MICROCONTROLLER BASED BUCK PID

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Signature : ______________________________

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Date : 17 NOVEMBER 2008

Specially dedicated to

My beloved family who keeps on supporting me throughout my life

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ABSTRACT

This thesis revises of power electronic conversion techniques for switch-mode power converters for buck topology. Since the DC/DC converters are often used to provide a DC regulated output voltage, it also can be used to provide voltage isolation as well as the required regulated output voltage. The future project or demand is looking towards alternative power sources all of which will need to be regulated in one form or another with highest efficiency, high availability and high reliability with the lowest cost, smallest size and weight. Therefore, the parameters required for implement this converter based on system design. In addition to do this, the closed loop feedback system using PID controller method will be implement to against the voltage drop or load change in the system. This project perform is only limited to design the closed-loop feedback system using proportional technique for buck converter. The controller will be implemented on a PIC microcontroller (PIC18F4550) and programmed through a computer using software of Microcode Studio. The programmed PIC184550 will be able to automatically control the duty cycle of the system in order to apply an appropriate duty cycle to the system. The benefit of this project is result to improvement in percent overshoot depend on the voltage change and maintain output voltage needed.

ABSTRAK

Tesis ini meninjau kembali bidang penukaran kuasa secara elektronik menggunakan teknik suis bagi “*Buck converter*”. Oleh kerana topologi penurunan voltan arus terus kepada nilai voltan arus terus yang dikehendaki seringkali diguna dalam menyediakan arus terus yang lebih teratur, ia juga boleh digunakan untuk menyediakan pengasingan voltan seperti yang dikehendaki oleh keluaran voltan. Untuk projek dan permintaan di masa hadapan, penghasilan voltan melalui teknik suis dilihat sebagai pilihan kepada sumber kuasa yang diperlukan untuk mengatur voltan dari satu bentuk kepada bentuk yang lain dengan keupayaan keluaran yang lebih efisien, berkebolehan dan dipercayai kegunaannya melibatkan kos yang rendah, saiz yang kecil dan lebih ringan. Oleh kerana itu parameter yang diperlukan untuk melaksanakan penurunan voltan ini bergantung kepada rekaan sistem model. Sebagai tambahan untuk membuat sistem ini,“*closed-loop feedback*” menggunakan teknik kawalan algoritme “PID” akan dilaksanakan bagi menghalang kejatuhan voltan atau perubahan nilai beban didalam sistem. Projek ini akan melakukan penurunan voltan arus terus terbatas menggunakan teknik ”*proportional*” sahaja.Pengawalan “*losed-loop feedback*” ini akan dilaksanakan menggunakan mikro cip PIC18F4550 dan seterusnya diprogramkan melalui komputer menggunakan perisian “*MicroCode Studio*”. Program yang telah dimasukan ke dalam mikro cip secara automatik akan mengawal denyutan didalam sistem dimana denyutan yang tepat akan digunakan bagi kawalan frekuensi suis sistem ini. Kelebihan projek ini ialah membaiki peratus voltan yang melampaui bergantung kepada perubahan voltan yang diberi dan mengekalkan kepada nilai yang dikehendaki.

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LIST OF SYMBOLS

C	-	Capacitance
d	-	Diameter
D	-	Duty cycle
f	-	Frequency
I	-	Current
L	-	Inductance
R	-	Resistance
T	-	Time
V	-	Potential difference / Voltage

LIST OF ABBREVIATION

DC	-	Direct Current
PWM	-	Pulse Width Modulation
IC	-	Integrated Circuit
PID	-	Proportional Integral Derivative
ICD	-	Circuit Debugging
IDE	-	Integrated Development Environment
ADC	-	Analog to Digital Converter

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CHAPTER 1

INTRODUCTION

1.1 Overview

The fast improvement of power electronics circuits due to new application demand, advance technology growth in semiconductor switches, microelectronics and new ideas in control algorithms increase power switches or power semiconductor devices utilities. The goal of electronic power conversion is to convert an electrical energy from one form to another form from the given source to the output load demand with highest efficiency, high availability and high reliability of the system performance. As can see nowadays, an application such as power switches devices increasingly used for changing the levels of electrical supply to the desire levels such as switch mode power supply (SMPS), DC motor control, battery chargers, and etc. At this time, the various dc to dc converters topologies like buck converter, boost converter, buck-boost converter and others converter topology well to use for different applications in various parts start from portable devices utilities until aircraft power system utilities. In power switches, system features essentially looking for higher performances especially in power handling. Thus this project will consider the factor such as power handling performance based on system efficiency of power deliver to output.

1.2 Research Problem

This project is concentrate in power electronic conversion techniques for buck converter topology. Therefore, the parameters necessary for implement this converter based on system design. In addition to do this, the closed loop feedback system using PID controller technique will apply in order to maintain the desired output system due to any changing given in input supply.

1.3 Objective

The aim of this project is to evaluate the importance of control system in buck conversion system design in terms of power efficiency deliver from input to output supply. To achieve this aim, the project is carried out for the following objectives.

i. To design Microcontroller Based Buck PID system in order to regulated dc supply from an unregulated dc supply at desired level using controller technique.
ii. To ensure power conversion delivery to the output system is efficient. This conversion will carry out in two stages. First stage is rectifying 240Vac to get unregulated dc supply and the second stage is regulating it dc supply using Buck converter.
iii. To apply close- loop feedback conversion system using Proportional Integral Derivative (PID) technique for design process.
iv. To explore control algorithms through PID controller model and conversion of analogue to digital (A/D).

1.4 Scope of Work

The scope of project at first focused on the designing Buck converter (dc-dc step-down converter) for converting 350Vdc supply to 35Vdc supply. Second focused on the designing feedback controller using PID technique to ensure error produce is less overshoot and fast changing at output voltage. Then, the three focused on the control signal (PWM) that will be applied in the system using single PIC microcontroller for switching conversion scheme.

1.5 Importance of Study

This project is essential in terms of power efficiency and power handling deliver to output system. It is important because this aspect related to the most electrical and electronic equipment requirements.

