(100\ \mu H)} = 1.52\ \text{A}$$

$$I_{min} = \frac{V_S}{(1-D)^2 R} - \frac{V_S DT}{2L} = \frac{(8\ V)}{(1-0.67)^2(75\ \Omega)} - \frac{(8\ V)(0.67)(1/50\ kHz)}{2(100\ \mu H)} = 0.44\ \text{A}$$

Therefore, the minimum capacitance required to limit the output ripple voltage to 0.2 percent is determined from Equation (2-20) and Equation (2-21),

$$C = \frac{D}{R(\Delta V_O/V_O)f} = \frac{(0.67)}{(75\ \Omega)\ (0.002)(50\ kHz)} = 89\ \mu F$$

The capacitance chosen for the circuit is $100\ \mu F$.

$$\frac{\Delta V_O}{V_O} = \frac{D}{RCf} = \frac{0.67}{(75\ \Omega)(100\ \mu F)(50\ kHz)} \approx 0.002\ @\ 0.2\ \%\ \text{(appropriate value)}$$

3.4.2 MATLAB Simulink Block Diagram

The block diagrams of the DC-DC boost converter by using open-loop and closed-loop control schemes are designed.

3.4.2.1 Open-loop Boost Converter

The simulation of open-loop boost converter is divided into 2 separate operating voltages that are $V_s = 5$ V and $V_s = 8$ V respectively.

1) Simulation of Open-loop with $V_s = 5$ V.

Table 3.3: Parameters for simulation of open-loop boost converter with $V_s = 5$ V.

Input voltage, V_s	5 V
Output voltage, V_o	24 V
Load resistance, R	75 Ω
Duty ratio, D	0.79
Switching frequency, f	50 kHz
Inductor, L	100 µH
Capacitor, C	100 µF

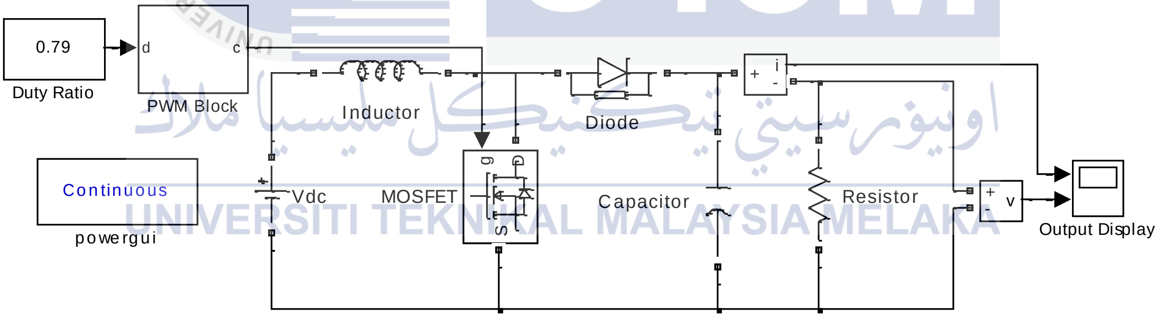


Figure 3.2: Block diagram of open-loop boost converter with $V_s = 5$ V.

2) Simulation of Open-loop with V_s = 8 V.

Table 3.4: Parameters for simulation of open-loop boost converter with V_s = 8 V.

Input voltage, V_s	8 V
Output voltage, V_o	24 V
Load resistance, R	75 Ω
Duty ratio, D	0.67
Switching frequency, f	50 kHz
Inductor, L	100 µH
Capacitor, C	100 µF

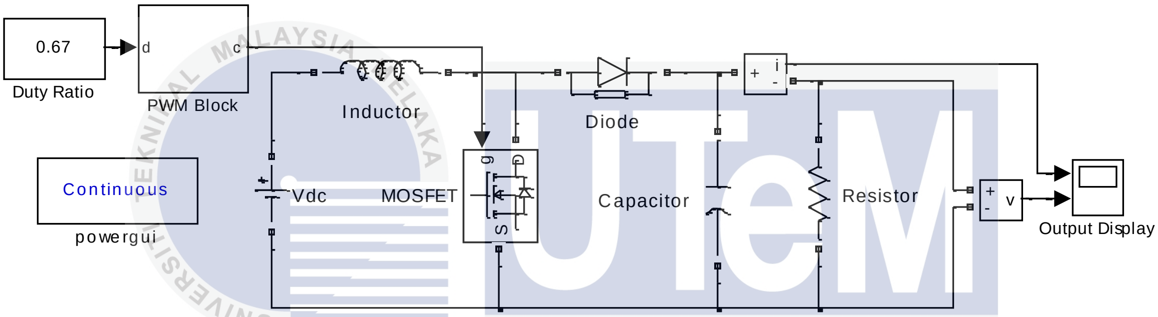


Figure 3.3: Block diagram of open-loop boost converter with V_s = 8 V.

3.4.2.2 Closed-loop Boost Converter

The simulation of closed-loop boost converter is divided into 2 separate operating voltages that are $V_s = 5$ V and $V_s = 8$ V respectively.

1) Simulation of Closed-loop with $V_s = 5$ V.

Table 3.5: Parameters for simulation of closed-loop boost converter with $V_s = 5$ V.

Input voltage, V_s	5 V
Output voltage, V_o	24 V
Load resistance, R	75 Ω
Switching frequency, f	50 kHz
Inductor, L	100 µH
Capacitor, C	100 µF

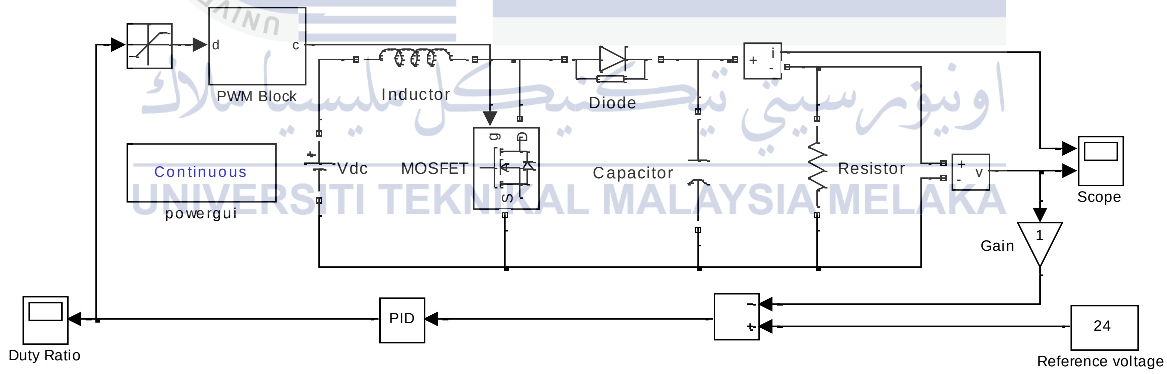


Figure 3.4: Block diagram of closed-loop boost converter with $V_s = 5$ V.

2) Simulation of Closed-loop with V_s = 8 V.

Table 3.6: Parameters for simulation of closed-loop boost converter with V_s = 8 V.

Input voltage, V_s	8 V
Output voltage, V_o	24 V
Load resistance, *R*	75 Ω
Switching frequency, *f*	50 kHz
Inductor, *L*	100 µH
Capacitor, *C*	100 µF

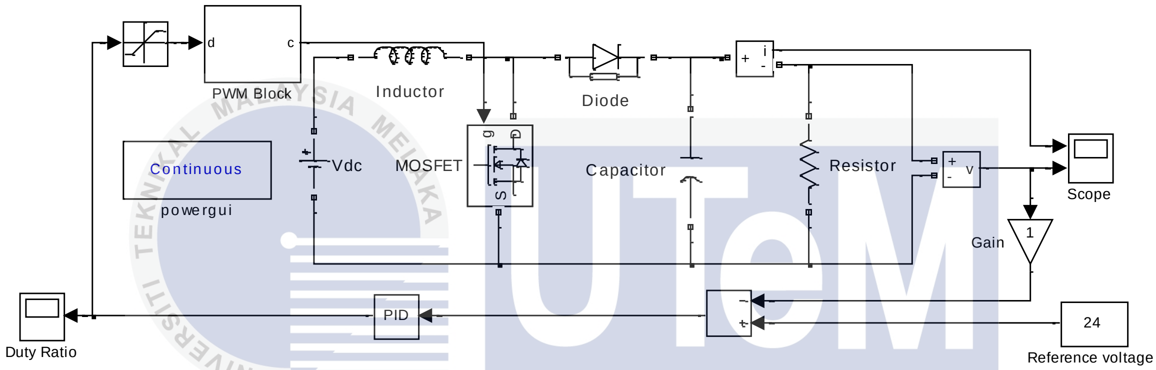


Figure 3.5: Block diagram of closed-loop boost converter with V_s = 8 V.

3.5 Hardware Implementation

The specifications of DC-DC boost converter are briefly described in terms of the parameters, the major components existed in the circuit and hardware designs according to PWM controller mechanisms under open-loop and closed-loop control system.

3.5.1 Hardware Specifications

Table 3.7: The specifications of boost converter.

Input voltage	5 V ~ 8 V
Output voltage	24 V
Rated output power	100 Watts
Output voltage ripple	less than 0.2 %
Switching frequency	50 kHz
Conduction Mode	Continuous Conduction Mode (CCM) at 100 W and above.

Table 3.8: Major components for the power stage.

DC-DC converter	IQ0515SA
MOSFET	IRF510
DIODE	MUR415
Inductor	100 μH
Capacitor	100 μF

Table 3.9: Major components for PWM control and driving circuit.

PWM controller	Arduino Uno
MOSFET driver	HCPL-3120-000E

3.6 Hardware Design of Boost Converter

Figure 3.6 shows the boost converter circuit designed in OrCAD software. The input voltage source is 5 V to 8 V by adjusting the duty ratio value and the expected output voltage source is about 24 V. If the duty ratio is at 50 %, the magnitude of the output voltage will be two times the value of input voltage. Higher duty ratio increases the output voltage and vice versa. MUR415 fast recovery diode is practiced on the circuit, while the IRF510, N-Channel Power MOSFET is used for the switching process which easily available in the market. The load used is 75 Ω, designed inductor is 100 µH and the capacitor is 100 µF. Some of these components are available in the electronic shops or through online transaction.

The schematic circuit of boost converter is shown as Figure 3.6 while the hardware implementation is shown as Figure 3.7. The value of the designed circuit is tabulated in Table 3.10.

