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M.Sc. in Electrical and Electronics Engineering

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**UNIVERSITY OF GAZIANTEP
GRADUATE SCHOOL OF
NATURAL & APPLIED SCIENCES**

**DESIGN, SIMULATION AND IMPLEMENTATION OF A
BUCK-BOOST CONVERTER USING PIC 18F4550
MICROCONTROLLER**

**M. Sc. THESIS
IN
ELECTRICAL AND ELECTRONICS ENGINEERING**

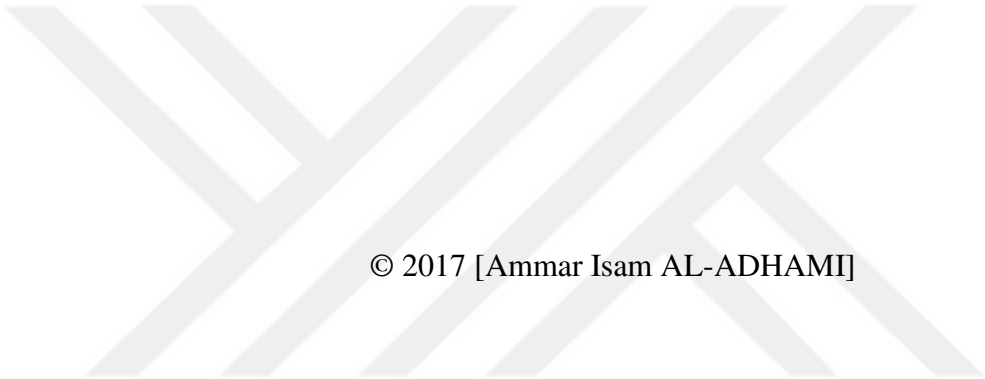
**BY
AMMAR ISAM AL-ADHAMI
MAY 2017**

**Design, Simulation and Implementation of a Buck-Boost
Converter Using PIC 18f4550 Microcontroller**

**M.Sc. Thesis
in
Electrical and Electronics Engineering
University of Gaziantep**

**Supervisor
Prof. Dr. Ergun ERÇELEBİ**

**by
Ammar Isam AL-ADHAMI
May 2017**



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REPUBLIC OF TURKEY
UNIVERSITY OF GAZİANTEP
GRADUATE SCHOOL OF NATURAL & APPLIED SCIENCES
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Ammar Isam AL-ADHAMI

ABSTRACT

DESIGN, SIMULATION AND IMPLEMENTATION of A BUCK-BOOST CONVERTER USING PIC 18F4550 MICROCONTROLLER

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M.Sc. in Electrical and Electronics Engineering

Supervisor: Prof. Dr. Ergun ERÇELEBİ

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This thesis describes the design, simulation and implementation of a buck-boost converter using PIC18F4550 microcontroller. Two stages of DC to DC converters are used for producing positive regulated output voltage. A PIC 18F4550 microcontroller is used to control these two stages. The first stage of DC to DC converter is buck converter while second stage of DC to DC converter is boost converter. The buck converter (first stage) is made as a source of the boost converter (second stage). The PIC 18F4550 microcontroller is programmed such as the buck converter operates in buck mode when the output voltage needs to be less than the input voltage while the boost converter is made in OFF state. When the output voltage needs to be greater than the input voltage, the PIC 18F4550 microcontroller is programmed such as the boost converter operates in boost mode while the buck converter is made in ON state. The overall converter is simulated using computer simulation program. A prototype of a buck-boost converter operates at a frequency 20 kHz with input voltage range (15-20) V and output voltage range (3-30) V is successfully implemented.

Key words: Buck Converter, Boost Converter, DC-DC Converter.

ÖZET

PIC 18F4550 MİKRODENETLEYİCİSİ KULLANILARAK YAPILAN BUCK-BOOST DÖNÜŞTÜRÜCÜSÜNÜN DİZAYNI , SİMÜLASYONU VE UYGULAMASI

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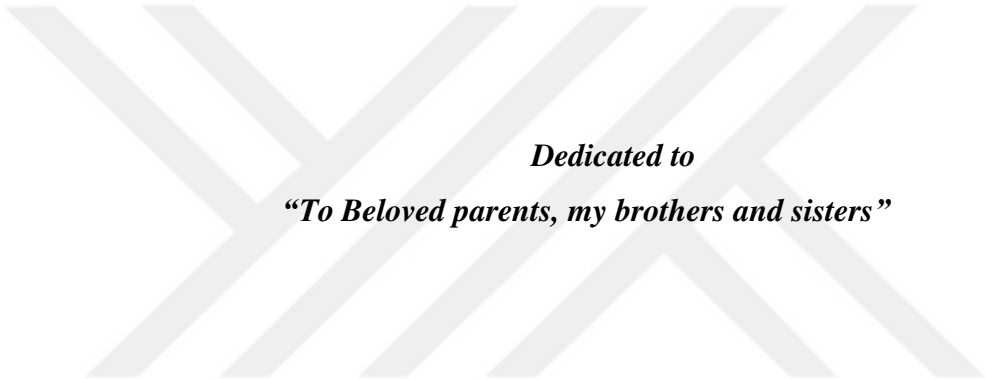
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53 Sayfa

Bu tez PIC 18f4550 mikrodnetleyicisi kullanılarak yapılan buck-boost dönüştürücüsünün Tasarımını, benzetimini ve gerçekleştirilmesini anlatmaktadır. İki aşamalı DC/DC çeviriciler pozitif ayarlanmış çıktı gerilimini üretmek için kullanılmaktadır. PIC 18f4550 mikrodnetleyicisi bu iki aşamayı kontrol etmek için kullanılmıştır. DC/DC çeviricinin ilk aşaması buck dönüştürücü olup ikinci aşaması ise boost dönüştürücüdür. Buck dönüştürücü (birinci aşama), boost dönüştürücünün (ikinci aşama) bir kaynağı olarak yapılmıştır. Boost dönüştürücü kapalı durumdayken çıkış geriliminin giriş geriliminden az olması gerektiği zaman buck dönüştürücünün buck modunda çalışacağı PIC 18F4550 mikrodnetleyicisinde bu şekilde programlanmıştır. Çıkış gerilimi giriş geriliminden büyük olması gerektiği zaman ise buck dönüştürücü açık duruma getirildiğinde boost dönüştürücünün boost modunda çalışacağı PIC 18f4550 mikrodnetleyicisinde bu şekilde programlanmıştır.

Bütün dönüştürücüler bilgisayar benzetim programı kullanılarak benzetimi yapılmıştır. Buck-boost dönüştürücünün bir prototipi (modeli) (15-20 V) giriş voltajı ve (3-30 V) çıkış gerilimi ile 20 kHz frekansında başarılı bir şekilde çalıştığı uygulanmıştır.

AnahtarKelimeler: Buck dönüştürücü, Boost dönüştürücü, DC/DC Dönüştürücü.



