

MICROCONTROLLER BASED BOOST PID

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CHAPTER 1

INTRODUCTION

1.1 Background

Boost converter is in the category of DC-to-DC converter where it also known as chopper, it converts an unregulated input DC voltage to a regulated or variable DC output voltage. Boost converter operates by periodically opening and closing an electronic switch. It is called a boost converter because the output voltage is larger than the input. For this project the supply input voltage is 24Vdc from the power supply are required to produce an output voltage of 350Vdc. The operation of the electronic switch or also known as power switches in the boost circuit needs a driver to operate it periodically opening and closing. Instead of using the driver and function generator to produce the Pulse Width Modulation (PWM), Microcontroller can be programmed to produce the PWM for the power switches. The circuit needs to operate on continuous current modes (ccm) because the output has to produce a constant voltage 350Vdc in both on-state and off-state of power switches. In this case at the end of on-state of power switches the current in the inductor never go zero and continuously supply the current for the output. The output then is feedback to the PID controller where the PID are programmed to measure an error occur at the output terminal compare to the set point and make a correction to produce suitable PWM signal.

1.2 Objectives

- i. To increase the output voltage to 350Vdc from the input supply of 24Vdc takes from the power supply in the laboratory. The output voltage is increase so that the circuit can supply to the inverter.
- ii. To develop PID programming scheme for boost converter. The programming is use in the feedback control so that the controller can measure the error occur at the output and make a correction for the desired output

1.3 Scoop of Work

- i. To built boost converter. Where the circuit consists of input power supply, inductor, power switches, diode, capacitor and output resistor
- ii. Test circuit using function generator. Where functions generator produce the PWM.
- iii. Replace function generator with PIC Microcontroller. Using the PIC Microcontroller to produce PWM instead of using function generator.
- iv. Implement feedback loop control. PID are program to support the feedback control to measure error occur at the output terminal.

1.4 Thesis Overview

Microcontroller based boost PID is the title of this thesis where it contain of combination of five chapters from the introduction of this project to the outcome and result of this project. The thesis writes detail on each of every step to take under consideration on the progression of the project.

Chapter 1 elaborate briefly what the project is all matter. Here clearly stated the background of the project, the objective, the scoop of work of this project and the overview of each of the chapter contains.

Chapter 2 is some of the literature review from an article, paper work, book and all the written text that are related to the project topic. Where in this thesis, it is included a literature review on Boost converter, PID controller and on Insulator Gate Bipolar Transistor as all of the materials is used in this project.

Chapter 3 is on the methodology of overall project. It discuss on the each of the component used in this project and why the component is choose. But it not limited to the hardware choose, it also discuss on the peripheral used in the PIC Microcontroller and software implementation choose.

Chapter 4 will elaborate and discuss the overall result obtained from the project. Figure and Table also included in this chapter to make it more understandable.

Chapter 5 concludes the project and some recommendation suggested to improve the project in future. Cost and the commercial value of the project is also evaluated for the project in the market value.

CHAPTER2

LITERATURE REVIEW

2.1 IGBT: Insulated Gate Bipolar Transistor

Insulated Gate Bipolar Transistor (IGBT) is one of the most popular applications in power switches. The special characteristic of the switch are in between the characteristic of Bipolar Junction Transistor (BJT) and MOS Field Effect Transistor (MOSFET). The only different between the structure of MOSFET and IGBT is the additional of P-zone of IGBT. Due to the present of this layer, holes are injected into the highly resistive n-layer and a carrier overflow is created. These increase the conductivity of n-layer and reduce the on-state voltage of IGBT.