1.6 Limitation

This Buck converter project is limited to design closed-loop feedback conversion system using proportional technique.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Power electronics is one of the broadest growth areas in electrical technology. Today, electronic energy processing circuits are needed for every computer system, every digital product, industrial systems of all types, automobiles, home appliances, lamps and lighting equipment, motor controllers, and just about every possible application of electricity (Professor Ir. Dr. Abdul Halim Bin Mohamed Yatim, 2006). However, when designing the switch mode power supply, SMPS using power electronics element such as power MOSFET, there have several factors will be considered in the system design. In this chapter, the factors considered in the design of power conversion are discussed.

2.2 Design Concept

The project design constraints on power efficiency, lower cost, and less reduce space and components used. For higher power application, power supplies that need to provide higher current not suitable use to the chip since the current is too high for handled and it might cause IC damage. And therefore it may cause instability condition when the load or input voltage changing may cause system at risk. Dynamic power losses are due to the switching behavior of the selected pass devices (MOSFETs, Power Transistors, IGBTs, etc.). These losses include turn-on and turn-off switching losses and switch transition losses.

Since an increasing of power electronics circuits in many applications such used in automobiles to laptops which use an integrated circuit (IC) and form in smaller size. The lower system cost improvement of power supply show in designing of power supplies using analogue techniques requires components to be oversized to compensate for component variation and component drift. Using analog circuitry to implement system control functions is not always cost-effective or flexible.

Losses in an electric or power electronics circuits come from many source, in this project the losses such a resistive losses in the controllable switch, capacitive losses due to charging of the controllable gates and parasitic capacitances, short circuit current through the controllable switch especially current flow during switch open and voltage drop across when switch is closed and the parasitic losses of filter in an inductor and capacitor. More that, in order to regulate the output voltage, the duty cycle to the buck converter is set by a feedback control loop, but to associate the controller design to buck converter power elements, it may cause inefficient in power conversion. To ensure the system stability and for improving transient output response, the more complex proportional integral derivative (PID) controller can be implemented.

2.3 Components Review

2.3.1 Ultra-low VF hyper fast rectifier for discontinuous mode power factor correction

This Ultra-low VF Hyper fast Rectifier for Discontinuous Mode Power Factor Correction is used to Buck converter because an average rectified forward current, is up to 15A. Since the input supply, Vdd to Buck converter need about 350Vdc, the current flow through circuit might be high then this rating should be considered in terms of semiconductor component used. Refer datasheet in APPENDIX F for details.

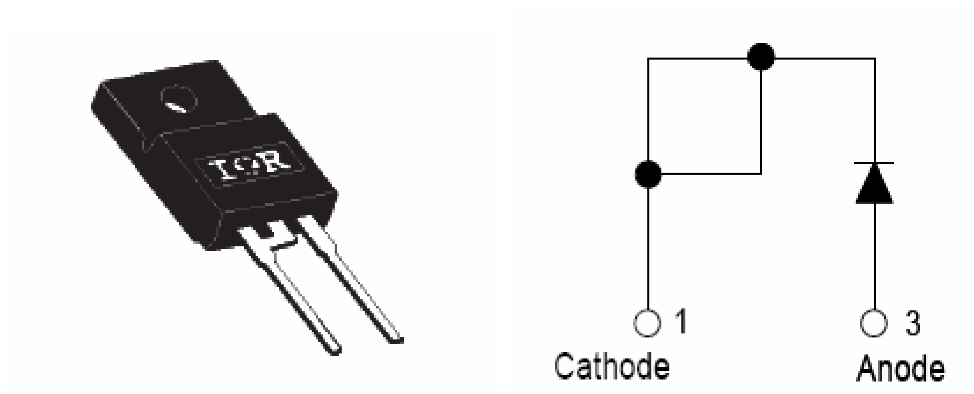

Figure 2.1: 15ETL06FPPbF pin out configuration

2.3.2 Half bridge driver

Since the gate drive requirements for SMPS MOSFET utilize as high side switch which mean the drain terminal connected to the high voltage rail for driven in full enhancement. This IR2109 half bridge driver is required to drive on high side, HO.

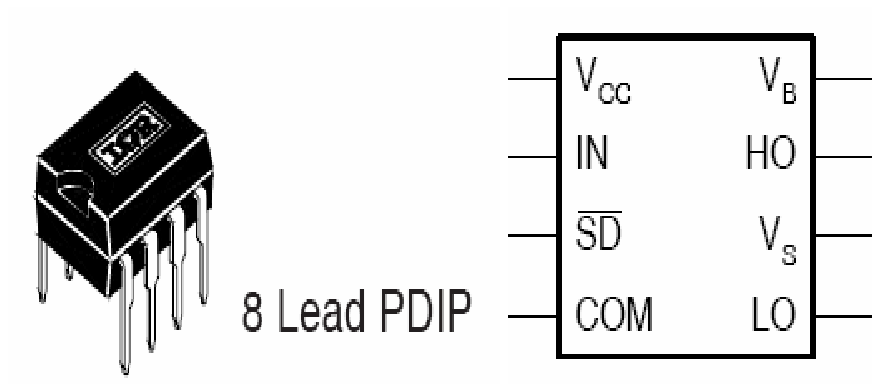

Figure 2.2: IR2109 pin out configuration

2.3.3 Bridge rectifier

In order to produces unregulated dc supply voltage up to 350Vdc from main supply of 240Vac, this silicon bridge rectifier is used to the circuit. The cost of this component is cheap with the features of rms voltage up to 700Vrm and maximum average forward output current is 25A. See APPENDIX G for datasheet.