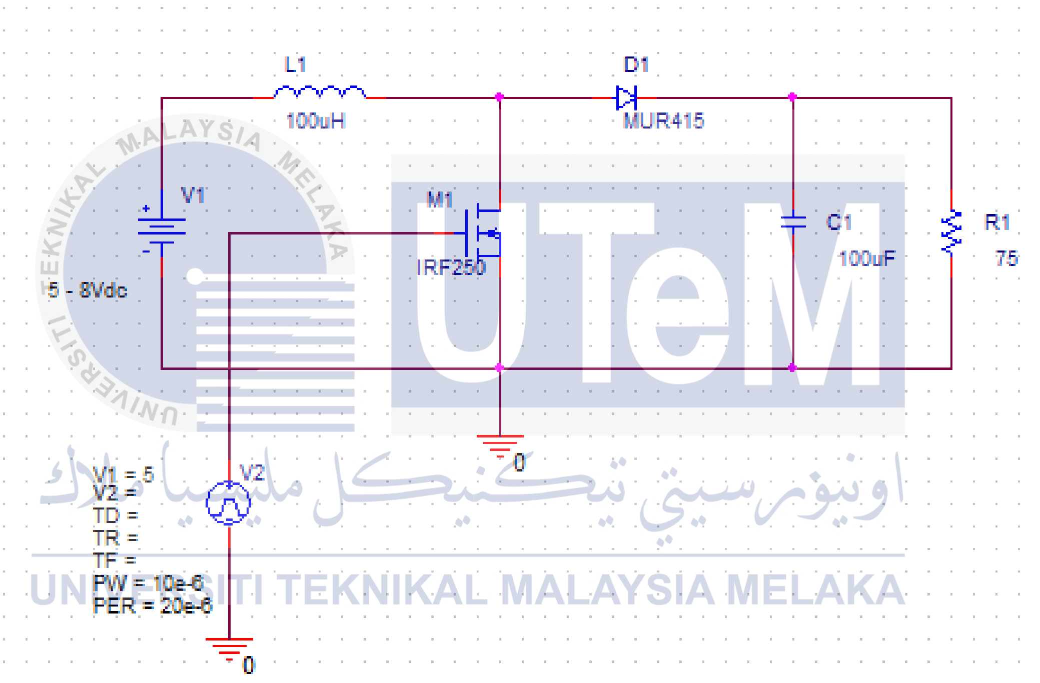


Figure 3.6: Boost converter hardware circuit.

Table 3.10: The specifications of boost converter.

Input voltage, V_S	5 V – 8 V
Load resistor, R	75 Ω, 3 W
Inductor, L	100 µH
Capacitor, C	100 µF

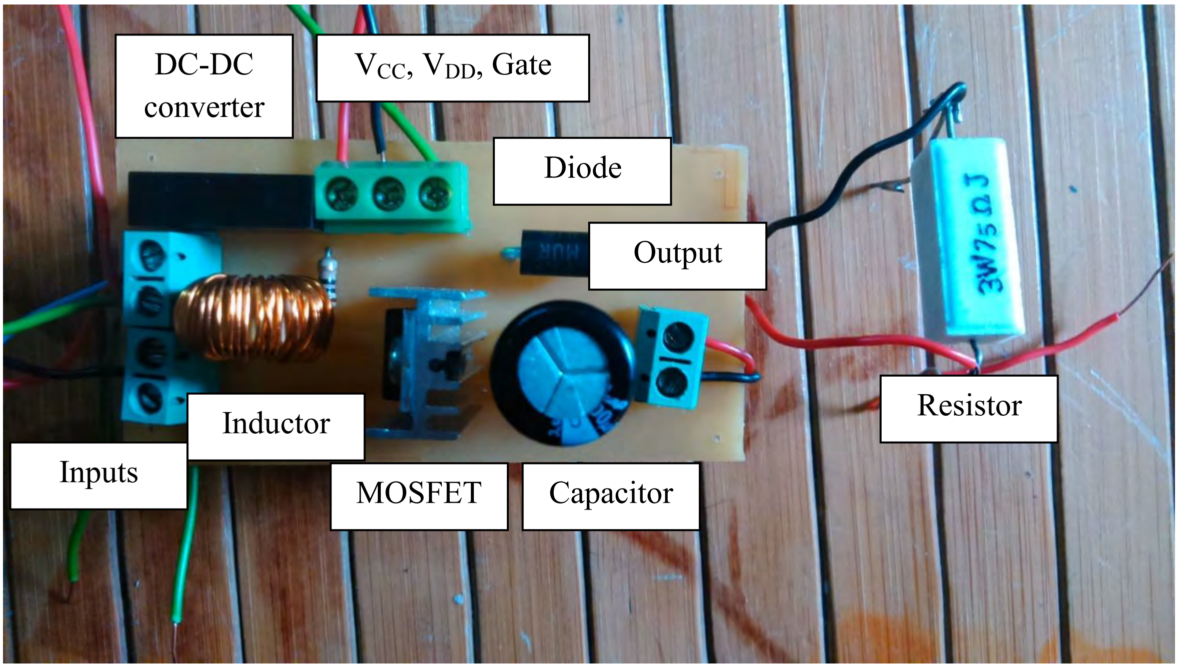


Figure 3.7: Classification of parts in boost converter hardware circuit.

3.7 Printed Circuit Board (PCB)

Several steps are crucial of designing the PCB circuit before testing, troubleshooting and taking the data analysis. By using OrCAD Capture and OrCAD Layout software, the basic procedures are stated as follows [18]. Firstly, the OrCAD Capture software is opened and a PCB project is set up using the PCB wizard. A circuit schematic is made using OrCAD Capture. Next, OrCAD Capture is used to generate a Layout netlist and it is saved as .MNL file for Layout. After that, the OrCAD Layout is started and a PCB technology template (.TCH file) is selected.

The Layout project is saved as a .MAX project file. The Layout is used to import the .MNL netlist into .MAX file as shown in Figure 3.8. A board outline and position of the component parts within the board outline are made. Lastly, the postprocessor is simulated to generate files used to manufacture the PCB. The file is saved in PDF format as shown in Figure 3.9. All the blueprint PDF file used to design PCB circuit for boost converter can be referred in Appendix E.

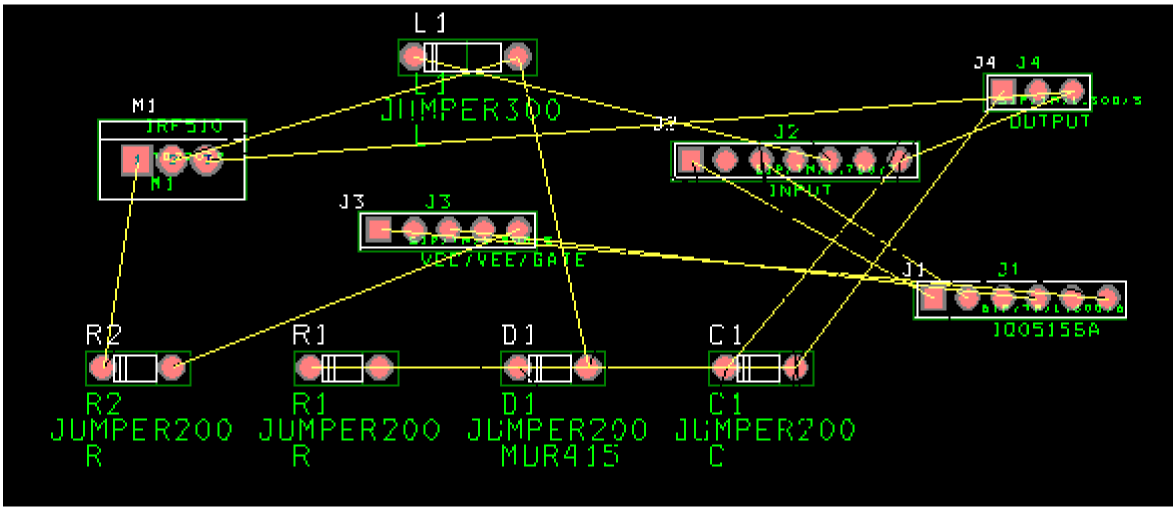


Figure 3.8: Example .MAX file for boost converter.

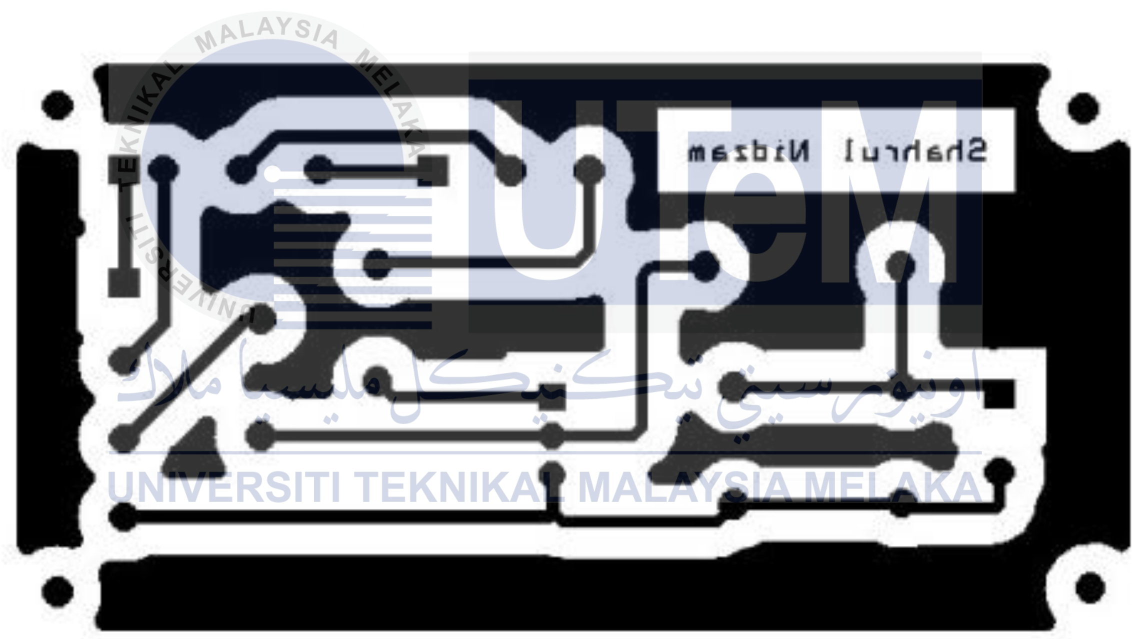


Figure 3.9: Board outline in PDF format.

The next procedure is to produce the PCB hardware circuit. Firstly, the circuit layout is printed out by using laser jet printer. Next, the UV board is cut according to the circuit layout size. The printed tracing paper is patched on the UV board and an appropriate method is applied to display the circuit on the board. The UV board is etched to remove and create the copper track. The step is continued by making the holes on each pin by using grinder. Lastly, the components are soldered on to its specified slots. The components are made sure to touch the track properly by using multimeter for continuity test.

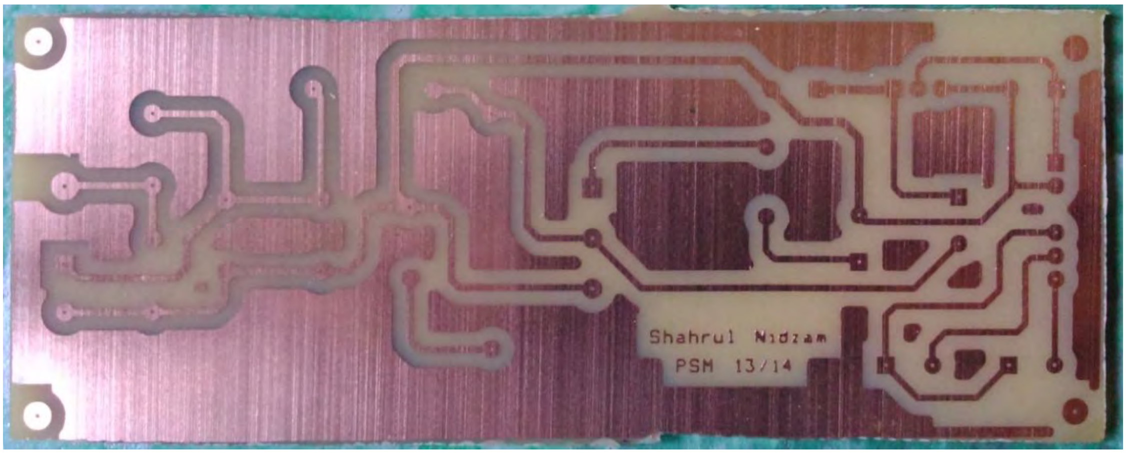


Figure 3.10: Example of PCB board after etching process and grinding hole.