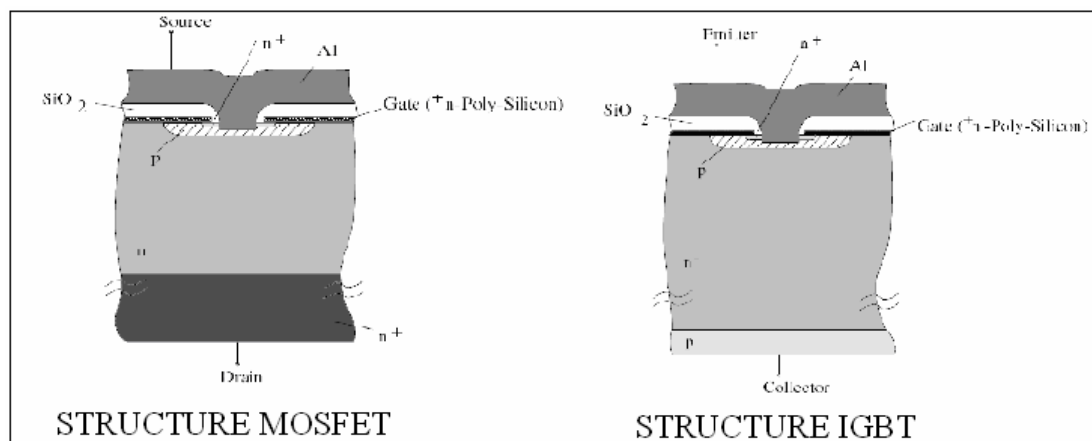


Figure 2.1 Transistor Structures

To suit today application there are two types of IGBT, **PT**-structure (punch through) and **NPT**-structure (non-punch through). The general switching behavior of IGBT, when the switch is turn-off the current are driven on by the load, by attaching suitable diode to enable the current flow. Then switching on the IGBT, the current flow through the diode causes the circuit work like a short at first. The stored charge has to be removed first for the diode to block the voltage. This appears as a surplus current additional to the load current which is called reverse recovery current of the diode. The maximum reverse recovery current of diode occur when the sum of the instantaneous voltage across the IGBT and the diode equal to the supply voltage. By turning-off the IGBT result in current change and makes an overvoltage spike by the current change in the parasitic inductances.

Short circuit behavior of IGBT generally define the negative temperature coefficient of the short circuit current causes the negative thermal feedback in the devices. There is two type of short circuit, the first type short-circuit describes the turn-on of an IGBT during the existing short-circuit in the output circuit. In this case the IGBT limits the maximum collector current according to the outputs characteristic. In the second type of short-circuit in the output circuit occur during the on-phase of the IGBT, limited by the inductivity the current in the output circuit increases.

2.2 PID Controller

PID stands for proportional, integral, derivative are one of the most popular feedback controller widely use in processing industry. It is easy to understand the algorithm to produce excellent control performance.

The PID consists of three basic modes that are proportional modes, integral modes and derivative modes. Generally three basis algorithm uses are P, PI and PID. This controller has a transfer function for each modes, proportional modes adjust the output signal in direct proportional to the controller output [2](M.J. Willis,1999). A proportional controller (k_p) reduced the error but not eliminated it [3](Power Design,2008). An integral controller (k_i) will have the effect of eliminating the steady-state error but it may worsen the transient respond. The derivative controller (k_d) will have the effect of increasing the stability of the system, reducing the overshoot and improving the transient respond.

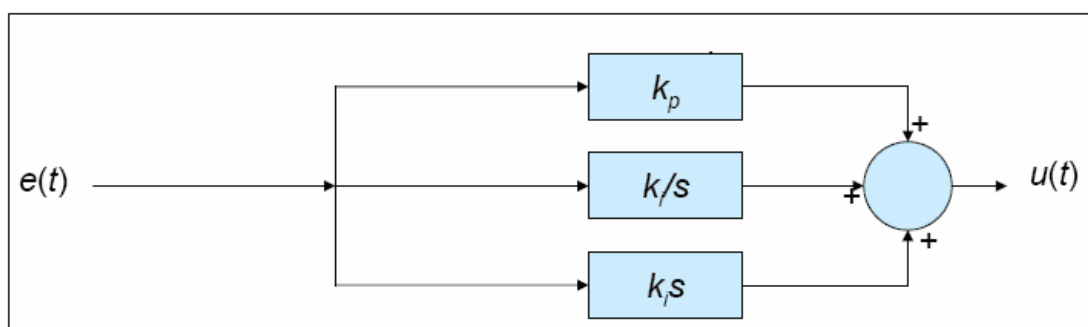


Figure 2.2 Proportional-Integral-Derivative (PID) Controller

In designing PID controller there are several steps to be applied in order to obtain desired output response. It is not necessary to implement all three controllers if not needed, if P or PI controller gives a good enough response there is no need to implement the derivative controller.

DESIGNING STEP:

1. Obtain open-loop response.
2. Determine what needs to be improved.
3. Add proportional control to improve rise time.
4. Add derivative control to improve the overshoot.
5. Add an integral control to eliminate the steady-state error.
6. Adjust each of k_p , k_i and k_d until overall desired response is obtained.