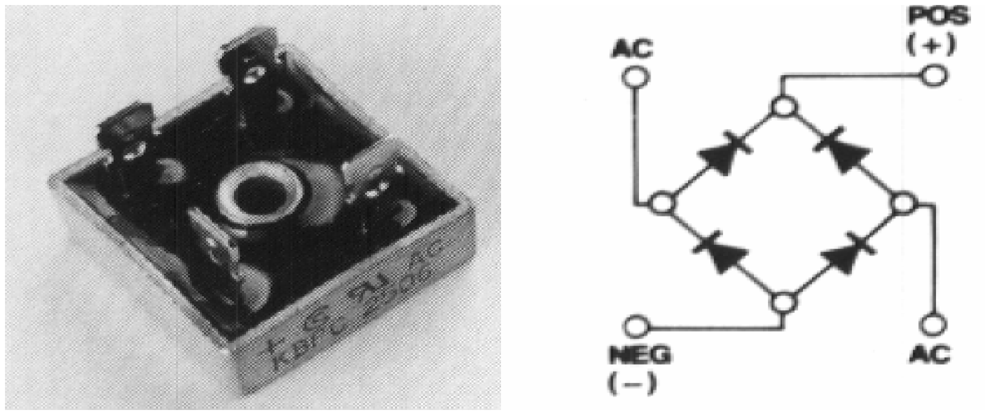

Figure 2.3: KBPC2510 terminal pin configuration

2.3.4 Phototransistor optoisolator

The optoisolator is used to convert the voltage mode (output voltage) read from Buck converter to an appropriate value of PIC18F4550 to perform closed loop feedback conversion system in order to maintain output voltage at desire level.

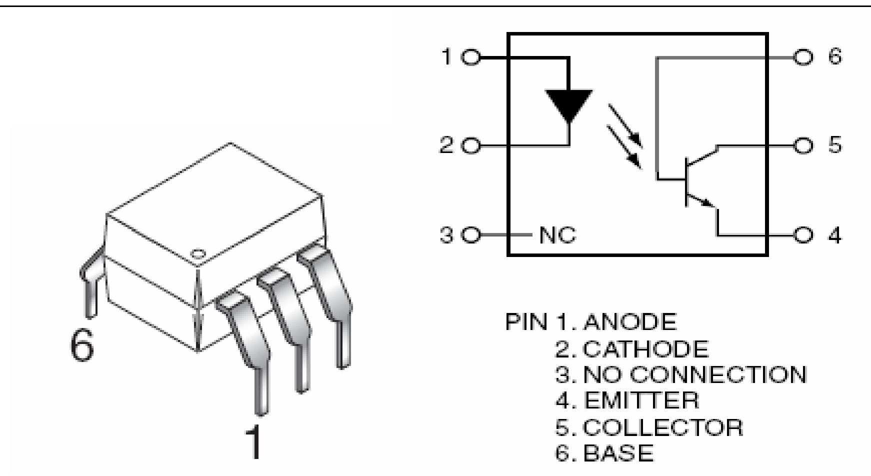

Figure 2.4: 4N25 pin out configuration

2.3.5 SMPS MOSFET

As illustrate on Figure 2.5, this SMPS MOSFET has limitations operation in terms of voltage, current and power dissipation. The power absorbed by the gate drive circuitry should not significantly affect the overall efficiency. The power MOSFET current rating is related with the heat dissipated in the devices. This rating will be take in consideration for designing appropriate circuit to protect power MOSFET against high voltage and current, thus cause heat generation. While considering protection of power MOSFET against over voltage, a distinction has to be made between slowly varying over voltage and short time surge.

It is about 400Vdc the minimum rating of drain to source breakdown voltage. Gate voltage must be 15-20V higher than the drain voltage. Being a high side switch, such gate voltage would have to be higher than the rail voltage, which is frequently the higher voltage available in the system. Refer APPENDIX C for details specification. The datasheet provided by manufacturers are given in order to ensure the devices neither connected in the specified limits nor exceeded.

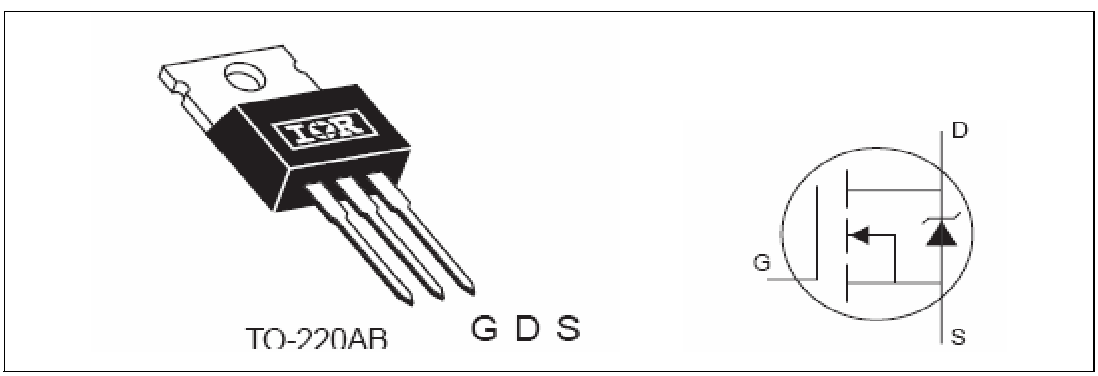

Figure 2.5: IRF7450A terminal pin configuration

2.3.6 Capacitor

Except refer to capacitor value and rating of voltage use in system, the capacitor also supposed to be choose with minimum loss because switched power regulators are usually used in high current-performance power supplies. Loss occurs because of its internal series resistance and inductance. Commonly capacitors for switched regulators are chosen based on the equivalent series resistance (ESR).

Figure 2.6: Capacitor with 220uF/450Vdc

2.3.7 Inductor

The function on inductor is to store energy and the value is selected to maintain a continuous current mode (CCM) operation as a rated of load (55 Ω) is decided for this Buck converter. In CCM, current flow continuously in inductor during the entire switching cycle and output inductance selected to limit the peak to peak ripple current flowing. The factors to be considered in selecting the inductor are its peak to peak ripple current (CCM), maximum dc or peak current (not overheat) and maximum operating frequency (maximum core loss is not exceeded, resulting in overheating or saturation).