Dedicated to
“To Beloved parents, my brothers and sisters”

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LIST OF SYMBOLS / ABBREVIATIONS

DC	Direct Current
AC	Alternating current
EMI	Electromagnteic Interference
MPPT	Maximum Power Point Tracking
PWM	Pulse Width Modulation
CCM	Continuse Conduction Mode
DCM	Discontinuse Conduction Mode
PV	Photo Voltaic
KVL	Kirchhoff's Voltage Law
KCL	Kirchhoff's Current Law
FB	Feedback Voltage
V_{ref}	Refernce Voltage
CCP	(Capture /Compare / PWM)
CCP _x CON	(Capture /Compare / PWM) Control Register
CCPR _x	(Capture /Compare / PWM) Date Register
CCPR _x L	(Capture /Compare / PWM) Low Byte

CCPR _x H	(Capture /Compare / PWM) High Byte
MOSFET	Matel- Oxide -Semiconductor Field- Effect Transistor
IR2010	International Rectifier
MCLR	Master Clear Pin External Reset
ADC	Analog-to-Digital converter



CHAPTER 1

INTRODUCTION

1.1 Introduction

Many electronic devices require a stabilized or regulated voltage source. The DC-DC converters are one of the important electronic circuits, which are widely used in power electronics. It is an electrical device that converts energy from an unregulated DC voltage source to a load with regulated output voltage. The energy is converted via solid-state switches (such as transistors and diodes) to energy storage devices (such as inductors or capacitors) and then subsequently converted from storage devices to the load. The output voltage is depended on the input voltage and the duty ratios of the switches. The DC-DC converter has many functions, these are:

- a) It converts a DC input voltage with certain level into a DC output voltage at another level.
- b) It regulates the DC output voltage deliver to the load.
- c) It reduces the AC voltage ripple on the DC output voltage as much as possible.
- d) It provides isolation between the load and the input source (if there is a need).
- e) It reduces the electromagnetic interference (EMI).
- f) It improves the power factor of the AC main source.

The main problem with operation of DC-DC converter is unregulated power supply, which leads to improper function of DC-DC converters. There are various analogue and digital control methods used for DC-DC converters and some have been adopted by industry including voltage and current-mode control techniques. The DC-DC converter inputs are generally unregulated DC voltage input and the required outputs should be a constant or fixed voltage. Application of a voltage regulator is that it should maintains a constant or fixed output voltage irrespective of variation in load current or input voltage. Various kinds of voltage regulators with a variety of control schemes are used to enhance the efficiency of DC-DC converters.

Today due to the advancement in power electronics and improved technology, a more severe requirement for accurate and reliable regulation are desired.

This has led to need or more advanced and reliable design of controller for DC-DC converters. There are four topologies of non-isolated DC to DC regulators, these are [1, 2]: Buck, Boost, Buck–boost and Cuk regulators.

Buck-boost converters are widely used when the load needs voltage above, equal or below input voltage. It is used in many applications such as: Voltage regulator, MPPT (maximum power point tracking) [3-5], Speed controlled motors such as switched reluctance motor [6], Power factor correction and battery charger [7], and LED driver and many other applications.

1.2 Theory of Buck-Boost Convertor

There are two topologies are used for step up and step down the output voltage. These are buck-boost and cuk convertors.

1.2.1 Principle Operation of Buck-Boost Convertor

The basic circuit of the buck-boost convertor is shown in Figure 1.1a. In this circuit, the output voltage may be greater than, equal or less than the input voltage, but the polarity of the output voltage is negative with respect to the input voltage.

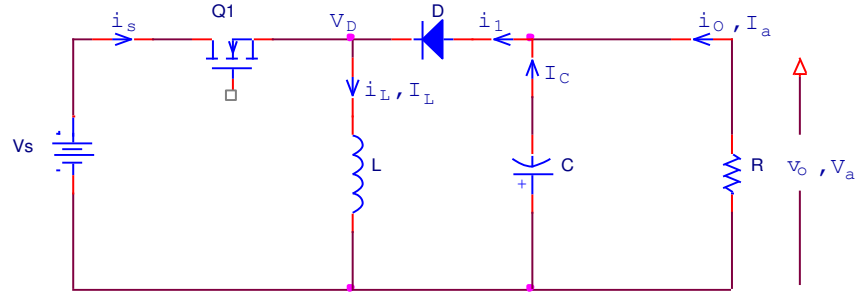
In the operation principle of the buck-boost convertor, there are two modes of operation as shown Figure 1.1b. The operation principle of buck-boost convertor is illustrated as follows [1, 2]:

Mode-1: When the transistor (Q1) is switched ON, the inductor current increases and flows through transistor (Q1) and inductor (L) while the diode is in OFF state (reversed biased). Through this mode the energy is converted from source (V_s) and stored into the inductor (L). For linear changing the current of the inductor from I_1 to I_2 during t_1 .

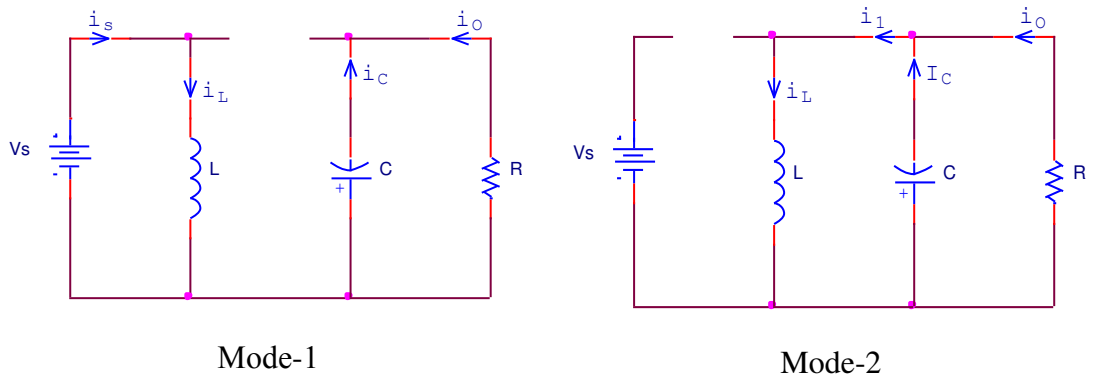
$$V_s = L \frac{I_2 - I_1}{t_1} = L \frac{\Delta I}{t_1} \quad (1.1)$$

Mode-2: When the transistor (Q1) is switched OFF, the diode provides a path for the inductor current and the current flows through diode (D), inductor (L), capacitor (C) and load (R). Through this mode the energy which is stored in the inductor (L) is converted to the capacitor (C) and load. At this case, the current of the inductor will be decreased till the transistor (Q1) is turned ON for the next period. The waveform for currents and voltages of the buck-boost converter for continuous conduction current are shown in Figure 1.1c. For this mode, the current of the inductor decrease linearly from I_2 to I_1 during t_2 ,

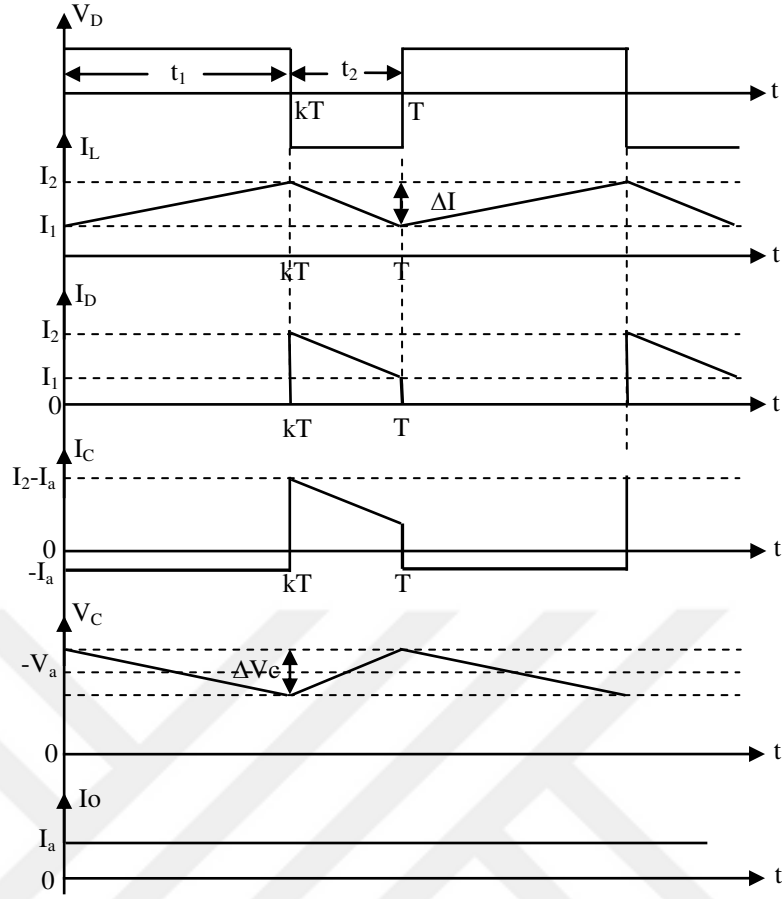
$$V_o = -L \frac{I_2 - I_1}{t_2} = -L \frac{\Delta I}{t_2} \quad (1.2)$$