3.8 Pulse Width Modulation Circuit (PWM)

The main component of this PWM circuit is Arduino. By applying different coding programming, the PWM can be adjusted manually or automatically. Open-loop PWM will apply manual coding mean while closed-loop PWM will use automatic coding. The duty ratio in open-loop circuit is manually tuned and the closed-loop circuit is automatically tuned by the feedback circuit. Since the generated switching frequency is set to be 50 kHz, the coding is produced based on this requirement. This coding can be referred in Appendix F.

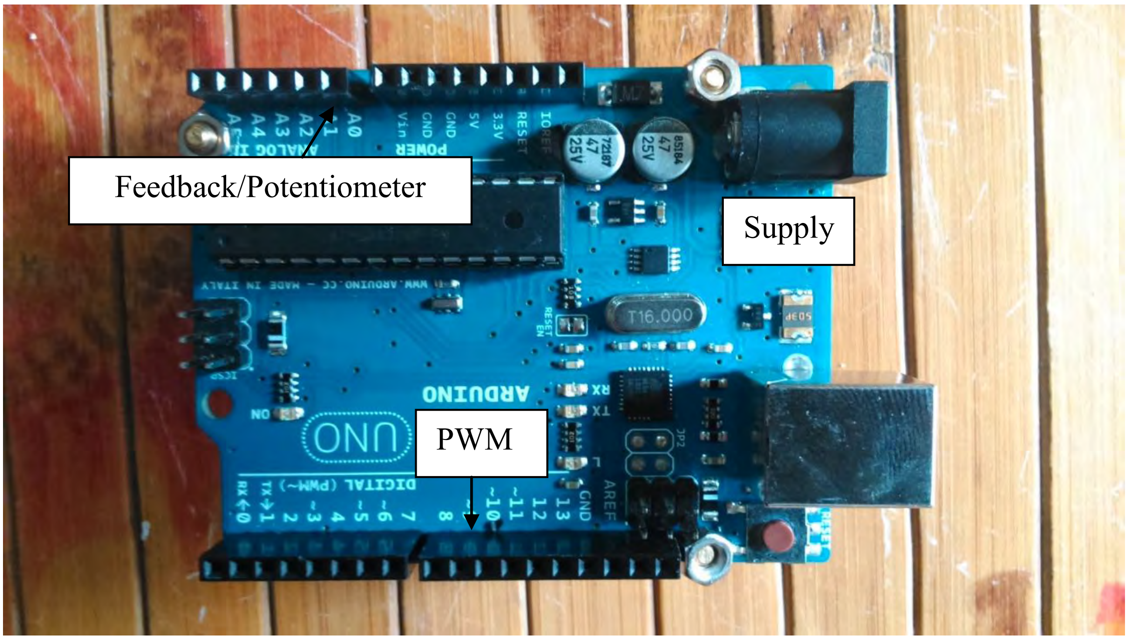


Figure 3.11: Arduino circuit.

3.9 Gate Driver Circuit

The gate driver circuit is implemented in this project in order to increase the voltage pulse to be sent to the MOSFET. The main function of this gate driver, HCPL-3120-000E is to drive the MOSFET. Figure 3.12 shows the schematic circuit for the gate driver and the hardware is shown in Figure 3.13. The datasheet of HCPL-3120-000E IC can be referred in Appendix D.

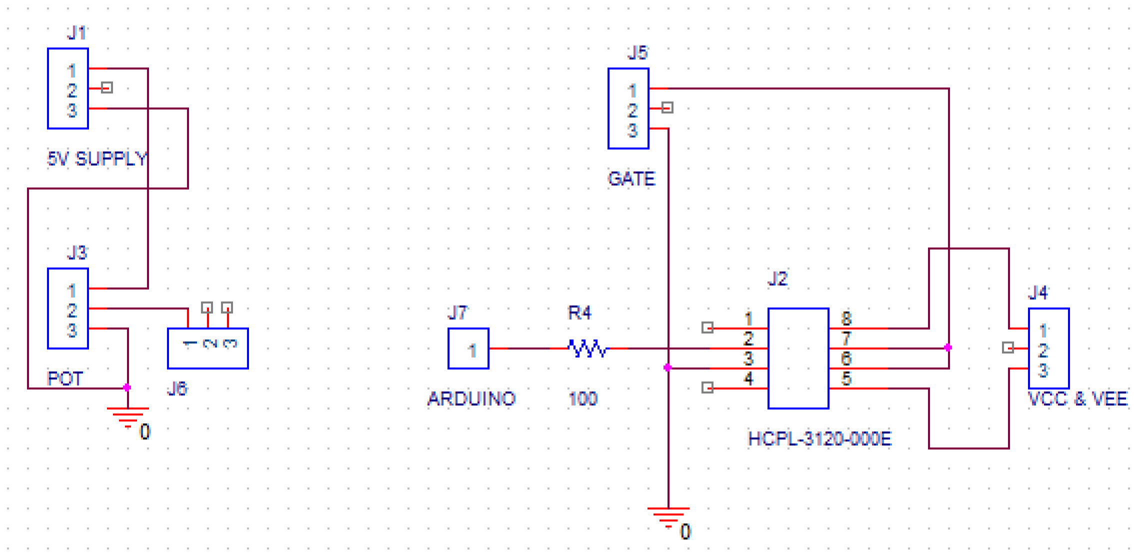


Figure 3.12: Gate driver circuit.

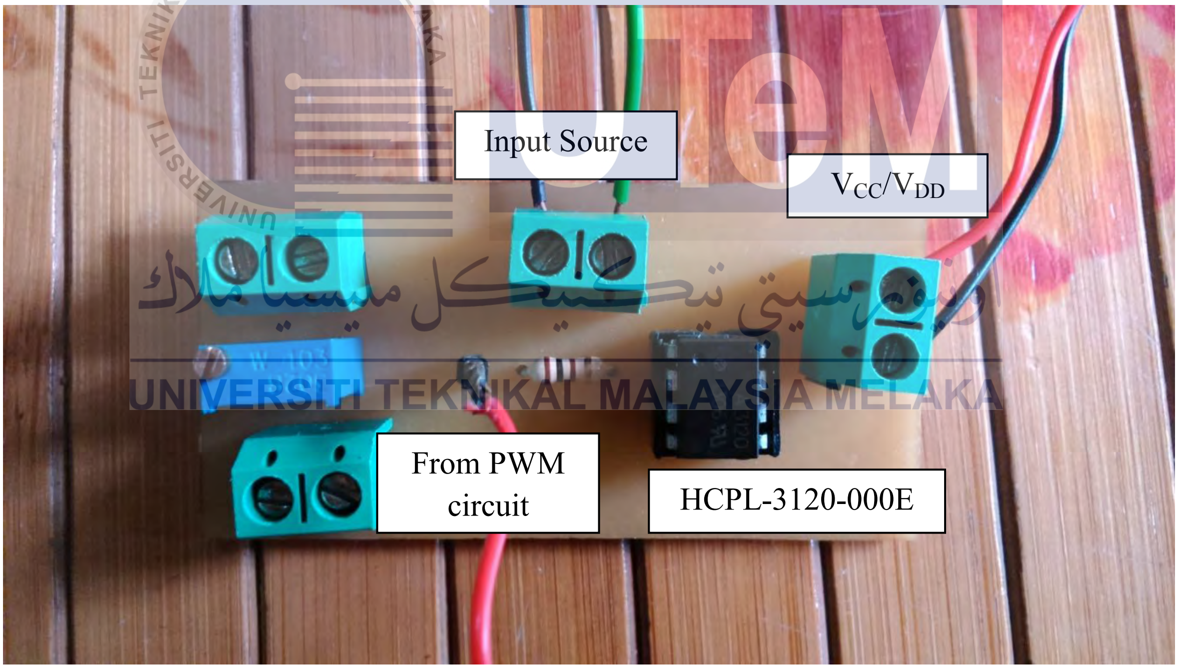


Figure 3.13: Gate driver hardware circuit.

3.10 Description of the Major Components

All the major components in the hardware circuits such as (Integrated Circuit) IC‟s and semiconductors are briefly described. These components are including MUR415, HCPL-3120-000E, IRF510 and IQO515SA.

3.10.1 HCPL-3120-000E MOSFET Driver

In this project, HCPL-3120-000E acts as Metal-Oxide-Semiconductor Field-Effect Transistor (MOSFET) driver. It is known as amp output current Insulated-Gate Bipolar Transistor (IGBT) Gate Drive Optocoupler. These optocouplers are suited for driving power MOSFET applications. The high operating voltage range of the output stage provides the drive voltages required by gate controlled devices. The voltage and current supplied by HCPL-3120-000E make them suited for directly driving MOSFET.

3.10.2 MUR415 Diode

MUR415 is a switch mode power rectifier. This device is designed for the use in switching power supplies, inverters and as freewheeling diodes. MUR415 can provide a low forward voltage and high reverse voltage. It is ideally suited in this project due to low leakage current during operation process thus; the power loss can be reduced.

3.10.3 IRF510 MOSFET

IRF510 is N-Channel enhancement mode Power MOSFET which is an advanced power MOSFET designed, tested and guaranteed to withstand a specified level of energy in the breakdown avalanche mode of operation. Other than that, IRF510 is available for applications such as switching regulators, motor drives and switching converters. So, the output of this project can be achieved accurately.

3.10.4 IQ0515SA DC-DC Converter

IQ0515SA is a device that provides the voltage isolation for the power supply. It regulates the output voltage. Since electronic circuit contains several sub-circuits, their own voltage levels are different. Furthermore, the battery voltage decreases as its power been used by the circuit. Therefore, IQ0515SA provide a solution to increase the voltage from a low battery voltage thus, saving space instead of using multiple batteries to accomplish the same thing.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

Chapter 3 shows the simulation of DC-DC boost converter by using open-loop and closed-loop control schemes. Besides, the hardware design also been introduced. This chapter will discuss the simulation results for both control schemes of DC-DC boost converter. Other than that, the results of the hardware project also been discussed. The results are recorded based on PCB; the hardware implementation. The recorded data obtained are in waveform shape from oscilloscope.

4.2 Simulation Results

This section describes the simulation results of the DC-DC boost converter on open-loop and closed control systems.

4.2.1 Open-loop Boost Converter

These sections display the simulation results of open-loop and closed-loop control in the form of waveforms.

4.2.1.1 Simulation Result of Open-loop with V_s = 5 V.

The simulation of open-loop boost converter is designed to verify the response of the converter. The voltage input is 5 V step up to 24 V for the voltage output. The DC-DC converter has been simulated under CCM operating condition and the parameters involved are $V_s = 5\ V$, $V_o = 24\ V$, $R = 75\ \Omega$, $D = 0.79$, f = 50 kHz, L = 100 µH and C = 100 µF. The output voltage, V_o and the output current, I_o are generated as shown in Figure 4.1. The PWM controller signal is displayed in Figure 4.2 is used to control the ON and OFF of the switches.