2.3.8 PIC microcontroller

The microcontroller selected to control the closed –loop feedback conversion power was the 40-pin PDPIP package of the PIC18F4550. As can see in Figure 2.7, pin 17 of the microcontroller is the CCP2 and CCP1 output pin, respectively, representing the PWM output. A primary benefit of this microcontroller is the flexibility of the many I/O pins to accommodate analog to digital signals other than easy to firm the program.

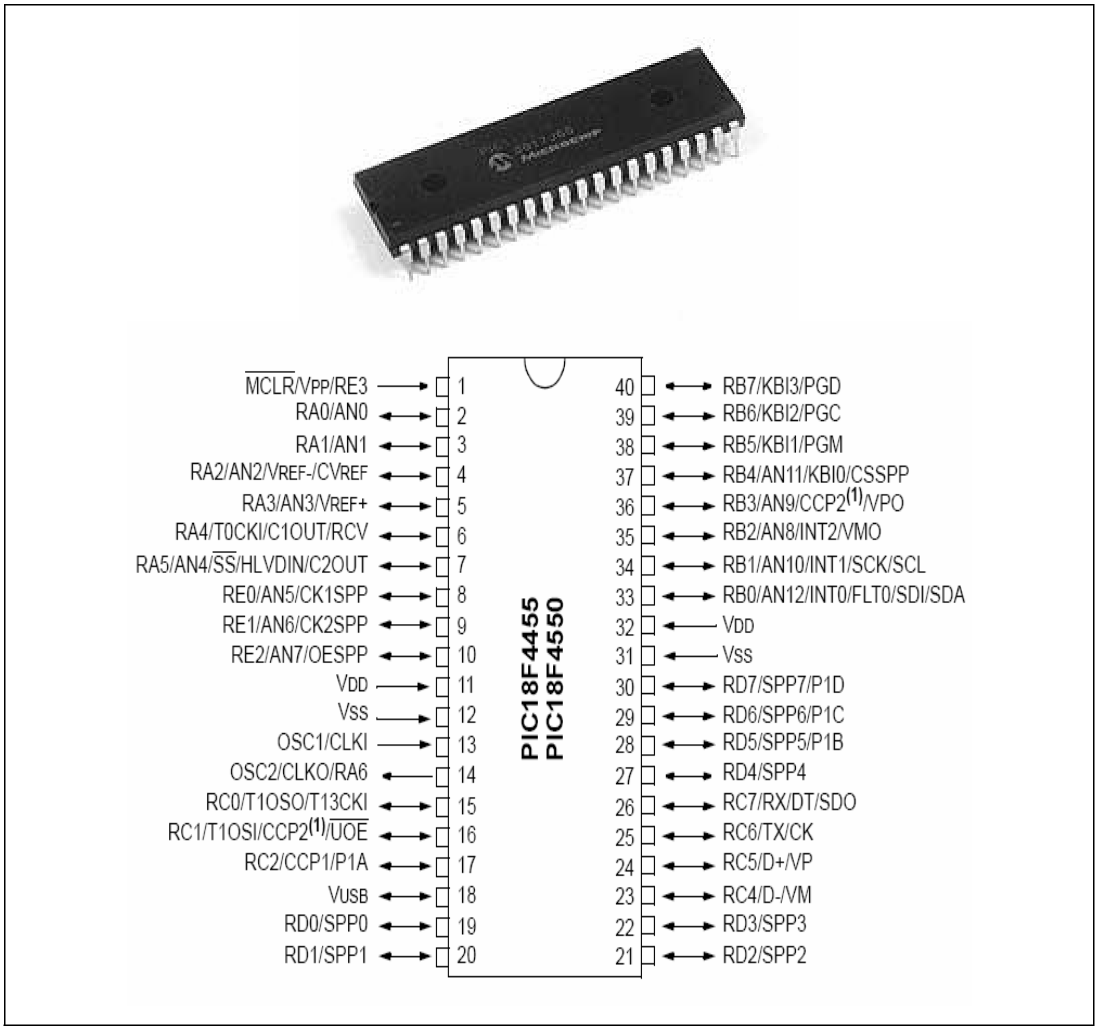

Figure 2.7: Pin out for the 40-pin PDPIP package of the PIC18F4550

2.3.9 Controller

This Buck system is closed loop feedback system, in order to simulate or to firm the program for controller, the basic such Proportional Error Gain (P-Gain) which this parameter produces a correction factor that is proportional to the magnitude of the output voltage error, an integral error gain (I-Gain) which this parameter uses the cumulative voltage error to generate a correction factor that eliminates any residual error due to limitations in offset voltages and measurement resolution an Derivative error gain (D-Gain) which this parameters produces a correction factor that is proportional to the rate of change of the output error voltage, which helps the system respond quickly to changes in the system conditions. Feed forward gain – this parameter produces a correction factor that is computed based on the magnitude of the input voltage, inductor current and circuit attributes such an inductor and capacitor value. This term allow the control loop to be protective rather than reactive. In other words, when the input voltage changes, feed forward gain responds so that the control loop does not have to wait until the output voltage changes before making the appropriate gain correction.

Using the PID algorithm, the proportional, integral and derivative error of the actual versus the desired output voltage is combined to control the PWM duty cycle. The PID algorithm will be used in voltage mode control loops. The PID software is typically small, but its execution rate is very high, often hundreds of thousands of iterations per second. This high iteration rate requires the PID software routine be as efficient as possible to minimize performance. The PID control-loop is interrupt-driven by the ADC on a fixed-time basis. Any system function that can be executed in the “idle loop” should be, in order to reduce the unnecessary workload within the PID control software. Functions such as voltage ramp up/down, error detection, feed-forward calculations and communication support routines are candidates for the idle loop. Any other interrupt-driven processes, such as communication, must be at lower priority than the PID loop.

2.3.10 Voltage –mode control

Voltage-mode control is the methods of control based on analog switch-mode power supply (SMPS) control techniques. In voltage mode, the difference between desired and actual output voltage (error) controls the time that the supply voltage is applied across the inductor, which indirectly controls current flow in the inductor. Varying the duty cycle essentially adjusts the input voltage drive to the Buck's LC components which directly effects. Voltage-mode can provide more stability in a noisy environment or over a wide operating range.