(a) Circuit diagram of buck-boost converter.



(b) Equivalent circuits of buck-boost converter.



(c) Waveforms.

Figure 1.1 Buck-boost converter, (a) Circuit diagram, (b) Equivalent circuits, (c) Waveforms

From equations (1.1) and (1.2) yield:

$$\Delta I = \frac{V_s \times t_1}{L} = \frac{-V_o \times t_2}{L} \quad (1.3)$$

From Fig.1.1c, $t_1 = kT$ and $t_2 = (1 - k)T$, where k is the duty cycle. Then the average output voltage is:

$$V_a = -V_s \frac{k}{1 - k} \quad (1.4)$$

Then, the transfer function (Mv) of the buck-boost and convertor is:

$$Mv = \frac{V_a}{V_s} = -\frac{k}{1 - k} \quad (1.5)$$

The output voltage $V_o = V_a$ is negative with respect to the ground. The magnitude of the output voltage can be either less than or greater than the input voltage. The output voltage will be equal to the input voltage when the duty cycle (k) equal to 0.5.

The value of the critical inductance (L_c) that determines the boundary between the continuous conduction mode (CCM) and discontinuous conduction mode (DCM) is given by [1, 2]:

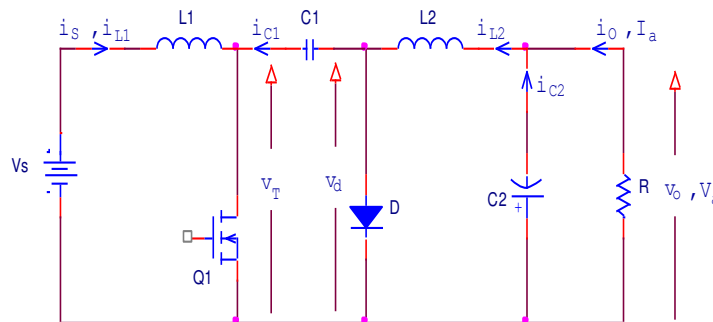
$$L_c = L = \frac{(1 - k)R}{2f} \quad (1.6)$$

Where f is switching frequency, $f = 1/T$.

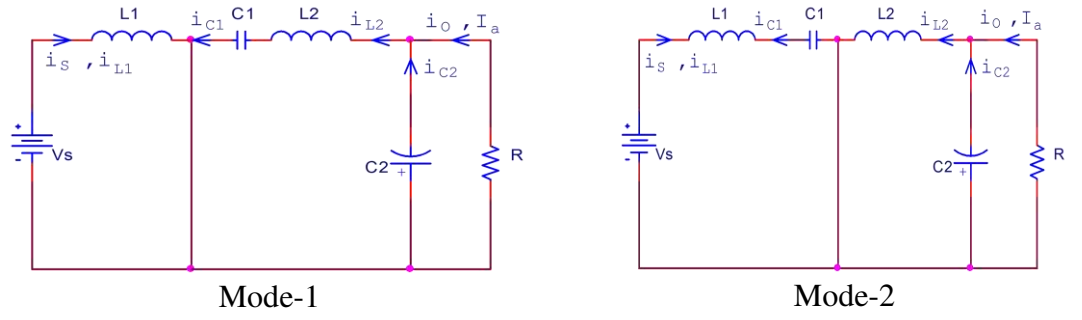
1.2.2 Principle Operation of Cuk Converter

The basic circuit of the cuk convertor is shown in Figure 1.2a. In this topology, the output voltage may be greater than, equal or less than the input voltage, but the polarity of the output voltage is negative with respect to the input voltage. In the cuk convertor, there are two modes of operation as shown Figure 1.2b. The operation principle of cuk convertor is illustrated as follows [1, 2]:

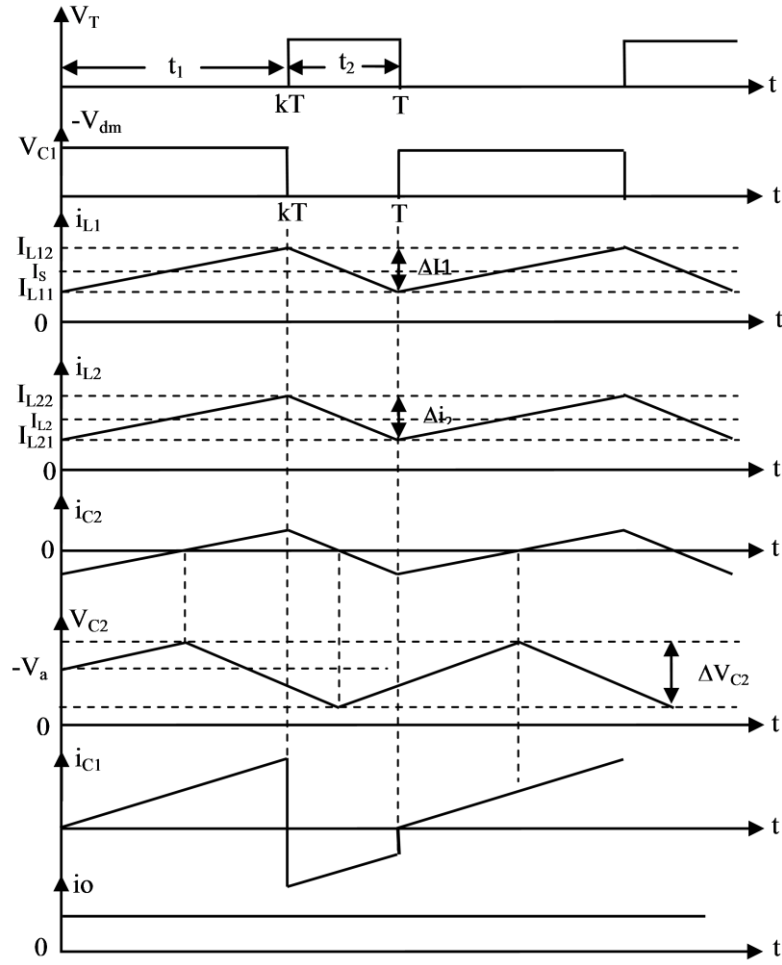
Mode-1: When the transistor (Q1) is switched ON, the inductor current increases and flows through transistor (Q1) and inductor (L_1). Through this mode the energy is converted from source (V_s) and stored into the inductor (L). During this interval, the capacitor voltage (V_{C1}) will make the diode (D) in OFF state (reversed biased). The storage energy in the capacitor (C_1) will discharged to the circuit configured by C_2 , R and L_2



(a) Circuit diagram of cuk converter.