2.3 Step-up Switch Mode Power Supply: Ideal Boost Converter

Boost converter is one of the kinds of switch mode power supply also known as step-up converter. This converter converts an unregulated DC voltage to regulated or variable DC voltage (chopper). The ideal basic component for boost converter is power semiconductor switch, inductor, diode, capacitors and pulse width modulator (PWM) controller. It has the same components as buck converter but the arrangement is different due to the different output level produced.

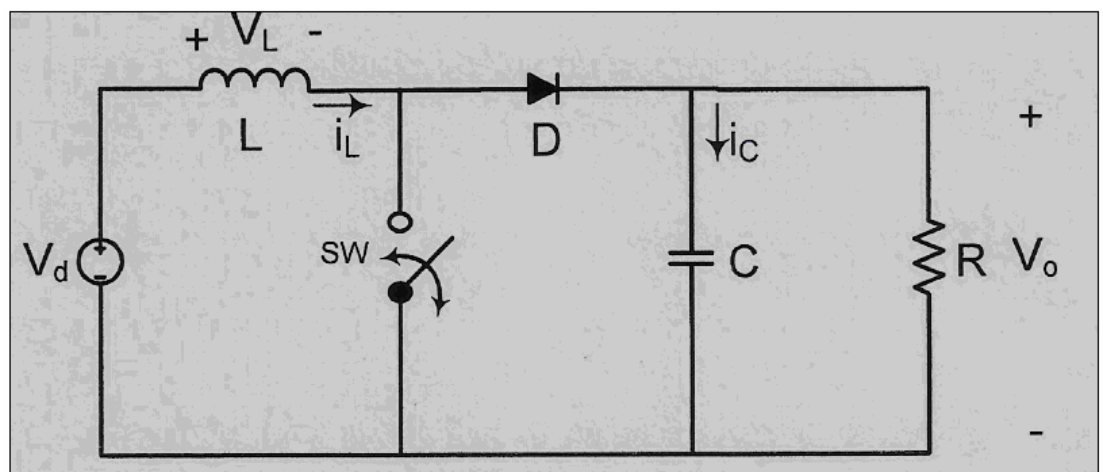


Figure 2.3 Basic circuit of Boost Converter

There are several assumptions to be made to analyze the ideal circuit:

1. When the switch on, the drop across it is zero and the current through it is zero.
2. The diode has zero voltage drops in conducting state and zero current in reverse-bias mode.
3. The time delay in switching on and off the switch and the diode are negligible.
4. The inductor and capacitor are lossless.
5. The response in the circuit is periodic. The value of inductor current at the start and end of a switching cycle is the same. The net increase in inductor current over a cycle is zero.
6. The switch is made ON and OFF at a fixed frequency and let the period corresponding to the switching frequency be T . Given that the duty cycle is D , the switch is on for a period equal to DT , and the switch is off for a time interval equal to $(1 - D)T$.
7. The inductor current is continuous and is greater than zero
8. The capacitor is relatively large. The RC time constant is so large, that the changes in capacitor voltage when the switch is ON or OFF can be neglected for calculating the change in inductor current and the average output voltage. The average output voltage is assumed to remain steady.
9. The source voltage V_S remains constant.