2.4 PIC Microcontroller Tools Development

2.4.1 Picbasic pro compiler (pbp)

PICBASIC PRO™ Compiler is the easiest way to program the fast and powerful Microchip Technology PICmicro microcontrollers (PIC18F4550). PICBASIC PRO converts BASIC programs into files that can be programmed directly into a PICmicro MCU. The BASIC language is much easier to read and write than the quirky Microchip assembly language. PBP compiler produces code that may be programmed into a wide variety of PICmicro microcontroller having from 8 up to 84 pins and various on-chip features including A/D converters, hardware timers and serial ports. The PIC18F4550 use Harvard technology to allow rapid erasing and reprogramming for program debugging. The PIC18F4550 devices also contain between 64 and 1024 bytes of non-volatile data memory that can be used to store program and data and other parameters even when the power is turned off.

2.4.2 Window interface software

MicroCode Studio is actually Integrated Development Environment (IDE) with In Circuit Debugging (ICD) capability designed specifically for PICBASIC PRO compiler. This software is easy to set up and capable to identify, correct the compilation and assembler an error. The controller algorithm programmings write in MicroCode Studio. See Figure 2.8.

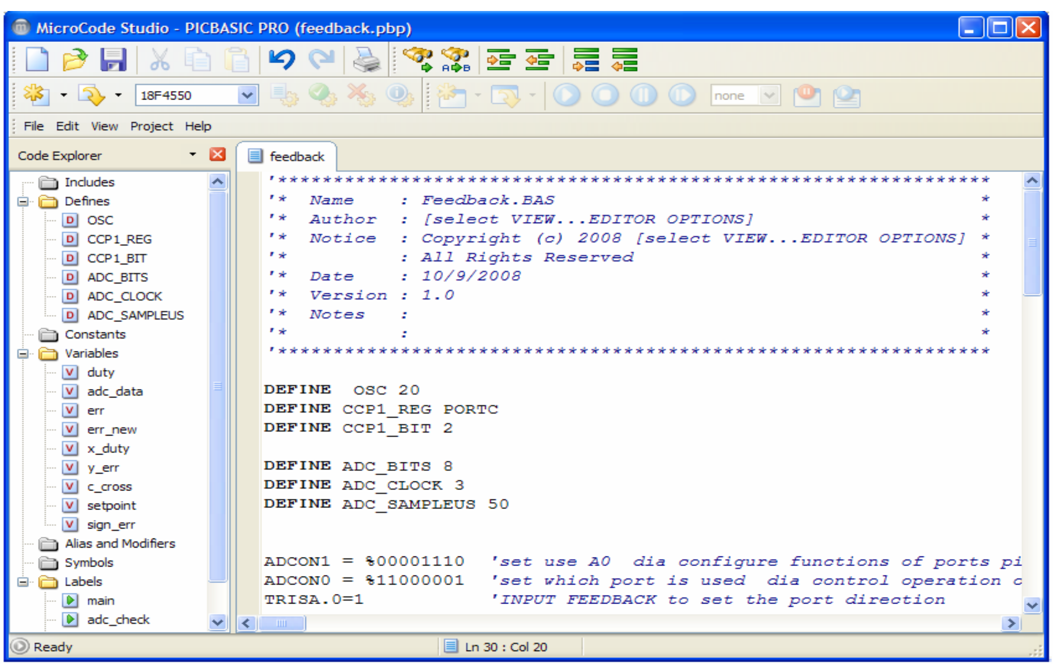

Figure 2.8: MicroCode Studio screenshots

2.4.3 Programming Adapters and melabs U2 pic programmer

The melabs U2 PIC Programmer is driven and powered from a single USB port on computer. Then adapters connect to the programmer's 40-pin expansion header to allow programming of PIC microcontrollers in DIP, PLCC or surface mount packages. See Figure 2.9 for programming adapters.