(b) Equivalent circuits of cuk converter.



(c) Waveforms.

Figure 1.2 Cuk converter, (a) Circuit diagram, (b) Equivalent circuits, (c) Waveforms.

The current of the inductor (L_1) increases linearly from I_{L11} to I_{L12} during t_1 , then:

$$V_s = L_1 \frac{I_{L12} - I_{L11}}{t_1} = L_1 \frac{\Delta I_1}{t_1} \quad (1.7)$$

Also, the current of the inductor (L_2) increases linearly from I_{L21} to I_{L22} during t_1 , then:

$$V_{C1} - V_a = L_2 \frac{I_{L22} - I_{L21}}{t_1} = L_2 \frac{\Delta I_2}{t_1} \quad (1.8)$$

Mode-2: When the transistor (Q1) is switched OFF, the diode provides a path for the inductor current and the current flows through diode (D), inductor (L), capacitor (C) and load (R). Through this mode, the energy which is stored in the inductor (L) is converted to the capacitor (C) and load. At this case, the current of the inductor will be decreased till the transistor (Q1) is turned ON for the next period. The waveform for currents and voltages of the cuk convertor are shown in Figure 1.2c.

For this mode, the current of the inductor (L_1) decrease linearly from I_{L12} to I_{L11} during t_2 ,

$$V_s - V_{C1} = -L_1 \frac{I_{L12} - I_{L11}}{t_2} = -L_1 \frac{\Delta I_1}{t_2} \quad (1.9)$$

Also, the current of the inductor (L_2) decrease linearly from I_{L22} to I_{L21} during t_2 ,

$$V_a = -L_2 \frac{I_{L22} - I_{L21}}{t_2} = -L_2 \frac{\Delta I_2}{t_2} \quad (1.10)$$

From equations (1.7) and (1.9) yield:

$$\Delta I_1 = \frac{V_s \times t_1}{L_1} = \frac{-(V_s - V_{C1})t_2}{L_1} \quad (1.11)$$

From equations (1.8) and (1.10) yield:

$$\Delta I_2 = \frac{(V_{C1} + V_a)t_1}{L_2} = -\frac{-V_a \times t_2}{L_2} \quad (1.12)$$

From Figure (1.2c), substitute $t_1 = kT$ and $t_2 = (1 - k)T$ into equations (1.11) and (1.12) respectively yield. The average capacitor voltage (V_{C1}) is:

$$V_{C1} = \frac{V_s}{1 - k} \quad (1.13)$$

And

$$V_{c1} = \frac{-V_a}{k} \quad (1.14)$$

From equations (1.13) and (1.14), the transfers function ($\mathbf{Mv}$) of the cuk converter is:

$$\mathbf{Mv} = \frac{V_a}{V_s} = -\frac{k}{1-k} \quad (1.15)$$

Equation (1.15) in cuk converter is similar as equation (1.5) in buck-boost converter. Where the output voltage ($V_o = V_a$) is negative with respect to the ground. The magnitude of the output voltage can be either less then or greater than the input voltage. The output voltage will be equal to the input voltage when the duty cycle (k) equal to 0.5. The values of the critical inductance (L_{c1} and L_{c2}) that determine the boundary between the continuous conduction mode (CCM) and discontinuous conduction mode (DCM) is given by [1, 2]:

$$L_{c1} = L_1 = \frac{(1-k)^2 R}{2kf} \quad (1.16)$$

And

$$L_{c2} = L_2 = \frac{(1-k)R}{2f} \quad (1.17)$$

Where f is switching frequency, $f = 1/T$. Also, the critical capacitances (C_1 and C_2) that determine the boundary between the continuous conduction mode (CCM) and discontinuous conduction mode (DCM) is given by [1, 2]:

$$C_{c1} = C_1 = \frac{k}{2fR} \quad (1.18)$$

And

$$C_{c2} = C_2 = \frac{1}{8fR} \quad (1.19)$$

1.3 Aim of The Work

The main aim of this project is to design and implemented low cost, efficient and convenient digital controller buck-boost DC/DC power converter using microcontroller such as PIC18F4550 with perfect stability. That can utilize the advantages of the digital controller so as to improve the dynamic performance of the switching power converters. The facility of using smart unit in designing buck-boost PWM DC/DC converter opens the area to overcome different variation issues in DC/DC converter according to the power consumption. To carry out practically buck-boost PWM DC/DC converter many objectives must be realized:

- 1- A comprehensive modeling of PWM DC/DC converter. This objective will be implemented using computer simulation program.
- 2- A comprehensive simulating PIC18F4550 microcontroller in order to make it works as PWM device of the DC/DC converter. This objective will be implemented using Flowcode software package.

1.4 General outline of the Thesis

The thesis is organized in six chapters including the introduction in chapter one. These chapters are:

Chapter 1: This chapter gives a simple detail of the work, including objective and the contribution of the thesis and the organization of the project.

Chapter 2: This chapter explains the literature related to the work and the place of this work in the literature

Chapter 3: includes modeling and analysis of the buck-boost converter using computer simulation program.

Chapter 4: includes a comprehensive study of PIC18F4550 microcontroller. Also, this chapter includes a full program using Flowcode software package to program PIC18F4550.

Chapter 5: includes a complete design of a buck-boost converter using PIC18F4550 microcontroller with practical results.

Chapter 6: includes conclusions and suggestions for future work.



CHAPTER 2

LITERATURE SURVEY

2.1 Introduction

Many of papers and researches have been carried out in the field of the buck-boost converter. A brief review of some preceding researches is:

2.2 Related Work in the Literature

Hamed Mashinchi Mahery, Ebrahim Babaei, (2012) have presented a mathematical model for analyzing a buck-boost DC to DC converter. In this research, a continuous conduction mode (CCM) was described in a mathematical model for the buck-boost DC to DC converter using Laplace transform. At the first step, the relations of output voltage and inductor current were calculated. At the second step, by using the Z-transform, the initial values of output voltage and inductor current were obtained in each switching interval. For bigger values of capacitance and inductance, the buck-boost DC to DC converter had slow transient response in continuous conduction mode (CCM). Also, the ripple value of the output voltage was independent of the inductance value. But the ripple value of the output voltage was decreased when increasing the capacitance and resistance values of the load. It was conclude that the ripple of the inductor current directly proportional with the resistance of the load. Also, the ripple of the inductor current is independent of the of the capacitance value in CCM [8].

Vahid Samavatian and Ahmad Radan, (2014) provided a novel low-ripple interleaved buck-boost converter with high efficiency and low oscillation for fuel-cell applications. In this paper, an interleave technique was used to achieve non-pulsating input/output currents with keeping the same voltage transfer ratio at step-down and step-up. The inner dynamic response of converter was improved by adding

damping network. A Matlab/Simulink software package was used for simulating the converter operation; also the experimental results were presented. The converter was practically implemented with output voltage 36V and 360W for a fuel cell. The converter had a high efficiency with impressive time domain responses in the steady [9].

A.M. Noghlbary et al., (2015) proposed a fully soft switched bidirectional buck-boost converter to interface an ultra-capacitor and a battery. This converter works as a buck zero current switching to charge the ultra-capacitor and works as a boost zero voltage switching to discharge the ultra-capacitor. The zero voltage switching and zero current switching conditions were ensured for all transistors. The efficiency of the buck-boost proposed converter reached higher than 95% with minimum components and had a small size. A prototype of the soft switched bidirectional buck-boost converter with 100 W was simulated and implemented successfully [10].