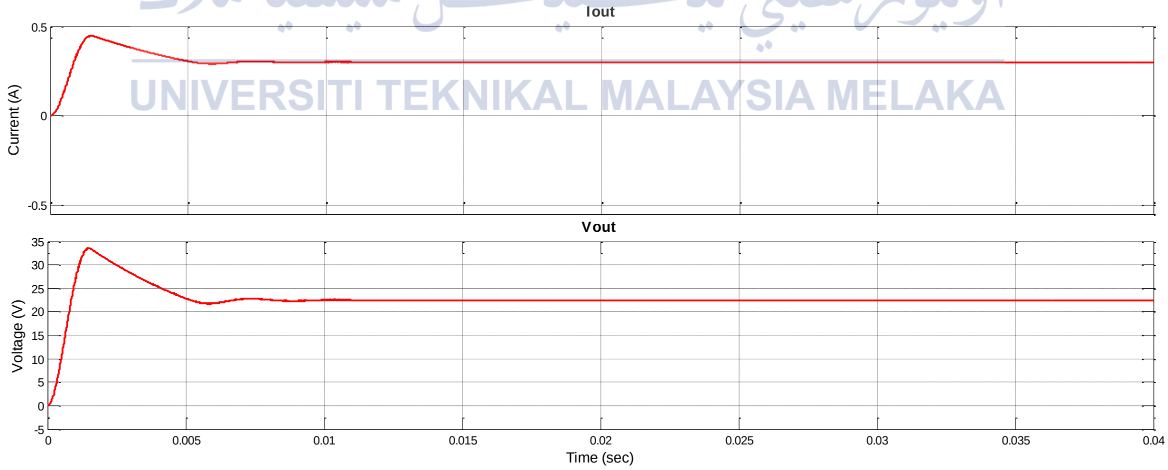


Figure 4.1: Output current and output voltage waveforms.

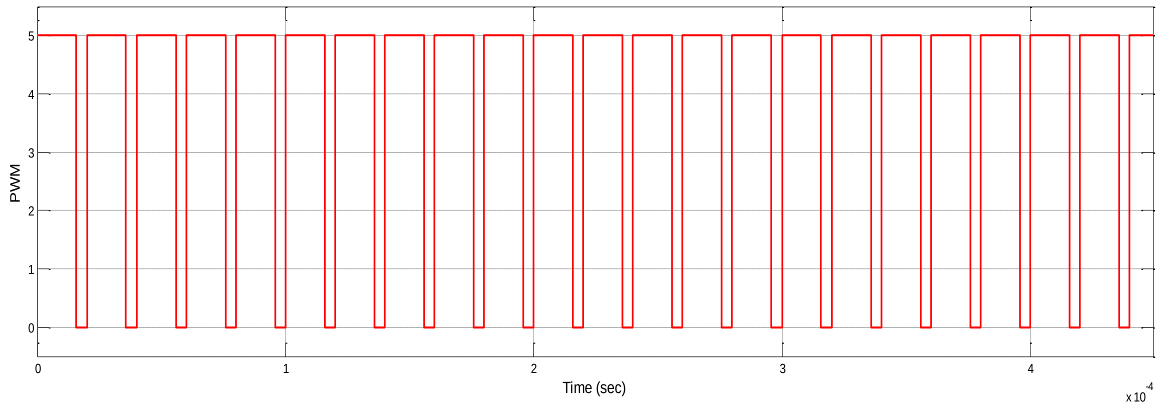


Figure 4.2: 79% duty ratio of PWM block diagram signals.

4.2.1.2 Simulation Result of Open-loop with $V_s = 8$ V.

The simulation of open-loop boost converter is designed to verify the response of the converter. The voltage input is 8 V step up to 24 V for the voltage output. The DC-DC converter has been simulated under CCM operating condition and the parameters involved are $V_s = 8$ *V*, $V_o = 24$ *V*, $R = 75\ \Omega$, $D = 0.67$, $f = 50$ kHz, $L = 100$ µH and $C = 100$ µF. The output voltage, V_o and the output current, I_o are generated as shown in Figure 4.3. The PWM controller signal is displayed in Figure 4.4 is used to control the ON and OFF of the switches.

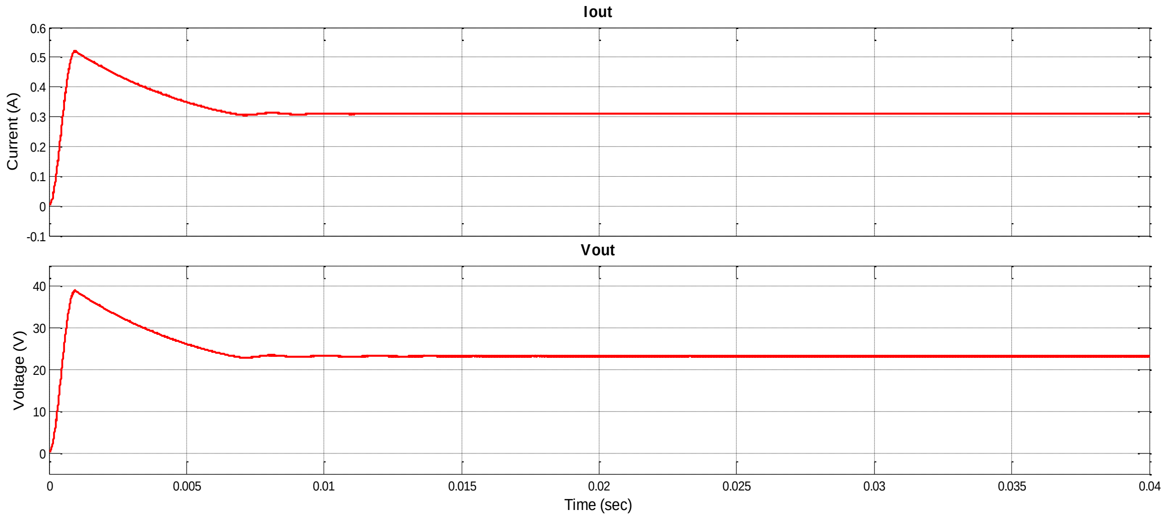


Figure 4.3: Output current and output voltage waveforms.

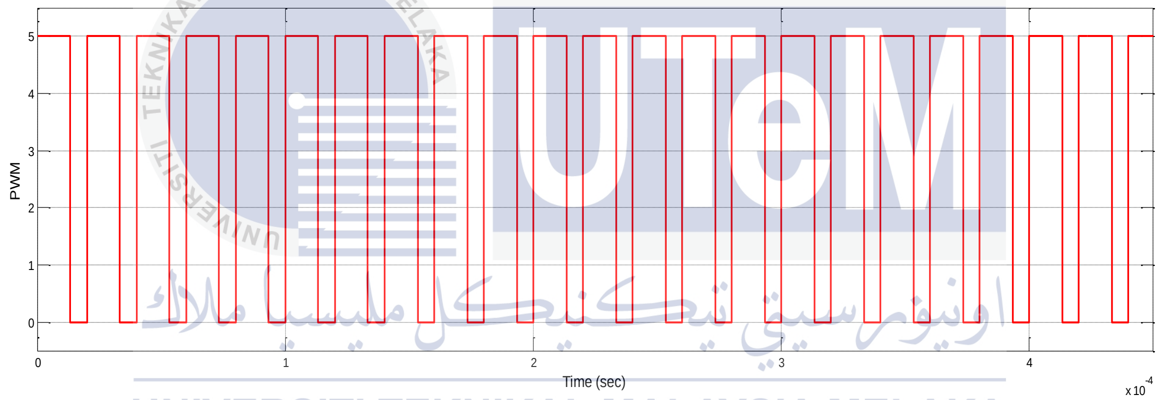


Figure 4.4: 67% duty ratio of PWM block diagram signals.

4.2.2 Closed-loop Boost Converter

These sections display the simulation results of open-loop control in the form of waveforms.

4.2.2.1 Simulation Result of Closed-loop with V_s = 5 V.

The simulation of closed-loop boost converter is designed to verify the response of the converter. The voltage input is 5 V step up to 24 V for the voltage output. The DC-DC converter has been simulated under CCM operating condition and the parameters involved are $V_s = 5\ V$, $V_o = 24\ V$, $R = 75\ \Omega$, f = 50 kHz, L = 100 μH and C = 100 μF. The output voltage, V_o and the output current, I_o are generated as shown in Figure 4.5. The duty ratio feedback of the converter is generated in Figure 4.6.

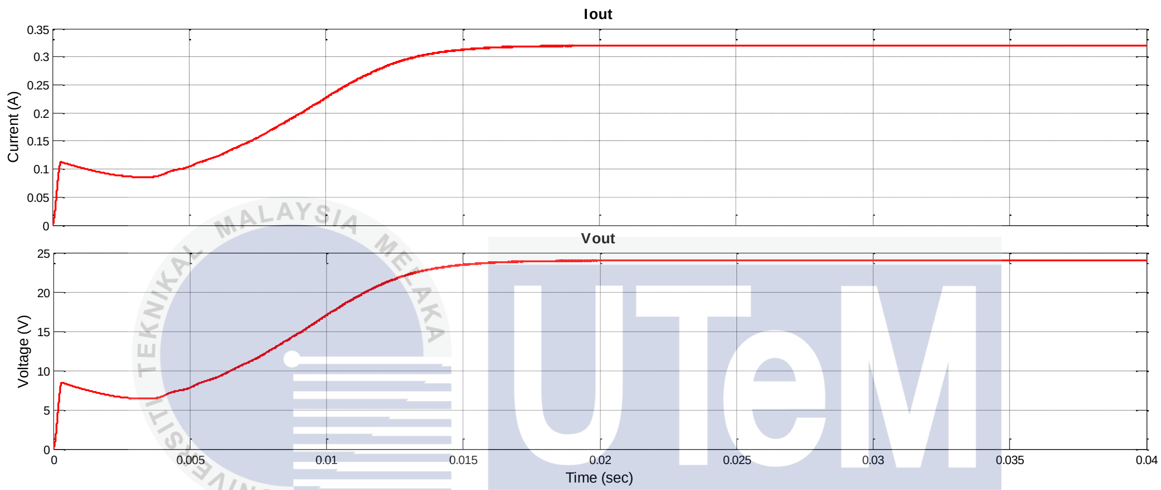


Figure 4.5: Output current and output voltage waveforms.

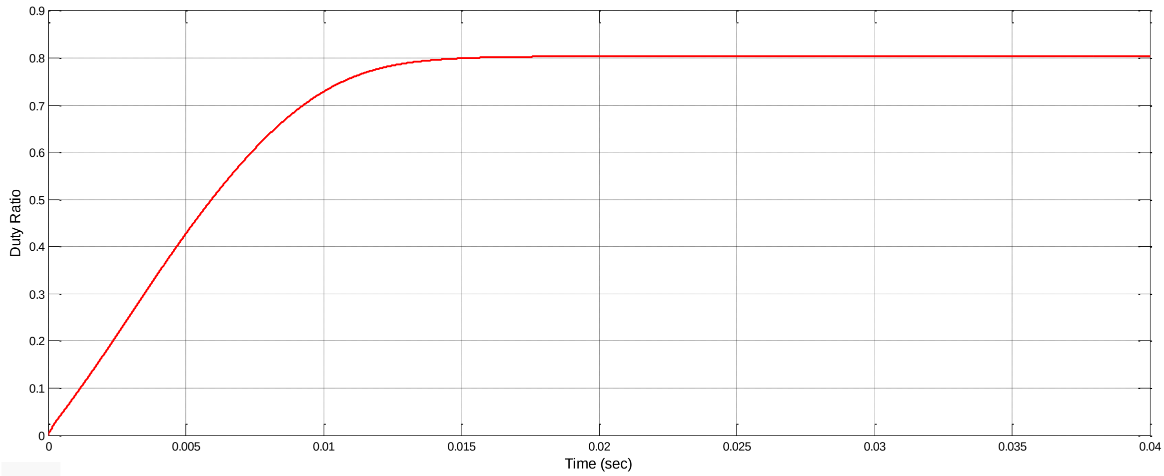


Figure 4.6: Duty ratio of PWM block diagram signals.