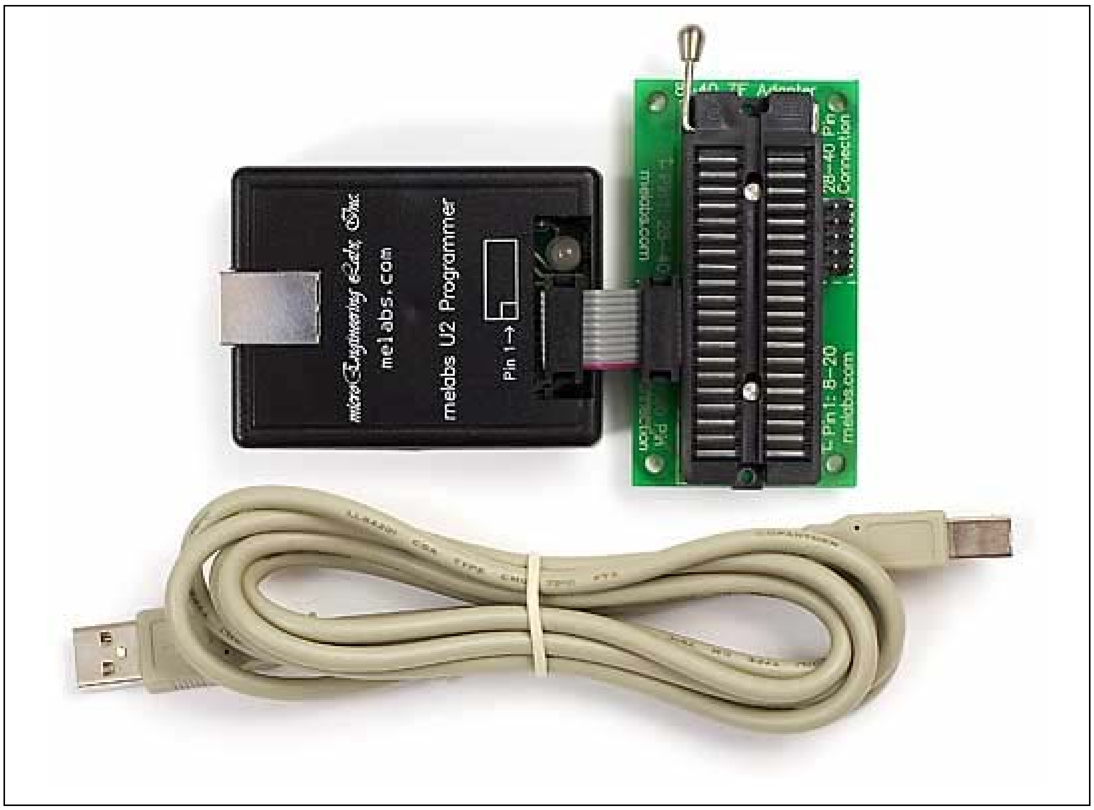

Figure 2.9: Melabs U2 PIC programmer (black chasing) and programming adapter

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter explains about hardware development such as equipments, procedures and method design for Buck converter including controller technique used in closed-loop feedback system. This chapter also explains about the software interface and the complete operation of the Buck converter.

Before looking at the details of all methods below, it is good to begin with brief review of the problem that is considered in this Buck converter. The changing of voltage from input supply will be consider as problem need to against by apply feedback controller in order to maintain an output from Buck converter

3.2 Hardware Development

3.2.1 Circuit function

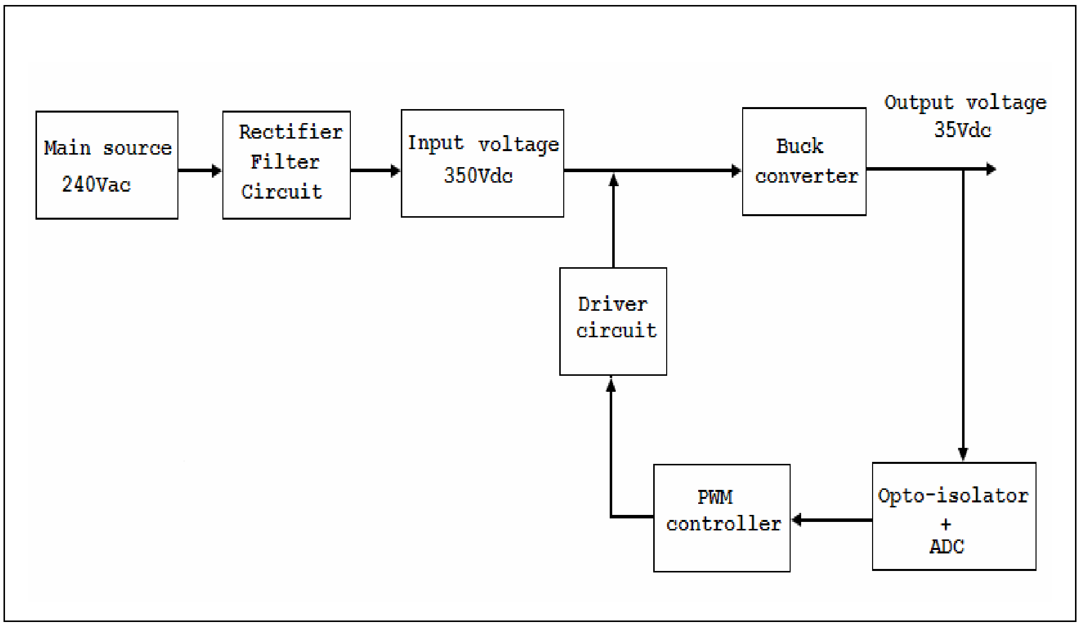

Figure 3.1: Design flow for Microcontroller Based Buck PID system

In the hardware part, the circuit is design to step down dc – to – dc voltage. The circuit included parts of Buck components such as controllable switch (IRF740A), inductor and capacitor, PIC18F4550 microcontroller, IR2109 Half Bridge Driver, optoisolator (4N25), and other basic components. Rectifier and filter circuit is design to obtain voltage up to 350Vdc from main source. The voltage obtained will be step down by Buck converter to 35Vdc. In order to maintain output voltage, controller will be operated in feedback circuit. The complete circuit for the system is shown in APPENDIX I.

PIC18F4550 is used to control SMPS MOSFET switching duty cycle which is connected to Buck converter circuit. PIC18F4550 has 40 pins. The important pint that connected to IR2109 drive is RC2/CCP1/P1A pin and to optoisolator 4N25 is pin RA0/AN0. Since the PWM that will be apply to Buck converter is varied in order to maintain the output voltage, the HPWM function pin at RC2/CCP1/P1A need to set in order to generate the PWM signal from the microcontroller. The 20MHz crystal oscillator is used for PIC18F4550 microcontroller internal clock.