Barnam Jyoti Saharia et al., (2015) presented a comparative study between buck-boost and buck non-isolated DC to DC converters for maximum power point tracing (MPPT) used in photovoltaic (PV) power systems. In this paper, a tracking algorithm for controlling the duty ratio for the buck-boost and converters were performed [15].

Shan Miao et al., (2016) explained a novel buck-boost converter with low stresses on switches and diodes. In this research, the out voltage of the buck-boost converter with $D^2/(1-D)$ positive gain. The stresses on the diodes and the transistors are low. Therefore, this converter is suitable for the broad range of positive output [11].

CHAPTER 3

MODELING AND ANALYSIS OF THE BUCK-BOOST CONVERTER USING COMPUTER SIMULATION PROGRAM

3.1 Introduction

In many applications of DC power supply, there is a need to be the output voltage positive and regulated. Therefore, two stages of DC to DC converter must be used to achieve adjustable positive output voltage regardless input voltage. The first stage is buck converter which is used for stepping down the output voltage while the second stage is boost converter which is used for stepping up the output voltage.

Before implementing the buck-boost converter practically, it must be analyzed and simulated. Many mathematical techniques are used to analyze the DC to DC converters [12, 13]. Also, many programs can be used to simulate the DC to DC converter such as Pspice [14], Matlab [15-20] and many other programs.

3.2 Modeling of the System Using State Space

To obtain the dynamic model of the buck-boost converter, state space is used. Many state space models for the buck, boost, and buck-boost converters were discussed [21-23]. The state space model of a linear system is a set of simultaneous, or coupled, first order differential equations. An example of two coupled, first order differential equations is the equation set

$$\left. \begin{aligned} \frac{dx_1}{dt} &= a_{11}x_1 + a_{12}x_2 + f(t) \\ \frac{dx_2}{dt} &= a_{21}x_1 + a_{22}x_2 \end{aligned} \right\} \quad (3.1)$$

Where

x_1 and x_2 are the state variables.

$a_{11} \dots a_{22}$ are constant coefficients.

$f(t)$ is a forcing function.

The state space model is a reformulation of the coupled equations into the matrix vector form

$$\dot{x} = Ax + Bu \quad (3.2)$$

Where the vectors x and u (the control vector) are:

$$x = \begin{bmatrix} x_1 \\ x_2 \end{bmatrix}, u = f(t).$$

And the matrix A (the transition matrix) and B (the control input matrix) are:

$$A = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix}, B = \begin{bmatrix} 1 \\ 0 \end{bmatrix}$$

The state space model can be simulated using simulation program which is the very good software package. This computer program has two methods to solve the state space model. The first one solves the differential equations using numerical solutions. The second method is Simulink which is considered in this chapter to solve the state space of the buck-boost converter.

3.3 Modeling of the Buck Converter

The buck converter is shown in Figure 3.1 it is used to produce regulated positive output voltage such that the output voltage less than the input voltage. This circuit can be representing into two equivalent circuits as shown in Figure 3.2 Figure 3.2a represents buck converter when transistor Q1 is turned ON while Figure 3.2b represents buck converter when transistor Q1 is turned OFF.

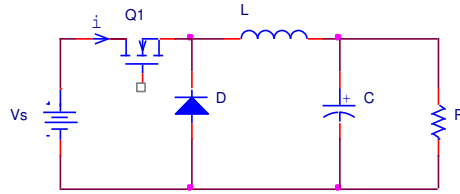


Figure 3.1 Buck converter circuit.

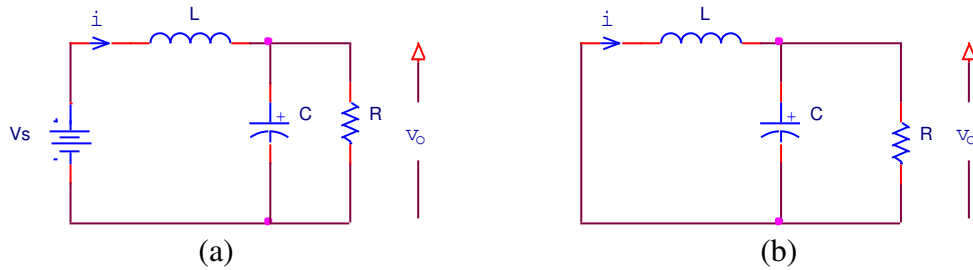


Figure 3.2 Equivalent circuits of the buck converter.

For CCM mode in which the inductor current is continuous all the time. By applying Kirchhoff's voltage law (KVL) and Kirchhoff's current law (KCL) to the circuit of Figure 3.2a yield two differential equations describe buck converter behavior when transistor (Q1) is turned ON:

$$V_s = L \frac{di}{dt} + v_o \quad (3.3)$$

And

$$i = C \frac{dv_o}{dt} + \frac{v_o}{R} \quad (3.4)$$

Also, applying KVL and KCL to the circuit of Figure 3.2b yield two differential equations describe buck converter behavior when transistor (Q1) is turned OFF:

$$0 = L \frac{di}{dt} + v_o \quad (3.5)$$

And

$$i = C \frac{dv_o}{dt} + \frac{v_o}{R} \quad (3.6)$$

Equations (3.4) and (3.6) are the same equation while equations (3.3) and (3.5) are collected to gather by using binary switch (u) yields:

$$u \times V_s = L \frac{di}{dt} + v_o \quad (3.7)$$

Where

$$u = PWM = \begin{cases} 1, & 0 \leq t \leq t_{on} \quad (\text{when } Q1 \text{ is turend ON}) \\ 0, & t_{on} \leq t \leq T \quad (\text{when } Q1 \text{ is turend OFF}) \end{cases} \quad (3.8)$$

By rearranging equations (3.6) and (3.7) respectively yield:

$$\frac{dv_o}{dt} = \frac{1}{C} i - \frac{1}{RC} v_o \quad (3.9)$$

$$\frac{di}{dt} = -\frac{v_o}{L} + \frac{V_s}{L} u \quad (3.10)$$

Equations (3.9) and (3.10) can be represented as the state space model of the buck converter:

$$\frac{d}{dt} \begin{bmatrix} i \\ v_o \end{bmatrix} = \begin{bmatrix} 0 & -\frac{1}{L} \\ \frac{1}{C} & -\frac{1}{RC} \end{bmatrix} \begin{bmatrix} i \\ v_o \end{bmatrix} + \begin{bmatrix} \frac{V_s}{L} \\ 0 \end{bmatrix} u \quad (3.11)$$

From the state space equation (3.11), the buck converter is single input system with constant coefficients.

3.4 Modeling of the Boost Converter

The boost converter outputs voltage is greater than the input voltage. The functional schematic of the boost converter is shown in Figure 3.3. The equivalent circuits of the boost converter, in accordance with the switch closures, are illustrated in Figure 3.4. As indicated in Figure 3.4a, the inductor is switched directly across the voltage source during the ON time (Q1 is turned ON). When the transistor (Q1) is opened and diode (D) is closed, as illustrated in Figure 3.4b, the inductor is load connected. With reference to Figure 3.4a when the transistor (Q1) is turned ON, application of KVL and KCL yield, respectively.