4.2.2.2 Simulation Result of Closed-loop with V_s = 8 V.

The simulation of closed-loop boost converter is designed to verify the response of the converter. The voltage input is 8 V step up to 24 V for the voltage output. The DC-DC converter has been simulated under CCM operating condition and the parameters involved are $V_s = 8\ V$, $V_o = 24\ V$, $R = 75\ \Omega$, f = 50 kHz, L = 100 μH and C = 100 μF. The output voltage, V_o and the output current, I_o are generated as shown in Figure 4.7. The duty ratio feedback of the converter is generated in Figure 4.8.

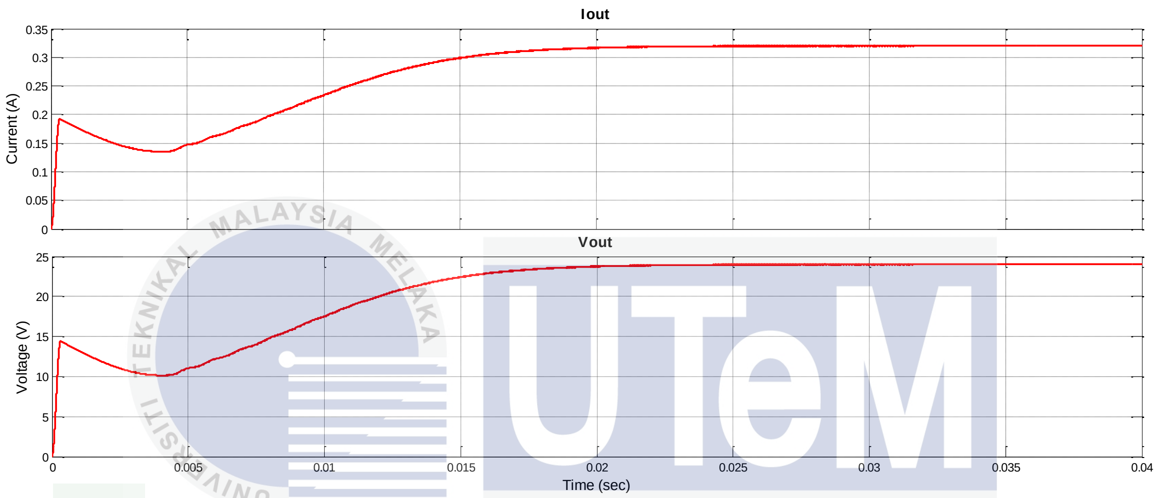


Figure 4.7: Output current and output voltage waveforms.

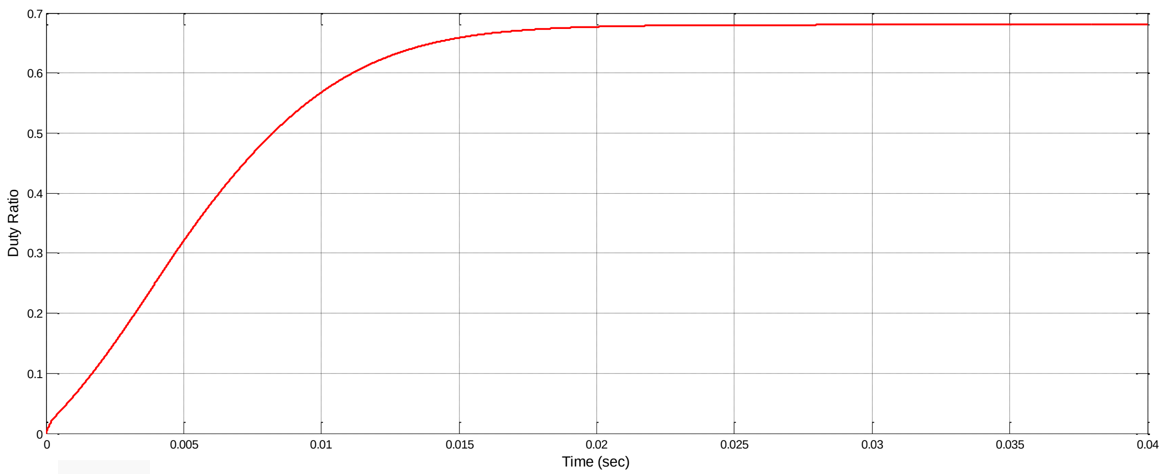


Figure 4.8: Duty ratio of PWM block diagram signals.

4.3 Experimental Results

The boost converter hardware has been tested to obtain the experimental results. The PWM circuit plays the important role in the overall boost converter. The main function of PWM circuit is to generate the duty ratio for the boost converter so that the targeted output voltage can be obtained. PWM is the effective way to control the circuit and the system.

4.3.1 Output from Boost Converter with PWM Circuit Result

The output voltage depends on the duty ratio and the voltage source. The PWM circuit is supplied with 9 V to 12 V input voltage, meanwhile gate driver circuit was supplied with 15 V input voltage. When the boost circuit is set to 5 V, the duty ratio from theoretical value that is 0.79 is injected into 50 kHz switching frequency. The PWM waveform is displayed in Figure 4.9.

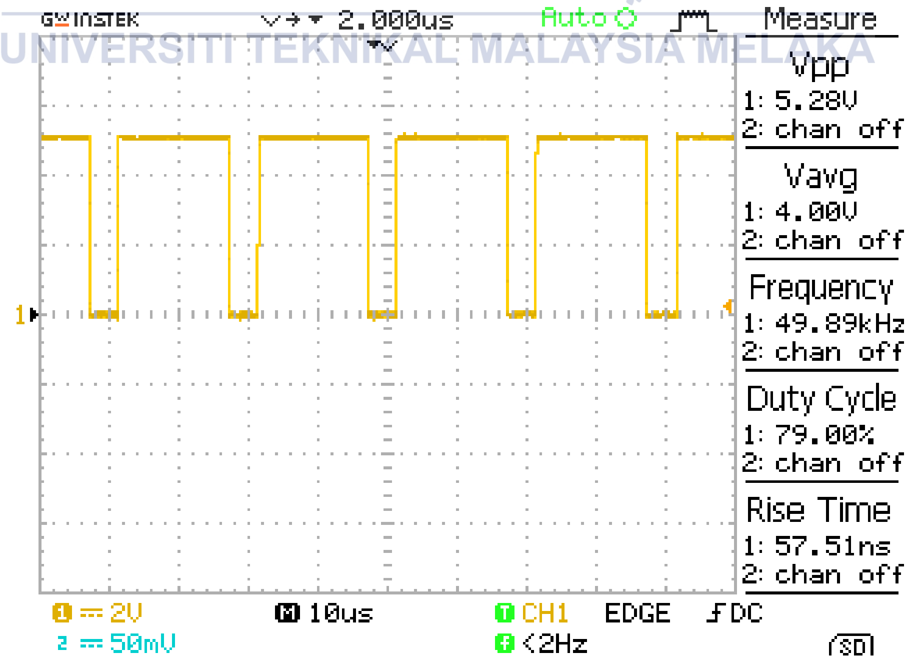


Figure 4.9: The output of the Pulse Width Modulation for D = 0.79.

When the boost circuit is set to 8 V, the duty ratio from theoretical value that is 0.67 is injected into 50 kHz switching frequency. The PWM waveform is displayed in Figure 4.10.

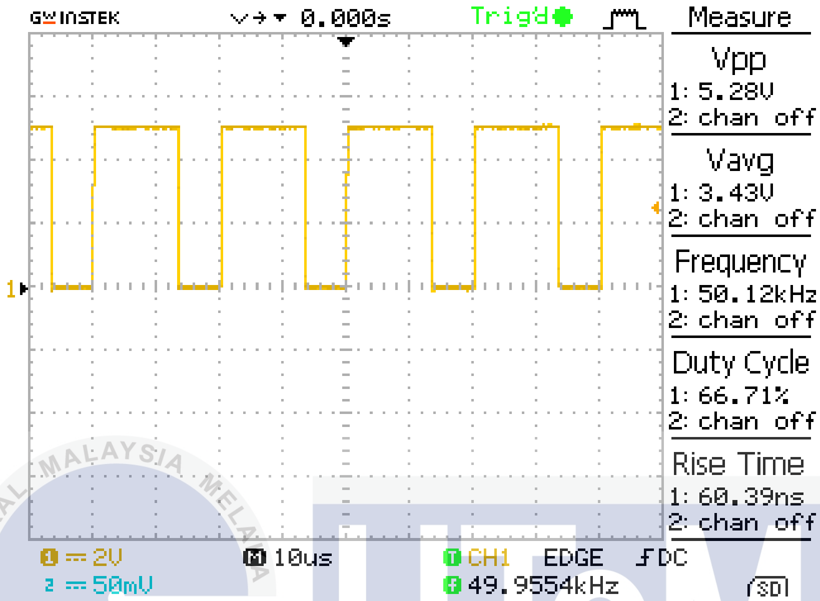


Figure 4.10: The output of the Pulse Width Modulation for D = 0.67.

4.3.2 Output Voltage from Boost Converter

The output voltage should be within the range of 24 V. Figure 4.11 and Figure 4.12 show the output voltages generated from the boost converter. It can be seen clearly that the readings obtained are not accurate and far away from the estimated value. It can be concluded that the values between theoretical and experimental have a slight different. This is due to the poor connection between driver circuit and power circuit.

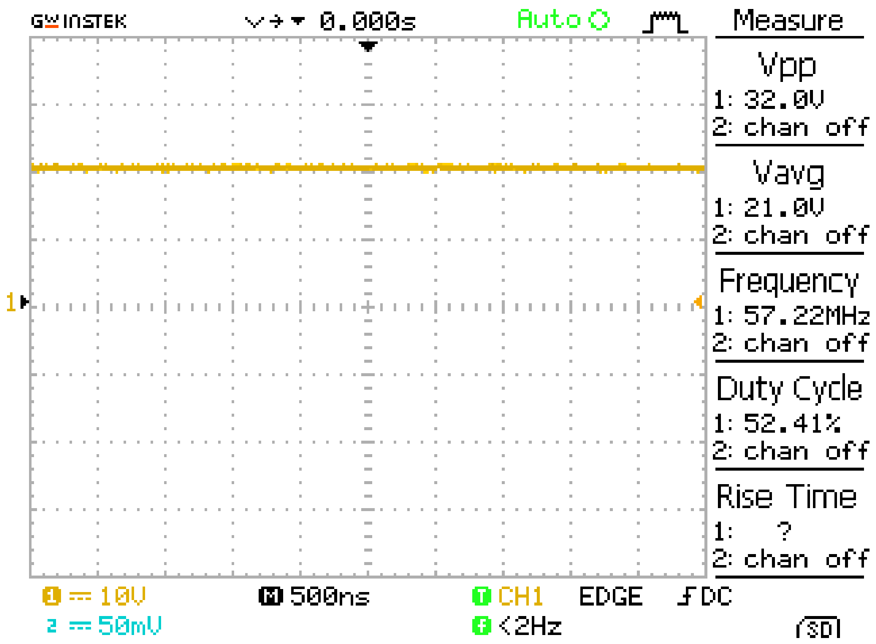


Figure 4.11: The output voltage generated from the circuit when V_S = 5 V.