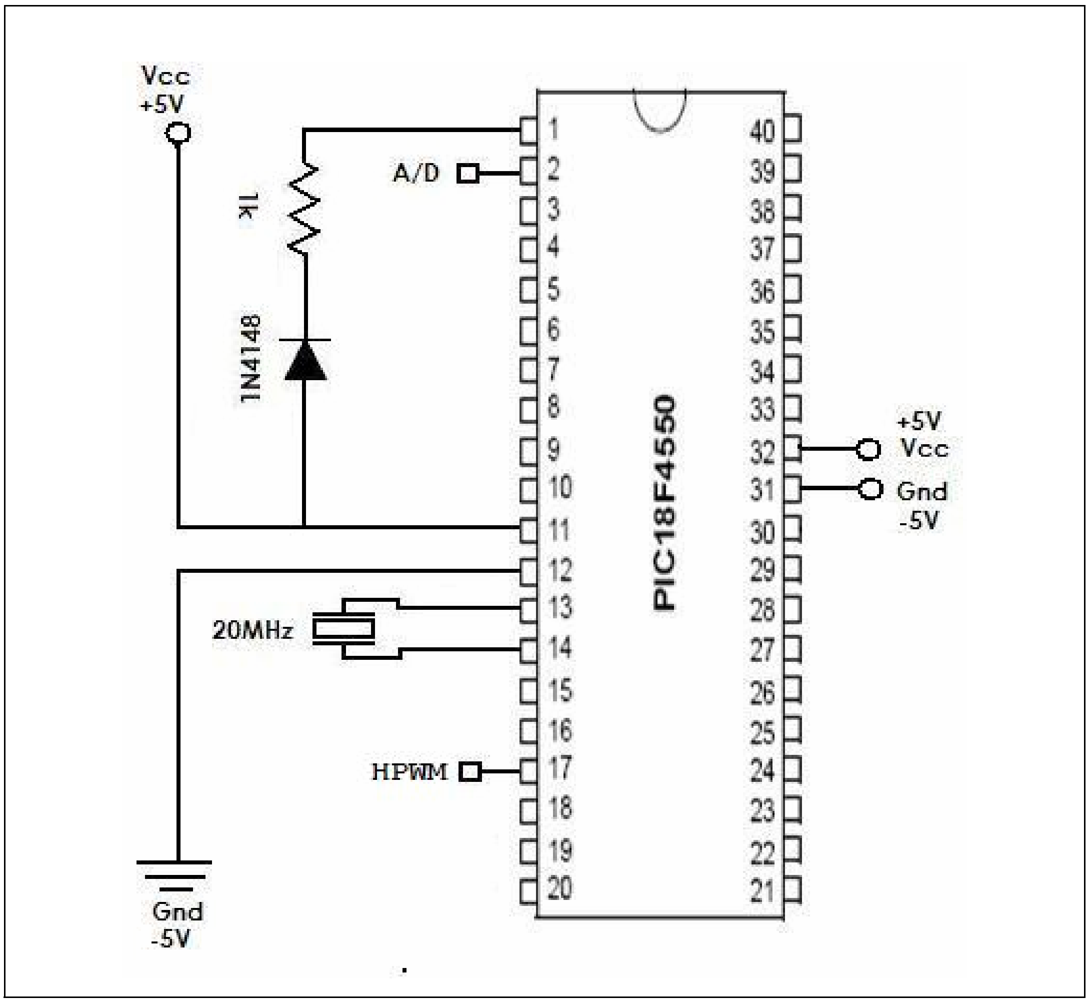

Figure 3.2: PIC18F4550 pin connection circuit

3.2.2 Basic Buck converter circuit operation

Figure 3.3 show the full Buck converter equivalent circuit. For determining the output voltage of Buck converter, the inductor current and inductor voltage should be examined first. Observations made during controllable switch closed and switch open. The method will explain base on Figure 3.4 and Figure 3.5.

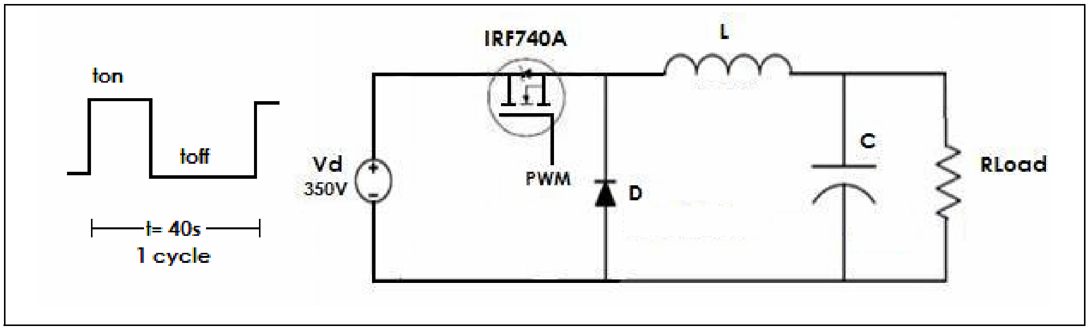

Figure 3.3: Buck dc-dc converter

Method 1: During duty cycle in ON state

Refer on Figure 3.4, when the duty cycle is in ON state, diode become as reversed biased and the inductor will deliver current and switch conducts inductor current. With the voltage (Vin -Vo) across the inductor, the current rises linearly (current changes, ΔiL). The current through the inductor increase, as the source voltage would be greater then the output voltage and capacitor current may be in either direction depending on the inductor current and load current. When the current in inductor increase, the energy stored also increased. In this state, the inductor acquires energy. Capacitor will provides smooth out of inductor current changes into a stable voltage at output voltage and it's big enough such that V out doesn't change significantly during one switching cycle.

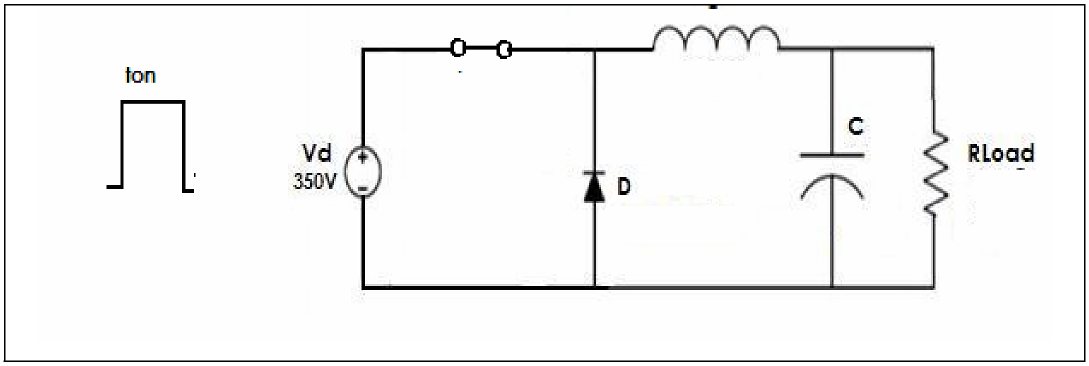

Figure 3.4: Equivalent circuit for switch closed

Method 2: During duty cycle in OFF state

As can see in Figure 3.5, in OFF state of duty cycle, the diode is ON and the inductor will maintains current to load. Because of inductive energy storage, iL will continues to flow. While inductor releases current storage, it will flow to the load and provides voltage to the circuit. The diode is forward biased. The current flow through the diode which is inductor voltage is equal with negative output voltage.