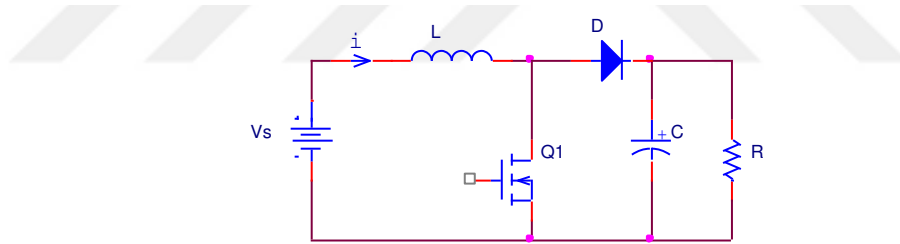


Figure 3.3 Boost converter circuit.

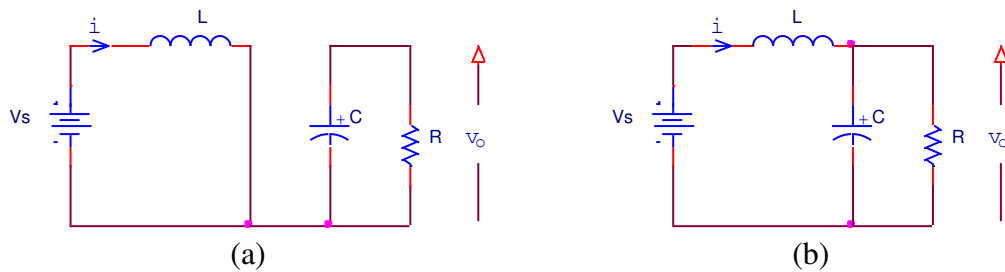


Figure 3.4 Equivalent circuits of the boost converter.

$$V_s = L \frac{di}{dt} \quad (3.12)$$

And

$$0 = C \frac{dv_o}{dt} + \frac{v_o}{R} \quad (3.13)$$

When the transistor (Q1) is turned OFF:

$$V_s = L \frac{di}{dt} + v_o \quad (3.14)$$

And

$$i = C \frac{dv_o}{dt} + \frac{v_o}{R} \quad (3.15)$$

The equations (3.12) and (3.14) are collected to gather by using binary switch (u) yields:

$$V_s = L \frac{di}{dt} - (1 - u)v_o \quad (3.16)$$

Where

$$u = PWM = \begin{cases} 1, & 0 \leq t \leq t_{on} \\ 0, & t_{on} \leq t \leq T \end{cases} \quad \begin{matrix} \text{(when Q1 is turend ON)} \\ \text{(when Q1 is turend OFF)} \end{matrix} \quad (3.17)$$

Also, the equations (3.13) and (3.15) are collected to gather by using binary switch (u) yields:

$$(1 - u)i = C \frac{dv_o}{dt} + \frac{v_o}{R} \quad (3.18)$$

By rearranging equations (3.16) and (3.18) respectively yield:

$$\frac{di}{dt} = \frac{1}{L}V_s - \frac{1}{L}v_o + \frac{1}{L}v_o u \quad (3.19)$$

$$\frac{dv_o}{dt} = \frac{1}{C}i - \frac{1}{RC}v_o - \frac{1}{C}iu \quad (3.20)$$

Equations (3.19) and (3.20) can be represented as the state space model of the boost converter:

$$\frac{d}{dt} \begin{bmatrix} i \\ v_o \end{bmatrix} = \begin{bmatrix} 0 & -\frac{1}{L} \\ \frac{1}{C} & -\frac{1}{RC} \end{bmatrix} \begin{bmatrix} i \\ v_o \end{bmatrix} + \begin{bmatrix} \frac{V_s}{L} & \frac{1}{L} \\ -\frac{i}{C} & 0 \end{bmatrix} \begin{bmatrix} u \\ V_s \end{bmatrix} \quad (3.21)$$

From the state space equation (3.21), the boost converter has two forcing functions.

3.5 Modeling of the Buck-Boost Converter

In order to produce positive output voltage less than or greater than the input voltage, a two stages of DC to DC converters are used for producing positive regulated output voltage. The buck and boost converters are collected together as shown in Figure 3.5 the first stage of DC to DC converter is buck converter while second stage of DC to DC converter is boost converter. The buck converter (first stage) is made as a source of the boost converter (second stage).

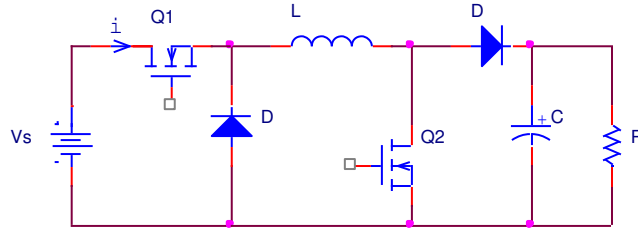


Figure 3.5 Buck-boost converter circuit.

For modeling buck-boost converter circuit, equations (3.11) and (3.21) are collected together using binary switch k .

Where

$$k = \begin{cases} 1, & \text{for buck operation} \\ 0, & \text{for boost operation} \end{cases} \quad (3.22)$$

Equations (3.9) and (3.19) are collected together using binary switch k yield:

$$\frac{di}{dt} = -\frac{1}{L}v_o + \frac{1}{L}V_s[(uk) + (1 - k)] + \frac{1}{L}v_o u(1 - k) \quad (3.23)$$

Also, Equations (3.10) and (3.20) are collected together using binary switch k yield:

$$\frac{dv_o}{dt} = \frac{1}{C}i - \frac{1}{RC}v_o - \frac{1}{C}iu_2(1 - k) \quad (3.24)$$

The above two equations (3.23) and (3.24) are solved using computer simulation program to simulate the buck and boost converter as shown in Figure 3.6. This Figure consists of one subsystem called U-subsystem. The internal construction of the U-subsystem is shown in Figure 3.7 U-subsystem is used to generate two signals PWM (u) signal and mode of operation signal (k). U-subsystem consists of two sawtooth waveform generators (sawtooth1 and sawtooth2). The sawtooth1 starts from 0V to 4V while sawtooth2 starts from 4V to 8V. Then the separator limit

between buck and boost mode of operation is 4V (Constant1). The two sawtooth signals are compared with a controlled signal (V_{set}) using two comparators (Relation Operator1 and Relation Operator2). The controlled signal (V_{set}) varies from 0V up to 8V.

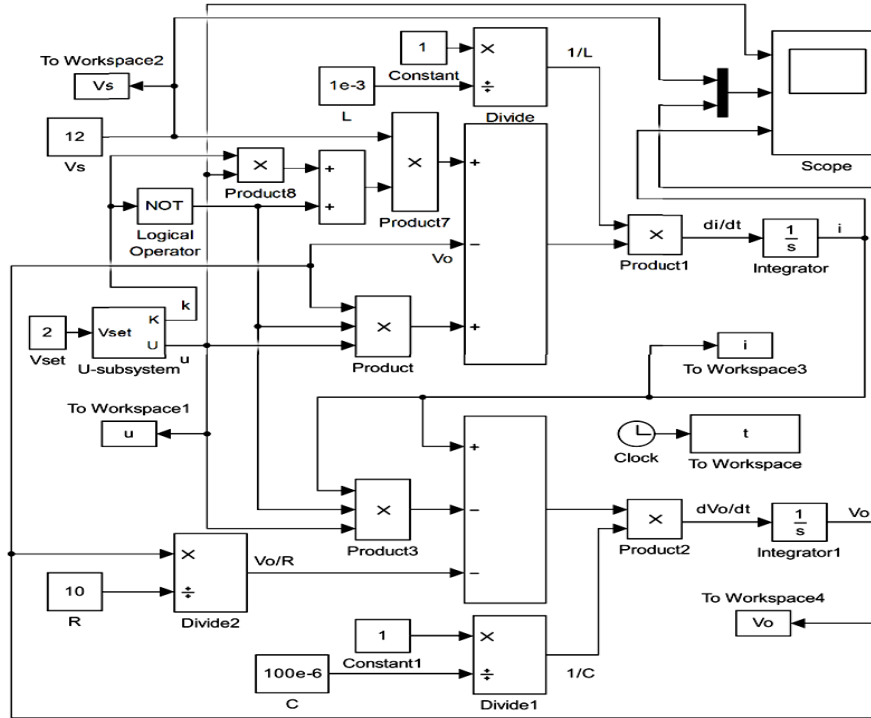


Figure 3.6 Computer simulation program model of the buck-boost converter using two equations (3.23) and (3.24).