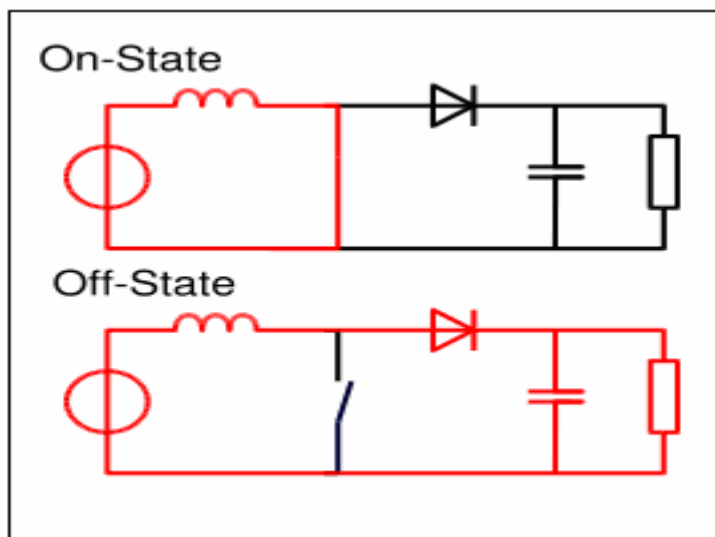


Figure 2.4 ON and OFF State of Converter

The operation of the circuit is essentially by controlling the mechanism of power semiconductor switch on and off. The inductor act like a pump where it store energy when the switch in on-state and transferring to RC network when the switch in off-state. When the switch in on-state, the source voltage applied across the inductor increase the current and the energy stored built-up. The rate of rise of inductor current depends on the source voltage (V_d) and inductance (L). If the source voltage remains constant, the rate of rise of inductor current is positive and remains fixed. During this period, the output voltage is sustained by the capacitor where the capacitor discharges part of its stored energy and it re-acquires this energy when the switch is open. The current in the inductor will flow through the diode, the RC network and back to source when the switch in off-state. The energy is discharge from the inductor. The voltage across the inductor is negative and the rate of rise of inductor current is negative.

CHAPTER 3

METHODOLOGY

3.1 Project Background

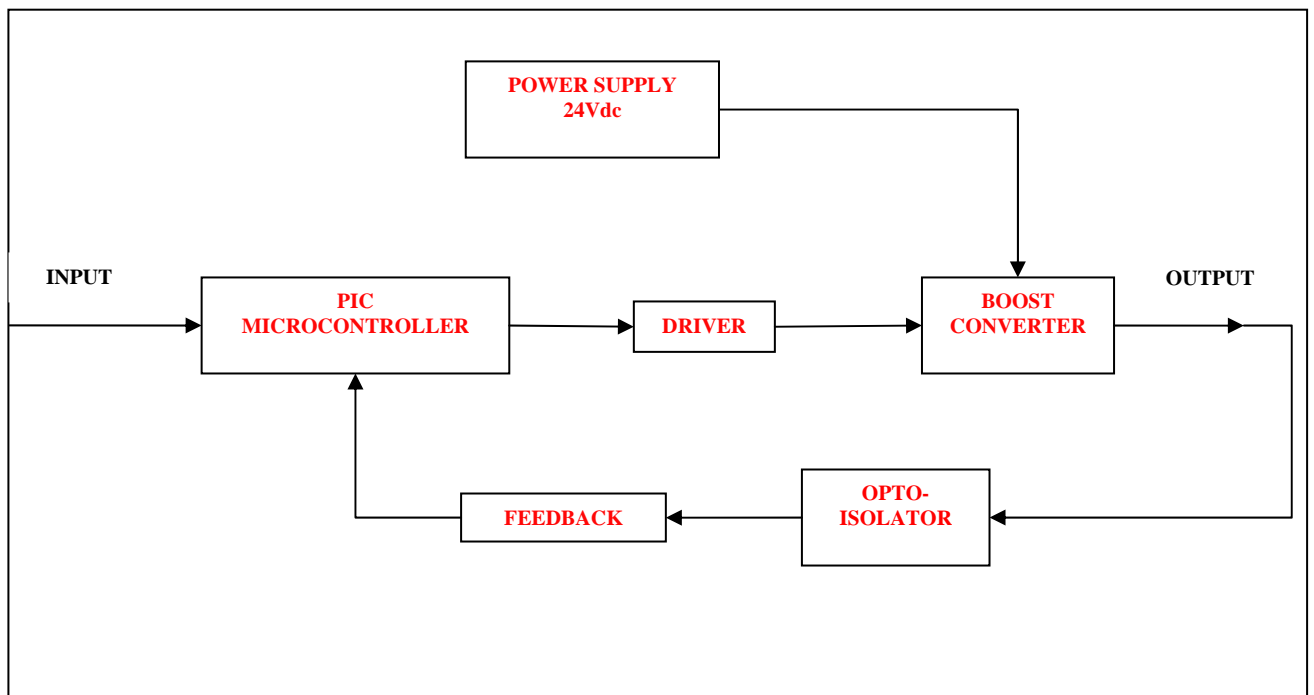


Figure 3.1 Block Diagram of Microcontroller Based Boost PID

The project are basically making boost converter using programmable intelligent controller, where boost circuit are use to increase the DC output voltage from the low DC voltage input power supply so it can be supply to the inverter to

convert 350Vdc to 240Vac. PID is program to control the Pulse Width Modulator (PWM) like the function of function generator and added by the feedback control. The circuit operates when the boost circuit get a input power of 24Vdc from the power supply and the circuit element are construct to produce an output voltage of 350Vdc. PID is program to produce suitable PWM to the driver of power switches and the output is then feedback to the controller to compare to a desired output value.