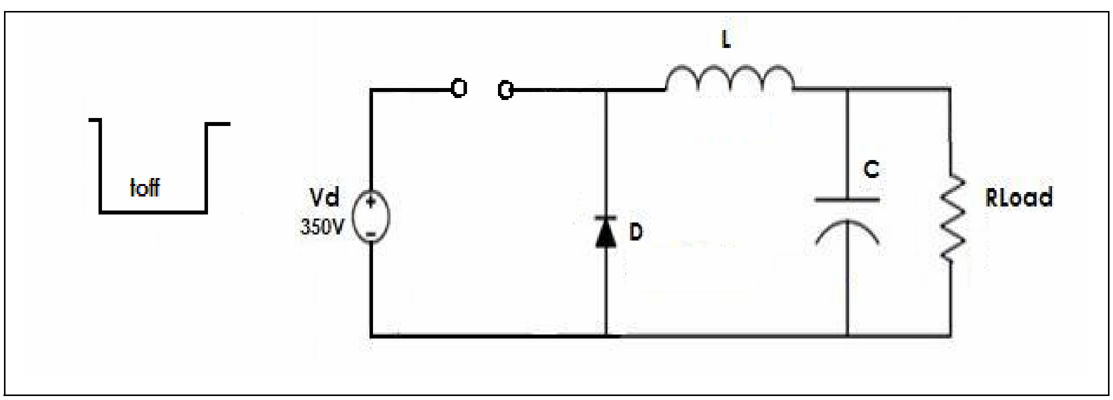

Figure 3.5: Equivalent circuit for switch open

3.2.2 Component determination

3.2.2.1 Switching frequency

Before Buck converter circuit is design, the PWM frequency should determine. Basically, the higher the frequency the higher is the efficiency of the Buck converter. Thus to choose a suitable PWM frequency for the Buck converter, both of power consumption and the efficiency of the system need to be consider. Here are three steps that can be used to determine a suitable PWM frequency range for the Buck converter.

<u>Step 1: Determine the whole system timing characteristics.</u>

The design of Buck converter input voltage should able to be decrease to 10% of its maximum value. Thus, the component at hand is SMPS MOSFET IRF740A for the switching element, IR2109 for the driver, 4N25 for the opto – isolator and PIC18F4550 for the PWM controller. The rise time, tr, the fall time, tf, the minimum on-time, ton (min) and the minimum off-time, toff(min) can be found in the datasheet. Table 3.1 lists the rise and fall times and Table 3.2 lists the on and off times of each components.

Table 3.1: Rise and Fall Time

Bil	**Component**	**tr(ns)**	**tf(ns)**
1	IRF740A	35ns	22ns
2	IR2109	150ns	50ns
3	4N25	1200ns	1300nus

Table 3.2: Minimum On and Off Time

Bil	**Component**	tr(ns)	tf(ns)
1	IRF740A	negligible	negligible
2	IR2109	750ns	200ns
3	4N25	2800ns	4500ns

Referring to Table 1, the slowest tr and tf of the components are 1200ns and 1300ns respectively. Referring Table 2, it can be seen that both the slowest ton (min) and toff(min) of all components is at opto-isolator. With the information, the frequency range for the de vice can be determined.

Step 2: Determine the frequency range available for the system.

A summary of data that we obtained from step 1 are as follows:

(a) D(min)=5%
(b) D(max)=10%
(c) tr(slowest)=1200ns
tf(slowest)=13008ns
(d) ton(min)=2800ns
(e) toff(min)=4500ns

Insert this data in the equation 3.1:-

$$\frac{4(1-D_{(\max)})}{3\left(tr_{(slowest)}+tf_{(slowest)}\right)+4t_{off\,(\min)}} \le \ fswitch \le \frac{4D_{(\min)}}{tr_{(slowest)}+tf_{(slowest)}+4t_{on(\min)}} \qquad (3.1)$$

$$\frac{4(0.9)}{3(2500ns)+4(4500ns)} \le \ fswitch \le \frac{4(0.05)}{1200ns+1300ns+4(2800ns)}$$

$$\frac{3.6}{25500ns} \le \ fswitch \le \frac{0.2}{13700ns}$$

$$141.18kHz \le \ fswitch \le 14.59kHz$$

<u>Step 3: Choose the frequency</u>

Based on the calculation frequency range, the lowest switching frequency is about 15 kHz and the maximum is about up to 141 kHz. Thus the switching frequency is set to be 25 kHz. This minimum value is selected in order to minimize power use in Buck converter. It can be concluded, to ensure that the Buck converter functions as intended, the switching frequency care must be taken when choosing the operating frequency.

3.2.2.2 Pulse width modulation

In order to generate pulse width modulation (PWM) frequency at PIC18F4550 microcontroller, early mentioned that pin RC2/CCP1/P1A (know as HPWM) is set to be PWM output and it connecting to IN pin in the IR2109 half bridge driver. Here the simple programming to write and define for PWM output.

```
DEFINE ccp1_reg portc
DEFINE ccp1 BIT 2

 Main:
 HPWM 1,26,4999   'Send  a 10% duty cycle PWM signal at 25kHz
 GOTO Main
```

Figure 3.6: Pulse width modulation generated program

The HPWM pin is determine as output hardware pulse width modulation pulse train. This pin is selected to run continuously in the system while the other program is executing other instructions. The PWM generated output can refer to result and the details about HPWM programming can refer to the PIC18F4500 datasheet and book (PICBASIC PRO Compiler, 2002).

Duty cycle need to write in terms of byte to read by microcontroller.

$$Duty\ cycle = D\ x\ 255 \tag{3.2}$$

$$Duty\ cycle = \frac{10}{100}\ x\ 255$$

$$Duty\ cycle = 25.5$$

$$Duty\ cycle \approx 26$$