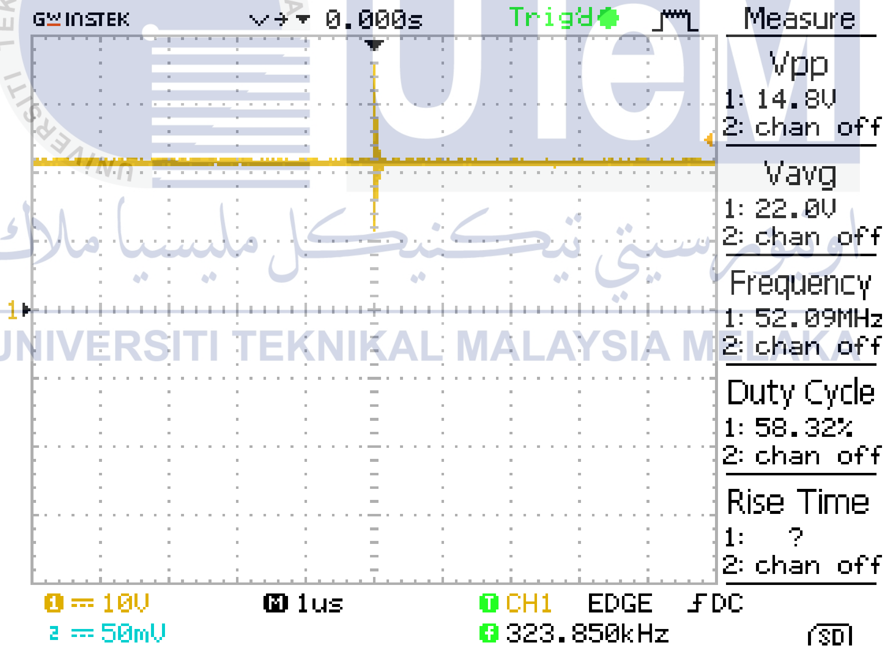


Figure 4.12: The output voltage generated from the circuit when V_S = 8 V.

4.4 Efficiency

Efficiency $\left(\frac{P_{out}}{P_{in}}\right)$ is measured on control loop design of boost converter. Open-loop control is selected due to the manual adjust of switching frequency which is easy and simple. The open-loop boost converter is tested by using V_S = 5 V and V_S = 8 V. The data collected are shown in Table 4.1 and Table 4.2 respectively. The graphs in Figure 4.13 and Figure 4.14 indicate the efficiency of boost converter with the power variation of load. The switching losses and conduction losses play the important roles to affect the efficiency of the boost converter.

Table 4.1: The open-loop control data for V_S = 5 V .

P_{load} (W)	R (Ω)	V_{in} (V)	V_{out} (V)	I_{in} (A)	I_{out} (A)	P_{in} (mW)	P_{out} (mW)	H
5	47.00	3.30	14.00	1.45 m	0.32 m	4.79	4.48	0.94
10	23.5	2.80	12.70	1.44 m	0.31 m	4.03	3.94	0.98
15	15.67	2.50	11.60	1.44 m	0.30 m	3.60	3.48	0.97
20	11.75	2.20	10.50	1.43 m	0.29 m	3.15	3.05	0.97
25	9.40	2.00	9.60	1.43 m	0.28 m	2.86	2.69	0.94

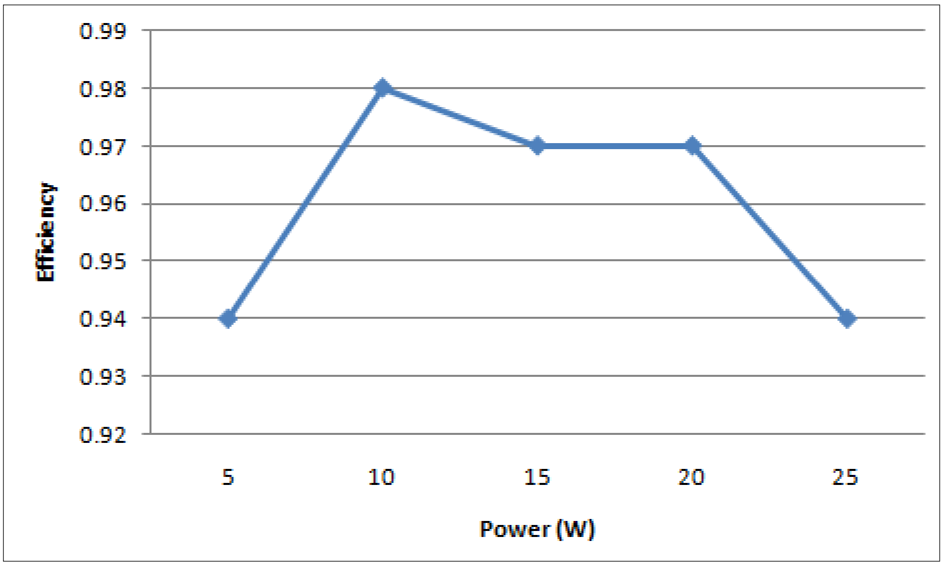


Figure 4.13: The efficiency versus power when V_S = 5 V.

From Table 4.1 and Figure 4.13, the boost converter is able to be efficient with the load variation. The efficiency of the hardware is within 94 % which is close to 100 %. The values of input voltage, V_{in} are different from the output voltage, V_{out}. But the input power, P_{in} and output power, P_{out} are quite similar. The currents in both input and output terminals are fundamental to make the boost converter become efficient.

Table 4.2: The open-loop control data for $V_S = 8$ V .

P_{load} (W)	R (Ω)	V_{in} (V)	V_{out} (V)	I_{in} (A)	I_{out} (A)	P_{in} (mW)	P_{out} (mW)	η
5	47.00	6.60	18.70	7.20 m	2.40 m	47.52	44.88	0.94
10	23.5	5.80	17.20	7.19 m	2.32 m	41.70	39.90	0.96
15	15.67	5.10	16.00	7.19 m	2.15 m	36.67	34.40	0.94
20	11.75	4.50	15.10	7.18 m	2.00 m	32.31	30.20	0.93
25	9.40	4.00	14.60	7.18 m	1.85 m	28.72	27.01	0.94

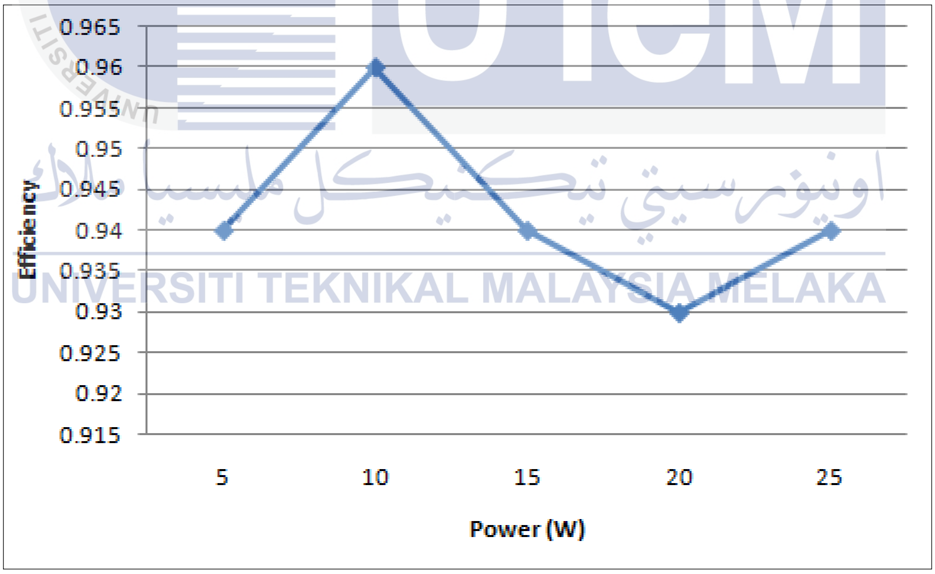


Figure 4.14: The efficiency versus power when $V_S = 8$ V.

From Table 4.2 and Figure 4.14, the boost converter is able to be efficient with the load variation. The efficiency of the hardware is also within 93 % which is close to 100 %. The values of input voltage, V_{in} are different from the output voltage, V_{out}. But the input power, P_{in} and output power, P_{out} are quite similar. The efficiency during the testing of 8 V in the boost converter is not stable compare to the testing of 5 V due to high currents in both input and output terminals.

CHAPTER 5

CONCLUSION

5.1 Introduction

This chapter will highlight the problems encountered throughout the project duration. Several improvement and suggestions are also stated for future works.

5.2 Conclusion

In this project, a boost converter is designed, developed and implemented for open-loop system and closed-loop system. The converter topology is selected after doing several calculations and estimations of various parameters. The open-loop and closed-loop system of converter is presented. The designed circuit is modelled and simulated using Simulink MATLAB. The simulation results of these systems are compared with the hardware implementation. The closed-loop system can provide constant output voltage without the effect of disturbance. It was observed that the closed-loop boost converter system has the advantages of stable output voltage, low ripple content and better efficiency compared to open loop system. The simulation results confirmed that the closed-loop boost converter gives better performance than the open loop boost converter. Besides that, the closed-loop boost converter proved to work efficiently even with the changes of load introduced to the system. The results show that the effect of boost converter is almost 100 % when tested with load variation.

5.3 Recommendation

Some recommendations to improve in future are designing the PCB layout properly and making sure the connection is correct before printing the layout in order to avoid wasting time of doing another circuit design. Other than that, use the right equipment for testing during troubleshooting and give off the accurate data readings. So, the results obtained during the analysis will be more precise.

REFERENCES

[1] D. W. Hart, *Power Electronics*. New York: McGraw Hill International Edition, 2011.

[2] X. Quansheng, "*Control System Study on PWM Boost DC-DC Converter in CCM.*" vol. Master: Dalhousie University, 2005.

[3] N. S. Nise, *Control System Engineering Sixth Edition*. New York: John Wiley & Sons, 2011.

[4] Mohan, Ned; Undeland, Tore M., Robbins, William P. *Power Electronics*. Hoboken: John Wiley & Sons, Inc, 2003.

[5] M. H. b. M. Aripin, "Controller Design of Boost Converter," Universiti Teknikal Malaysia Melaka, November 2005.

[6] B. M Hasaneen, Adel A. Elbaset Mohammed, "*Design and Simulation of DC/DC Boost Converter,*" pp. 335-340, 2008.

[7] F. P. Christophe Batard, Christhope Millet, Nicolas Ginot, "*Simulation of Power Converters using Matlab-Simulink,*" France: InTech, 2012.

[8] S. H. E. Narendran, K. C. Ramya Ashokkumar, R. Malathi, "Simulation Analysis on High Step-up DC-DC Converter for Fuel Cell System," *Journal of Engineering and Technology Research,* vol. 2, pp. 168-176, July 27, 2010.

[9] L. Guo, "Design and Implementation of Digital Controllers for Buck and Boost Converters using Linear and Nonlinear Control Methods," in *Electrical and Computer Engineering*. vol. Doctor of Philosophy Alabama: Auburn University, p. 128.

[10] Y. T. Y. K. I. Hwu, "Performance Enhancement of Boost Converter based on PID Controller plus Linear-to-Nonlinear Translator," *IEEE Transictions on Power Electronics,* vol. 25, pp. 1351-1361, May 2010.

[11] S. K. Kapat, P.T., "Formulation of PID Control for DC-DC Converters based on Capacitor Current: A Geometric Content," in *Control and Modelling for Power Electronics (COMPEL), 2010 IEEE 12th Workshop on* Boulder, CO, pp. 1-6.