Basically in the project Microcontroller Based Boost PID, the main hardware circuit of the project is the boost converter circuit and the microcontroller circuit. For the software is the programming of the Proportional Integral Derivative, PID. Initially the project progress up till now is in building the hardware. The operation of the main hardware circuit needs a basic circuit to make the converter and microcontroller function appropriately. There are three basic circuit need to built to support the function of the main circuit, there are two voltage regulator circuit that produce an output of 5volt and 15volt and the driver circuit that supply a pulse to the switch use in boost circuit.

3.2 Regulator Circuit

Voltage regulator is needed because not every component in the circuit is using a same value of voltage to operate. In this project there are two voltage regulators to be use. One to produce an output of 5volt and the other one will produce an output of 15volt. The main power supply in this circuit is 24volt direct current from the power supply in the laboratory. Where from the 24volt main supply will be the input for the first voltage regulator circuit using IC LM7815 and then produce an output of 15volt. The output from the first voltage regulator and then be the input for the second voltage regulator and a power supply for the switch driver IR2109. For the second voltage regulator we were using IC LM7805 to produce an output of 5volt so it can be the input power of PIC microcontroller.

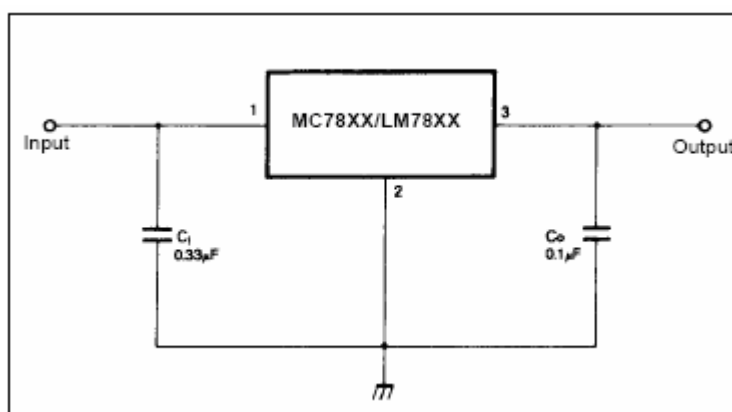


Figure 3.2 Voltage Regulator

The circuit in figure 6 above shows the basic component in voltage regulator. Where the circuit consists of input power, input capacitor (C_i), voltage regulator IC (LM7805/LM7815), and output capacitor (C_o). The IC used in this circuit is a Fixed Regulator ICs where the output voltage produce is smaller than the

input voltage. The voltage different between the input and output appears as heat and dissipated through head sink. The capacitor attached at the input and output is used to remove an unwanted noise and spike.

3.3 Driver Circuit

Driver circuit function is to generate pulse needed by the switch so the switch can operate appropriately. IC IR2109 is used as a driver in this project as an IGBT switch driver. IR2109 has dependent high and low side referenced output channels. Different driver will produce different output result depending to the driver characteristic.

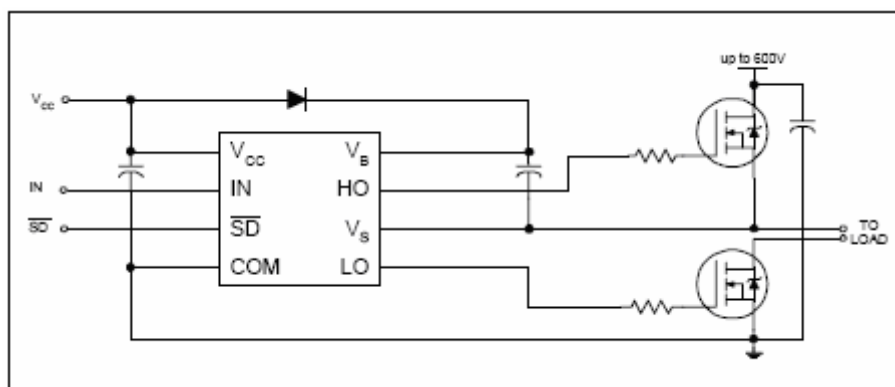


Figure 3.3 Driver Circuit

As in IGBT switch for boost converter only the low side referenced channel is used. This is because when using the low side the driver output and the power switch will be in parallel so that the output will boost the voltage. On the other side the output result by using the low side driver is it will invert from the input supply.

Since using the low side referenced channel the output result will turn high, this is happen because of the characteristic of the driver itself.