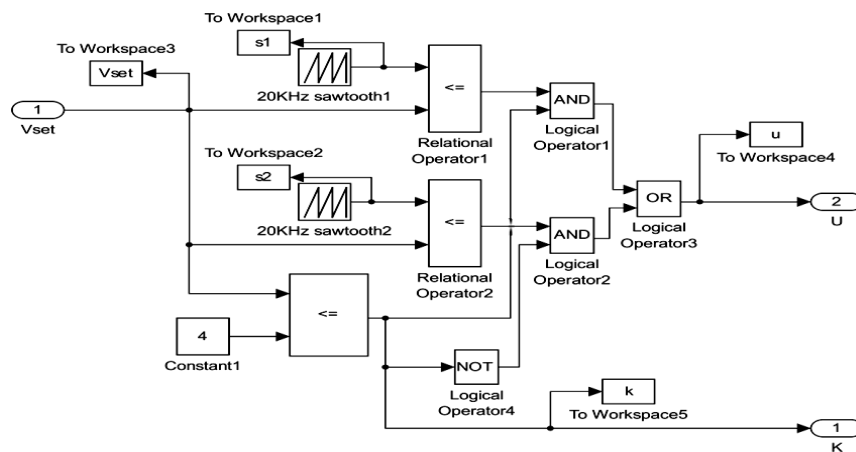


Figure 3.7 U-subsystem is used to generate two signals PWM (u) signal and mode of operation signal (k).

Figures 3.8 - 3.11 show how PWM signal (u) and the mode of operation signal (k) are generated from two sawtooth signals. The buck and boost operation states are determined by comparing two sawtooth signals with the controller voltage (V_{set}). In Figure 3.8, $V_{set}=1V$ which is within the range of the sawtooth1 signal fluctuates between 0 (minimum) and 4V (maximum). At this case, the $k=1$ and the system will operate at buck mode of operation while the output of the u signal is PWM with duty cycle=0.25. In Figure 3.9, $V_{set}=2V$ which is within the range of the sawtooth1 signal. At this case, the $k=1$ the system will operate at buck mode of operation while the output of the u signal is PWM with duty cycle=0.5. In Figure 3.10, $V_{set}=5V$ which is within the range of the sawtooth2 signal fluctuates between 4 (minimum) and 8V (maximum). At this case, the $k=0$ and the system will operate at boost mode of operation while the output of the u signal is PWM with duty cycle=0.25. In Figure 3.11, $V_{set}=6V$ which is within the range of the sawtooth2 signal. At this case, the $k=0$ and the system will operate at boost mode of operation while the output of the u signal is PWM with duty cycle=0.5.

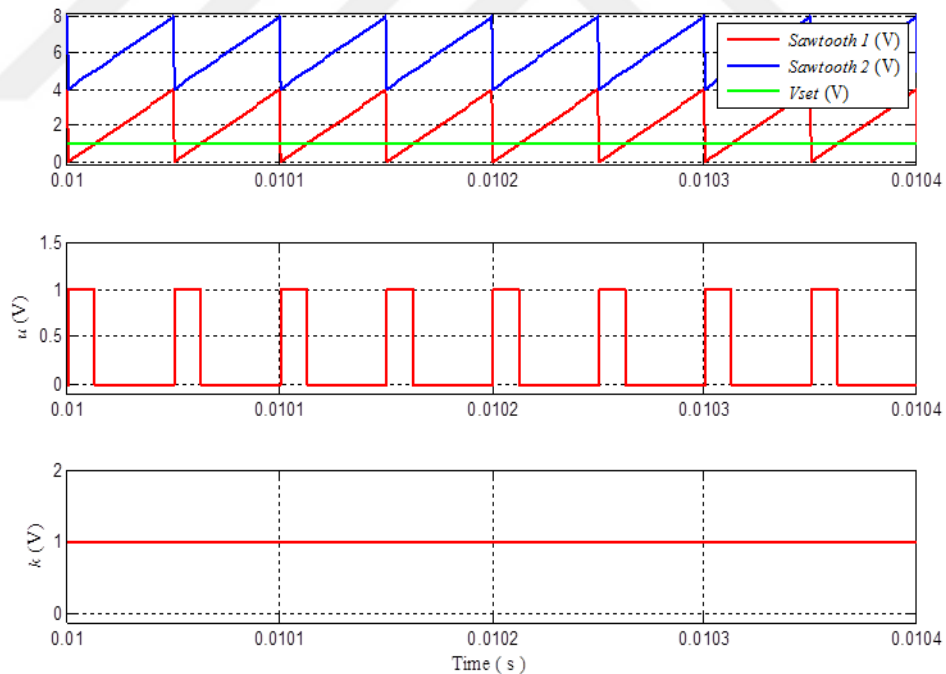


Figure 3.8 Generation of u signal (PWM) and k signal (buck of operation mode at 0.25 duty cycle and $k =1$).

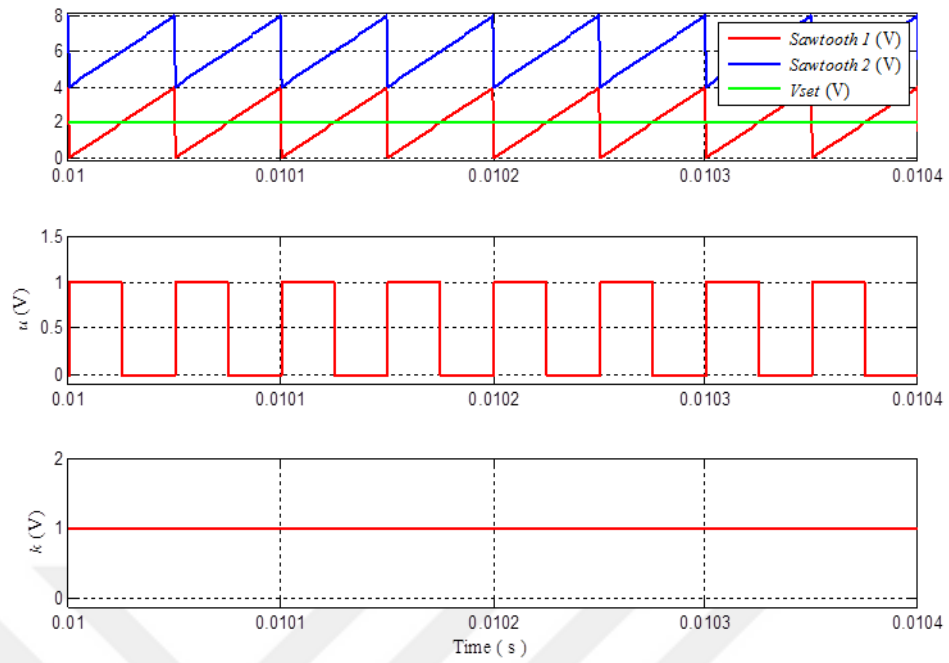


Figure 3.9 Generation of u signal (PWM) and k signal (buck of operation mode at 0.5 duty cycle and $k = 1$).