[12] C. M. A. Libau, "Transient Response Analysis for DC-DC Boost Converter," in *Faculty of Electrical and Electronics Engineering*.vol. Master of Electrical Engineering Johor: Universiti Tun Hussein Onn Malaysia, 2012, pp. 1-74.

[13] E. M. Omid Eghterafi, Rahul Tikia, "Boost Converter Lab," Irvine: University of California, 2005.

[14] H. A. V. Patel Pradipkumar S., B.N. Vaidya, "Design of DC/DC Boost Converter for the Application of Photovoltaic System," L. D. College of Engineering, NavrangpuraApril 2013.

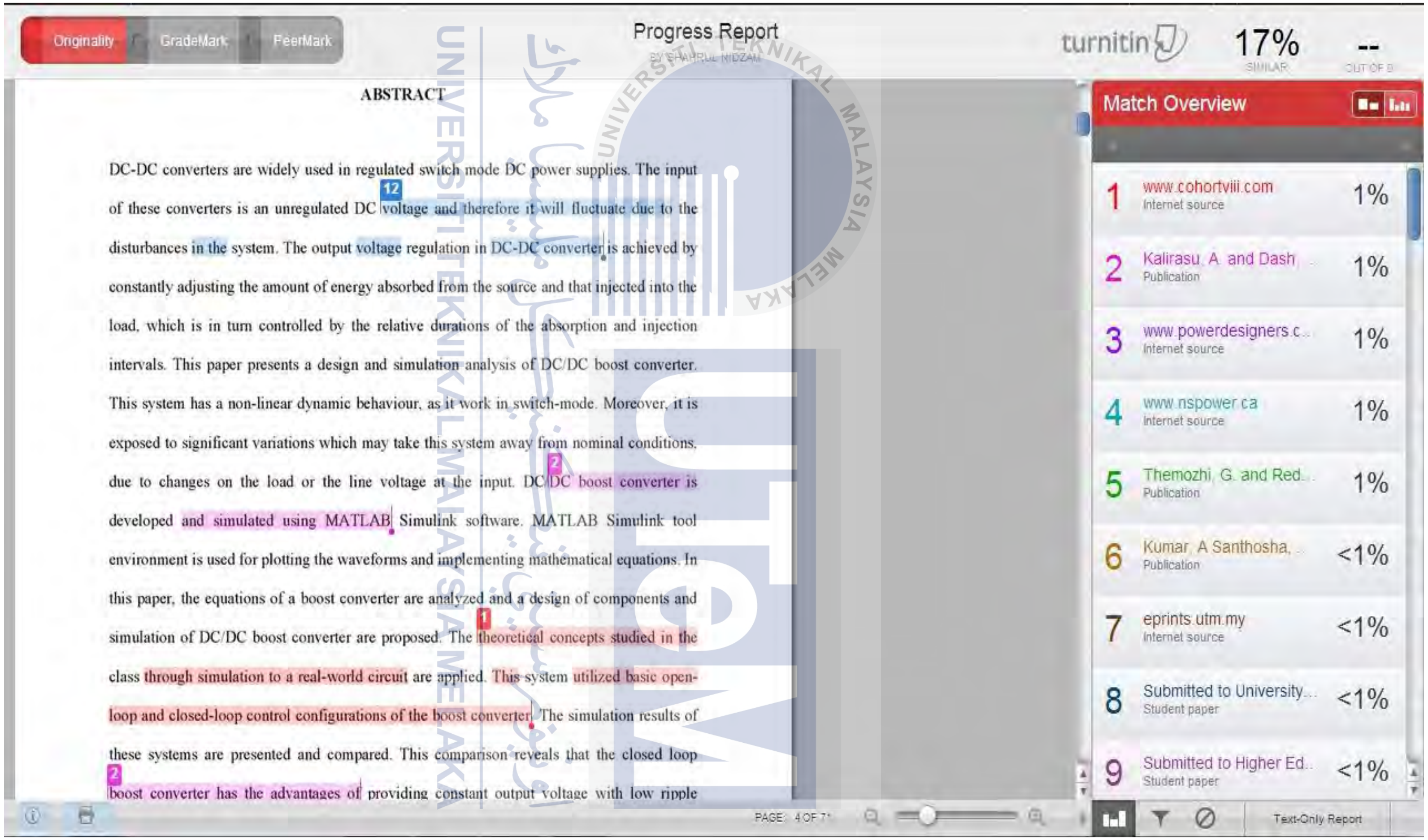
[15] M. H. Rashid, "*Power Electronic Handbook"*. USA: Academic Press, 2001.

[16] H. Yau, "Modelling and Design of a Current Mode Current Boost Converter," in *Department of Electrical and Computer Engineering*. vol. Master of Science Colorado: Colorado State University, 2012.

[17] "Introduction to SSMPS Control Techniques," Microchip Technology, 2006.

[18] Mitzner K, "*Complete PCB Design Using OrCAD Capture and PCB Editor*". Elsevier Inc. 2009.

APPENDIX A



ABSTRACT

DC-DC converters are widely used in regulated switch mode DC power supplies. The input of these converters is an unregulated DC voltage and therefore it will fluctuate due to the disturbances in the system. The output voltage regulation in DC-DC converter is achieved by constantly adjusting the amount of energy absorbed from the source and that injected into the load, which is in turn controlled by the relative durations of the absorption and injection intervals. This paper presents a design and simulation analysis of DC/DC boost converter. This system has a non-linear dynamic behaviour, as it work in switch-mode. Moreover, it is exposed to significant variations which may take this system away from nominal conditions, due to changes on the load or the line voltage at the input. DC/DC boost converter is developed and simulated using MATLAB Simulink software. MATLAB Simulink tool environment is used for plotting the waveforms and implementing mathematical equations. In this paper, the equations of a boost converter are analyzed and a design of components and simulation of DC/DC boost converter are proposed. The theoretical concepts studied in the class through simulation to a real-world circuit are applied. This system utilized basic open-loop and closed-loop control configurations of the boost converter. The simulation results of these systems are presented and compared. This comparison reveals that the closed loop boost converter has the advantages of providing constant output voltage with low ripple

APPENDIX B

MUR405, MUR410, MUR415, MUR420, MUR440, MUR460

SWITCHMODE Power Rectifiers

These state–of–the–art devices are a series designed for use in switching power supplies, inverters and as free wheeling diodes.

Features

- Ultrafast 25 ns, 50 ns and 75 ns Recovery Times
- 175°C Operating Junction Temperature
- Low Forward Voltage
- Low Leakage Current
- High Temperature Glass Passivated Junction
- Reverse Voltage to 600 V
- Shipped in Plastic Bags, 500 per Bag
- Available in Tape and Reel, 1500 per Reel, by Adding a "RLG" Suffix to the Part Number
- MUR460 available in Fan Fold Ammo Pak, 1000 per Box, by adding a "FFG" suffix to the part number
- These are Pb–Free Packages*

Mechanical Characteristics:

- Case: Epoxy, Molded
- Weight: 1.1 Gram (Approximately)
- Finish: All External Surfaces Corrosion Resistant and Terminal Leads are Readily Solderable
- Lead Temperature for Soldering Purposes: 260°C Max. for 10 Seconds
- Polarity: Cathode indicated by Polarity Band

*For additional information on our Pb–Free strategy and soldering details, please download the ON Semiconductor Soldering and Mounting Techniques Reference Manual, SOLDERRM/D.

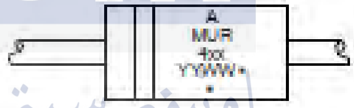
ON Semiconductor®

http://onsemi.com

ULTRAFAST RECTIFIERS
4.0 AMPERES, 50–600 VOLTS

AXIAL LEAD
CASE 267
STYLE 1

MARKING DIAGRAM



A = Assembly Location
MUR4xx = Device Number
x = 05, 10, 15, 20, 40, 60
YY = Year
WW = Work Week
• = Pb–Free Package
(Note: Microdot may be in either location)

ORDERING INFORMATION

See detailed ordering and shipping information in the package dimensions section on page 3 of this data sheet.

APPENDIX C

FAIRCHILD SEMICONDUCTOR™

IRF510

Data Sheet **January 2002**

5.6A, 100V, 0.540 Ohm, N-Channel Power MOSFET

This N-Channel enhancement mode silicon gate power field effect transistor is an advanced power MOSFET designed, tested, and guaranteed to withstand a specified level of energy in the breakdown avalanche mode of operation. All of these power MOSFETs are designed for applications such as switching regulators, switching convertors, motor drivers, relay drivers, and drivers for high power bipolar switching transistors requiring high speed and low gate drive power. These types can be operated directly from integrated circuits.

Formerly developmental type TA17441.

Ordering Information

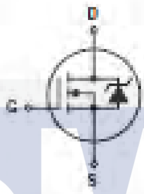
PART NUMBER	PACKAGE	BRAND
IRF510	TO-220AB	IRF510

NOTE: When ordering, include the entire part number.

Features

- 5.6A, 100V
- $r_{DS(ON)} = 0.540\Omega$
- Single Pulse Avalanche Energy Rated
- SOA is Power Dissipation Limited
- Nanosecond Switching Speeds
- Linear Transfer Characteristics
- High Input Impedance
- Related Literature
  - TB334 "Guidelines for Soldering Surface Mount Components to PC Boards"

Symbol



Packaging

JEDEC TO-220AB

APPENDIX D

1 Watt
IQ Series

- Single & Dual Output
- SIP Package
- 1000 VDC Isolation
- Optional 3000 VDC Isolation
- -40 °C to +85 °C Operation
- Semi-regulated
- 3 Year Warranty

Specification

Input

Input Voltage Range	• Nominal ±10%
Input Reflected Ripple Current	• 5 & 12 V: 20 mA, 15 V: 30 mA 24 V: 40 mA, 48 V: 50 mA pk-pk, 5 Hz to 20 MHz
Input Reverse Voltage Protection	• None

Output

Output Voltage	• See table
Minimum Load	• None[1]
Line Regulation	• 1.2%/1% Δ Vin
Load Regulation	• See table (10-100%)
Setpoint Accuracy	• ±3%
Ripple & Noise	• 50 mV pk-pk max, 20 MHz bandwidth
Temperature Coefficient	• 0.02%/°C
Maximum Capacitive Load	• See table

General

Efficiency	• See table
Isolation Voltage	• 1000 VDC minimum, 3000 VDC option[2]
Isolation Resistance	• 10^9 Ω
Isolation Capacitance	• 60 pF typical
Switching Frequency	• Variable, 55 kHz - 85 kHz
MTBF	• >1.1 MHrs to MIL-HDBK-217F at 25 °C, GB

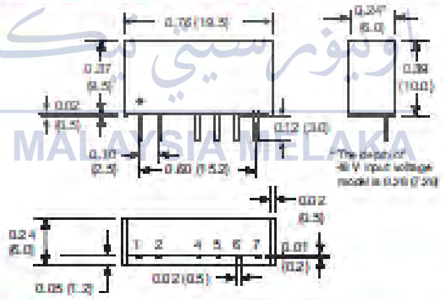
Environmental

Operating Temperature	• -40 °C to +85 °C
Storage Temperature	• -40 °C to +125 °C
Case Temperature	• 100 °C max
Cooling	• Convection-cooled