3.4 Boost Converter

Boost converter is one of the main circuits in this project; basic boost converter consists of inductor as the energy storage device, IGBT as a power switch, diode, capacitor is used to limit the output ripple and output resistor as show in figure 9 below. The design of boost converter need to be consider the Continuous Current Mode (CCM), input and output voltage, current, output ripple and component rating. Basic design start with a detail calculation on every value of component need to be used to produce an desired output. Select a suitable frequency range and find a component according to all value collected in the calculation.

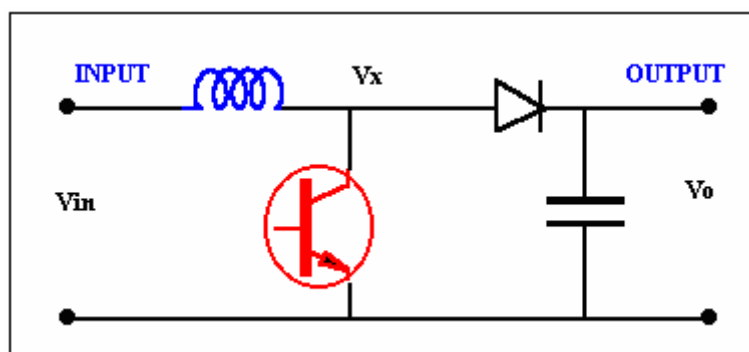


Figure 3.4 Boost Converter

3.4.1 Calculation

$$V_{in} = 24V_{dc}$$

$$V_{out} = 45V_{dc}$$

Assuming ripple voltage, $V_r = 2\%$

Load resistance, $R = 2700\Omega$

Duty Cycle, D:

$$\begin{aligned} D &= 1 - \frac{V_i}{V_o} \\ &= 1 - \frac{24}{45} \\ &= 0.467 \end{aligned} \tag{3.1}$$

To find frequency range, f:

Using IGBT driver IR2109

$$t_r = 150ns$$

$$t_{on(min)} = 750ns$$

$$D_{max} = 90\%$$

$$t_f = 50ns$$

$$t_{off(min)} = 200ns$$

$$D_{min} = 10\%$$

$$\frac{4(1 - D_{max})}{3(t_r + t_f) + 4t_{off(min)}} 2 \leq f \leq \frac{4D_{min}}{t_r + t_f + 4t_{on(min)}} \tag{3.2}$$

$$\frac{4(1 - 0.9)}{3(150 \times 10^{-9} + 50 \times 10^{-9}) + 4(200 \times 10^{-9})} \leq f \leq \frac{4(0.467)}{(150 \times 10^{-9}) + (50 \times 10^{-9}) + 4(750 \times 10^{-9})}$$

$$333kHz \leq f \leq 583kHz$$

Frequency choose, $f = 20kHz$

Minimum inductor value, L:

$$L_{\min} = \frac{D(1-D)^2 R}{2f} \quad (3.3)$$

$$L_{\min} = \frac{0.467(1-0.467)^2 (2700)}{2(20 \times 10^3)}$$

$$L_{\min} = 9mH$$

Standard inductor value, L= 9 mH

Inductor current, I_L:

$$T = \frac{1}{f} \quad (3.4)$$

$$T = \frac{1}{20 \times 10^3}$$

$$T = 50\mu s$$

$$I_L = \frac{V_{in}}{(1-D)^{2R}} \quad (3.5)$$

$$I_L = \frac{24}{(1-0.467)^2 (2700)}$$

$$I_L = 31.3mA$$

$$\frac{\Delta i}{2} = \frac{V_{in} DT}{2L} \quad (3.6)$$

$$\frac{\Delta i}{2} = \frac{24(0.467)(50 \times 10^{-6})}{2(9 \times 10^{-3})}$$

$$\frac{\Delta i}{2} = 31mA$$

$$I_{L(\max)} = 62.3mA$$

$$I_{L(\min)} = 0.3mA$$

Capacitor value, C:

$$C = \frac{D}{RfV_r} \quad (3.7)$$

$$C = \frac{0.467}{(2700)(20 \times 10^3)(0.02)}$$

$$C = 0.432 \mu F$$

Standard value of capacitor, $C = 0.47 \mu F$

3.4.2 Inductor

Boost topology circuit contain an inductor as an energy storage device.