Input Voltage	Output Voltage	Output Current	No Load Input Current	Max Capacitive Load	Efficiency	Load Reg.	Model[3] Number
5 VDC	5.0 V	200 mA	20 mA	200 µF	83%	6.0%	IQ0505SA†^
	9.0 V	111 mA	20 mA	200 µF	86%	5.5%	IQ0509SA†^
	12.0 V	83 mA	20 mA	100 µF	87%	5.5%	IQ0512SA†^
	15.0 V	67 mA	20 mA	100 µF	87%	5.0%	IQ0515SA†^
12 VDC	5.0 V	200 mA	15 mA	200 µF	84%	4.0%	IQ1205SA†^
	9.0 V	111 mA	15 mA	200 µF	86%	3.5%	IQ1209SA†^
	12.0 V	83 mA	15 mA	100 µF	88%	3.5%	IQ1212SA†^
	15.0 V	67 mA	15 mA	100 µF	88%	3.0%	IQ1215SA†^
15 VDC	5.0 V	200 mA	10 mA	200 µF	84%	4.0%	IQ1505SA†^
	9.0 V	111 mA	10 mA	200 µF	86%	3.5%	IQ1509SA†^
	12.0 V	83 mA	10 mA	100 µF	87%	3.5%	IQ1512SA†^
	15.0 V	67 mA	10 mA	100 µF	89%	3.0%	IQ1515SA†^
24 VDC	5.0 V	200 mA	7 mA	200 µF	81%	4.0%	IQ2405SA†^
	9.0 V	111 mA	7 mA	200 µF	84%	3.5%	IQ2409SA†^
	12.0 V	83 mA	7 mA	100 µF	85%	3.5%	IQ2412SA†^
	15.0 V	67 mA	7 mA	100 µF	86%	2.5%	IQ2415SA†^
48 VDC	5.0 V	200 mA	5 mA	200 µF	78%	4.0%	IQ4805SA†^
	9.0 V	111 mA	5 mA	200 µF	80%	3.5%	IQ4809SA†^
	12.0 V	83 mA	5 mA	100 µF	81%	3.0%	IQ4812SA†^
	15.0 V	67 mA	5 mA	100 µF	81%	3.0%	IQ4815SA†^

† Available from Farnell & element14. See pages 234-280.
^ Available from Newark. See pages 281-286.

Mechanical Details



Notes

1. Operation at no load will not damage unit but it may not meet all specifications.
2. For optional 3000 VDC isolation, add suffix '-H' to the model number.
3. For dual output delete suffix 'A' and split output current equally between rails.
4. All dimensions in inches (mm).
5. Pin pitch tolerance: ±0.014 (±0.35)
6. Case tolerance: ±0.02 (±0.5)
7. Weight: 0.06 lbs (2.8 g)

Pin	Single	Dual	Single-H	Dual-H
	Pin Connections			
1	+Vin	+Vin	+Vin	+Vin
2	-Vin	-Vin	-Vin	-Vin
4	-Vout	-Vout	N.P.	N.P.
5	N.P.	Common	-Vout	-Vout
6	+Vout	+Vout	N.P.	Common
7	N.P.	N.P.	+Vout	+Vout

APPENDIX E

HCPL-3120/J312, HCNW3120

2.5 Amp Output Current IGBT Gate Drive Optocoupler

Data Sheet

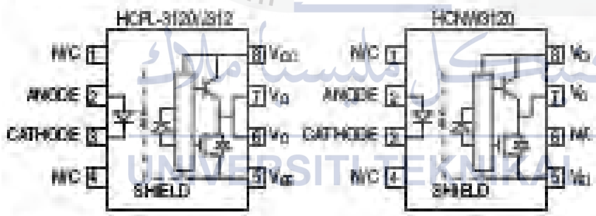
Lead (Pb) Free
RoHS 6 fully compliant

RoHS 6 fully compliant options available; -xxxE denotes a lead-free product

Description

The HCPL-3120 contains a GaAsP LED while the HCPL-J312 and the HCNW3120 contain an AlGaAs LED. The LED is optically coupled to an integrated circuit with a power output stage. These optocouplers are ideally suited for driving power IGBTs and MOSFETs used in motor control inverter applications. The high operating voltage range of the output stage provides the drive voltages required by gate controlled devices. The voltage and current supplied by these optocouplers make them ideally suited for directly driving IGBTs with ratings up to 1200 V/100 A. For IGBTs with higher ratings, the HCPL-3120 series can be used to drive a discrete power stage which drives the IGBT gate. The HCNW3120 has the highest insulation voltage of V_{IORM} = 1414 Vpeak in the IEC/EN/DIN EN 60747-5-2. The HCPL-J312 has an insulation voltage of V_{IORM} = 891 V_{peak} and the V_{IORM} = 630 V_{peak} is also available with the HCPL-3120 (Option 060).

Functional Diagram



TRUTH TABLE

LED	$V_{CC} - V_{EE}$ "POSITIVE GOING" (i.e., TURN-ON)	$V_{CC} - V_{EE}$ "NEGATIVE GOING" (i.e., TURN-OFF)	V_O
OFF	0 - 30 V	0 - 30 V	LOW
ON	0 - 11 V	0 - 9.5 V	LOW
ON	11 - 13.5 V	9.5 - 12 V	TRANSITION
ON	13.5 - 30 V	12 - 30 V	HIGH

A 0.1 μF bypass capacitor must be connected between pins 5 and 8.

Features

- 2.5 A maximum peak output current
- 2.0 A minimum peak output current
- 25 kV/μs minimum Common Mode Rejection (CMR) at V_{CM} = 1500 V
- 0.5 V maximum low level output voltage (V_{OL}) Eliminates need for negative gate drive
- I_{CC} = 5 mA maximum supply current
- Under Voltage Lock-Out protection (UVLO) with hysteresis
- Wide operating V_{CC} range: 15 to 30 Volts
- 500 ns maximum switching speeds
- Industrial temperature range: -40°C to 100°C
- Safety Approval:

  UL Recognized

  3750 Vrms for 1 min. for HCPL-3120/J312

  5000 Vrms for 1 min. for HCNW3120

  CSA Approval

  IEC/EN/DIN EN 60747-5-2 Approved

  V_{IORM} = 630 V_{peak} for HCPL-3120 (Option 060)

  V_{IORM} = 891 V_{peak} for HCPL-J312

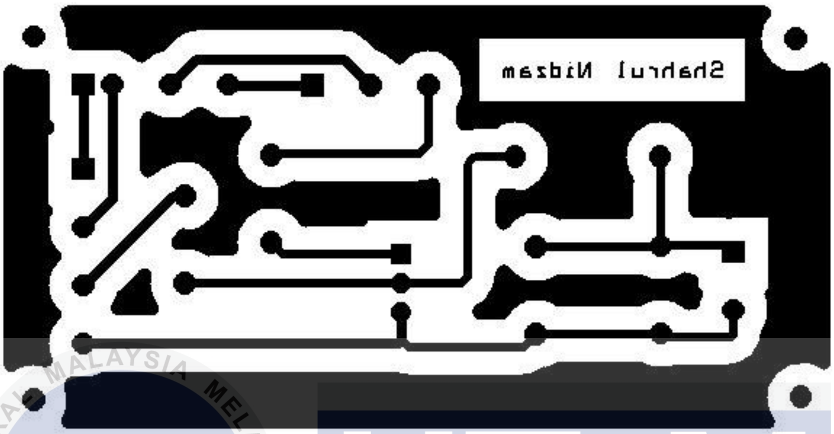
  V_{IORM} = 1414 V_{peak} for HCNW3120

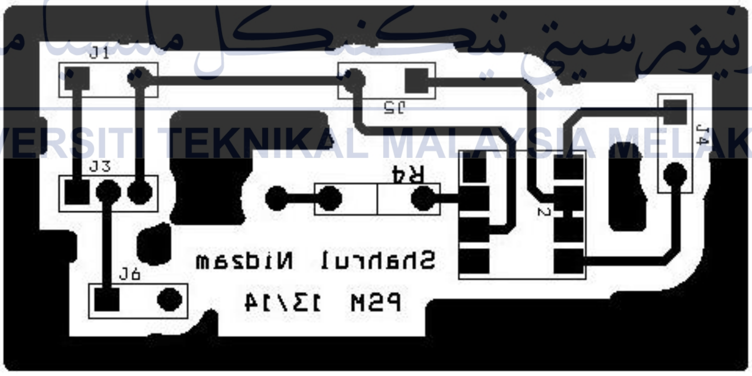
Applications

- IGBT/MOSFET gate drive
- AC/Brushless DC motor drives
- Industrial inverters
- Switch mode power supplies

CAUTION: It is advised that normal static precautions be taken in handling and assembly of this component to prevent damage and/or degradation which may be induced by ESD.

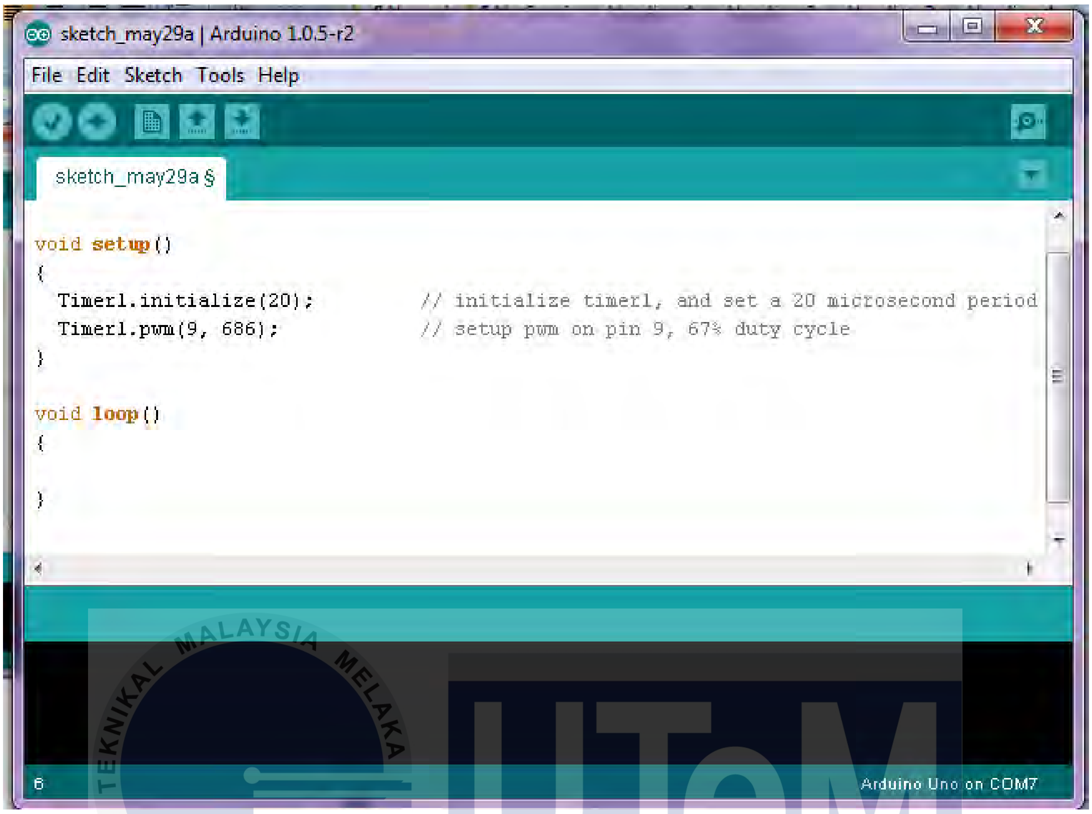
APPENDIX F





APPENDIX G

CODING FOR 67 % DUTY RATIO OF PWM



CODING FOR 79% DUTY RATIO OF PWM