11 μH Inductor value is needed to produce an output voltage of 350V_{dc}. But there is no 11 μH inductor standard value are produce, the nearest standard value available is 12 μH inductor with a specific current rating. According to the calculation have been made the maximum current flow through the inductor circuit is quit high about 10A. There is no standard inductor can stand the high current up to 10A, the solution to this problem is by built an inductor that are suitable to be use in this circuit.

There are several things need to be consider to designing the inductor. For this project ferrite core have been choose to produce an inductor of 11 μH . However in order to determine the A_L value a Ferrite core, we must have Inductance Meter or other method to determining the inductance. Below are the steps to know turns of different value of inductance.

1. First, wind a specific number of turns on the unknown core such as 10 or 20 and recommended turns are 100 turns because more turns will result in a more accurate answer. Then, measure the value of inductance
2. Now using the formula in the Equation 5, we can determine the AL Value depend the value that want either in μH or mH .
3. After that, we can know the actual number of turns using formula in Equation below

$$AL \text{ value} = \left(\frac{100}{\text{no.ofTurn}} \right)^2 (L \text{ in } \mu\text{H}) \quad (3.8)$$

$$\text{Number Of turn} = \sqrt{\frac{L(\mu\text{H})}{A_L(\mu\text{H} / 100\text{Turn})}}(100) \quad (3.9)$$

First, wounded 20 turns of enameled copper wire on a Ferrite Rod and then measured inductance was $22.5 \mu\text{H}$.

$$\begin{aligned} AL \text{ Value} &= \left(\frac{100}{10} \right)^2 (22.5) \\ &= 2250 \end{aligned}$$

The value of inductance that need in this project is equal to $9000 \mu\text{H}$, based on the above AL value. Using the appropriate formula for the number of turns from the equation above.

$$\begin{aligned} \text{Number of turns} &= \sqrt{\frac{9000}{2250}}(100) \\ &= 200\text{turns} \end{aligned}$$

However, the actual number of turns for $9000\mu\text{H}$ is 210turns

Since this project is high power, bigger wire diameters are used to support the input current 10A but in market only small diameter enamel copper wire are sold. So we must combine several enamel copper wire that it can carry large current. Finally, AWG 24 enamel copper wire was chosen where this copper wire can carry 3A per wire and should combine in 4wires where the total current that can carry of this copper wire is equal to 12A which is large than the minimum requirement.

Table 3.1: List of Component

no	Components	Specification
1	PIC MICROCONTROLLER	PIC18F4550
2	IGBT	IRGB14C40LPBF
3	DRIVER	IR2109
4	OPTO-ISOLATOR	4N25
5	CRYSTAL	20MHz
6	IGBT DRIVER	IR2109
7	CABLE	AWG 24 COPPER ENAMEL
8	TIRODIAL	FERRITE CORE
9	VOLTAGE REGULATOR	LM7815 AND LM7805
10	INDUCTOR	9mH
11	RESISTOR	$1\text{K}\Omega$, $2.7\text{K}\Omega$, 20Ω , 100Ω , $2.25\text{K}\Omega$
12	CAPACITOR	$0.1\mu\text{F}$, $4.7\mu\text{F}$, $330\mu\text{F}$, $220\mu\text{F}$, $0.47\mu\text{F}$

3.5 Opto-Isolator

Opto-isolator is also known as optical isolator, optocoupler, photocoupler, or photoMOS. It uses a short optical transmission path to transfer a signal between elements of a circuit while keeping them electrically isolated. With a photodiode as the detector, the output current is proportional to the amount of incident light supplied by the emitter. The diode can be used in a photovoltaic mode or a photoconductive mode. In photoconductive mode, the diode is connected to a supply voltage, and the magnitude of the current conducted is directly proportional to the intensity of light.

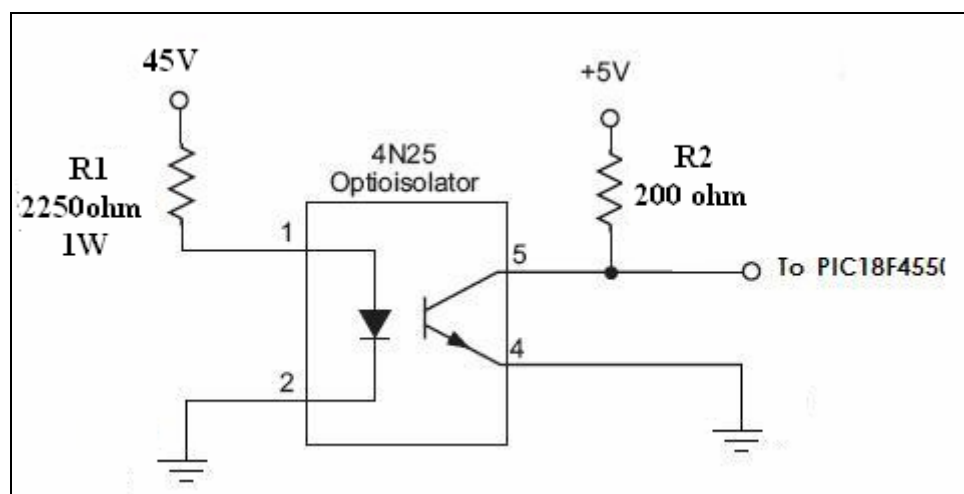


Figure 3.5 Opto-Isolator

PIC microcontroller only can withstand a voltage up to 5V. So it is impossible to directly connect the output of the boost converter feedback to the PIC microcontroller. In order to supply a relatively small voltage to PIC microcontroller, opto-isolator is used to convert high voltage to a correspondent smaller voltage range.

from 0 volt to 5 volt. Therefore the correspondent voltage now is suitable to connect to the PIC microcontroller.

At the input terminal of the opto-isolator, high voltage is not connected directly. Resistor is needed before entering the input terminal.

Calculation:

Assuming the highest voltage from the boost converter is 45 volt

$$V_i = 45V$$

Maximum LED current is 20 mA

$$I_{LED} = 20 \text{ mA}$$

Minimum resistor at the input terminal:

$$R = \frac{V}{I} \tag{3.10}$$

$$R = \frac{45}{20 \times 10^{-3}}$$

$$R = 2250\Omega$$

$$P = \frac{V^2}{R} \tag{3.11}$$

$$P = \frac{(45)^2}{2250}$$

$$P = 0.9W$$

$$P \approx 1W$$

The value of resistor used for this project is as calculate using equation is 2250ohm and 1Watt. The connection of the circuit is as shows in Figure 3.5.

3.6 PIC Microcontroller Circuit

PIC microcontroller is grouped by the sizes of the instruction word and their instruction set. For this project microcontroller based boost PID, PIC 18F4550 is used, where this PIC is an enhanced 16-bit instruction word length. Each part of the devices can be places in three of the groups, core, peripherals and special feature. The core contains the basic features that are required to make the devices to operate. In the peripherals contains a features added to different from a microprocessor. These make the interfacing to the external world and internal task easier. For special feature group unique features added to make the system cost less, increase system reliability and increase design flexibility. PIC 18F4550 memory type is indicate in the part number by the first letter after the family affiliation designation; e.g. PIC 18 'F'4550. The letter 'F' indicate the device have a flash type of memory, where this devices is electrical erasable. Being electrical erasable make the devices can be erased and reprogrammed without removal from the circuit.

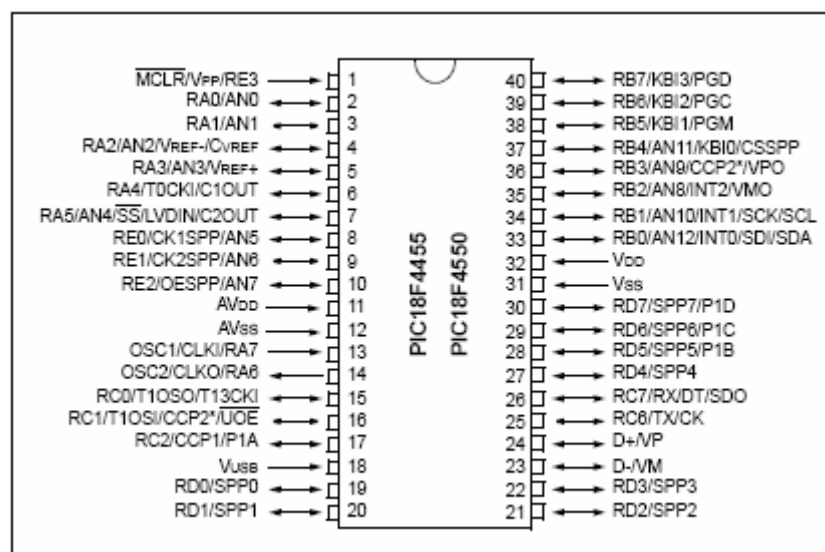


Figure 3.6 PIC 18F4550