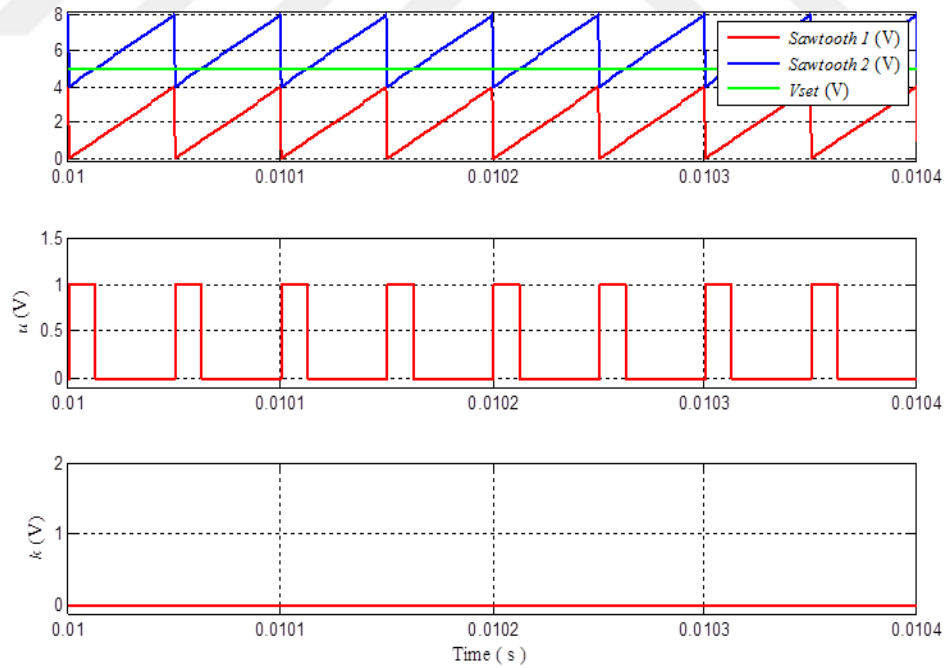


Figure 3.10 Generation of u signal (PWM) and k signal (boost of operation mode at 0.25 duty cycle and $k = 0$).

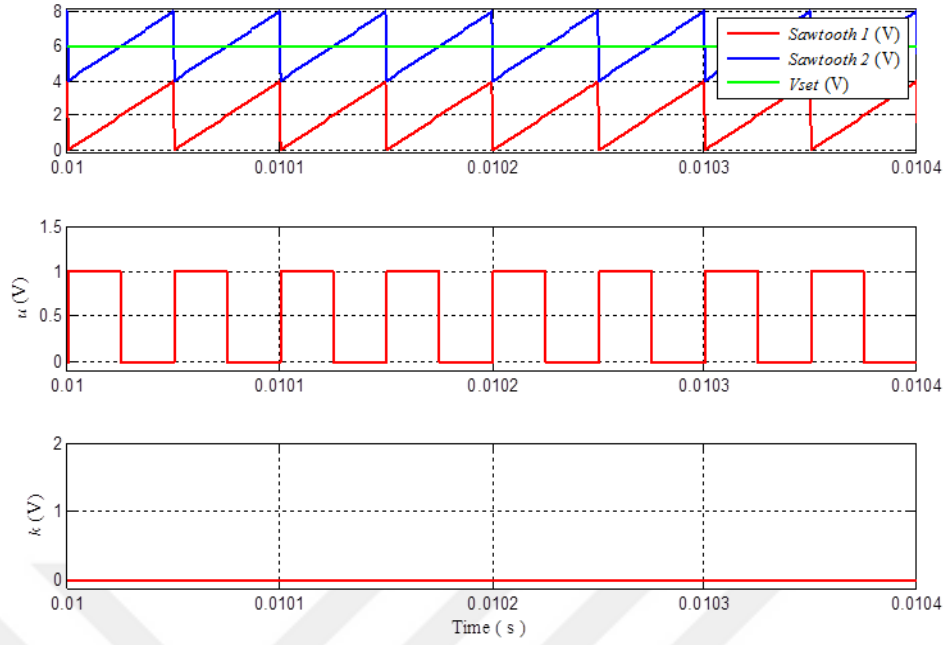


Figure 3.11 Generation of u signal (PWM) and k signal (boost of operation mode at 0.5 duty cycle and $k = 0$).

3.6 Simulation Results of the Buck-Boost Converter

The buck-boost converter is simulated relating to its behavior instead of using real transistor models. The mode of operation of the buck-boost converter follows the state of the mode of operation signal (k) while the output voltage of the converter follows the state of PWM (u) signal.

Figures 3.12 to 3.14 show the results of Simulink model for buck-boost converter at buck mode of operation. Figure 3.12 shows the results for PWM (u), input ($V_s = 12$) and output voltage ($v_o = 6$), and inductor current at $V_{set}=2$, $R=10\Omega$, $C=100\mu f$ and $L=1mH$ during 0.03second. Figure 3.12 shows that the inrush current reach up to 2A while the over voltage reach to 10V transient. Figure 3.13 shows the zooming of Figure 3.12 from 0 to 1ms while Figure 3.14 shows the zooming of Figure 3.12 from 0.01s to 0.0105s.

Figures 3.15 to 3.17 show the results of Simulink model for buck-boost converter at buck mode of operation. Figure 3.15 shows the results for PWM (u), input ($V_s = 12$) and output voltage ($v_o = 6$), and inductor current at $V_{set}=2$, $R=10\Omega$, $C=10\mu f$ and $L=1mH$ during 0.03second. Figure 3.15 shows that the inrush current reach up to

0.8A while the over voltage reach to 7V transient. Figure 3.16 shows the zooming of Figure 3.15 from 0 to 1ms while Figure 3.17 shows the zooming of Figure 3.15 from 0.01s to 0.0105s.

Figure 3.18 to 3.20 show the results of Simulink model for buck-boost converter at boost mode of operation. Figure 3.18 shows the results for PWM (u), input ($V_S = 12$) and output voltage ($v_o = 24$), and inductor current at $V_{set}=6$, $R=10\Omega$, $C=100\mu f$ and $L=1mH$ during 0.03second. Figure 3.18 shows that the inrush current reach up to 8A while the over voltage reach to 31V transient. Figure 3.19 shows the zooming of Figure 3.18 from 0 to 1ms while Figure 3.20 shows the zooming of Figure 3.18 from 0.01s to 0.0105s.

Figures 3.21 to 3.23 show the results of Simulink model for buck-boost converter at boost mode of operation. Figure 3.21 shows the results for PWM (u), input ($V_S = 12$) and output voltage ($v_o = 24$), and inductor current at $V_{set}=6$, $R=10\Omega$, $C=10\mu f$ and $L=1mH$ during 0.03second. Figure 3.21 shows that the inrush current reach up to 5A while the over voltage 28V transient with high ripple output voltage. Figure 3.22 shows the zooming of Figure 3.21 from 0 to 1ms while Figure 3.23 shows the zooming of Figure 3.21 from 0.01s to 0.0105s. The simulation results help for choosing the appropriate components such as power transistor, diode, inductor and output capacitor.

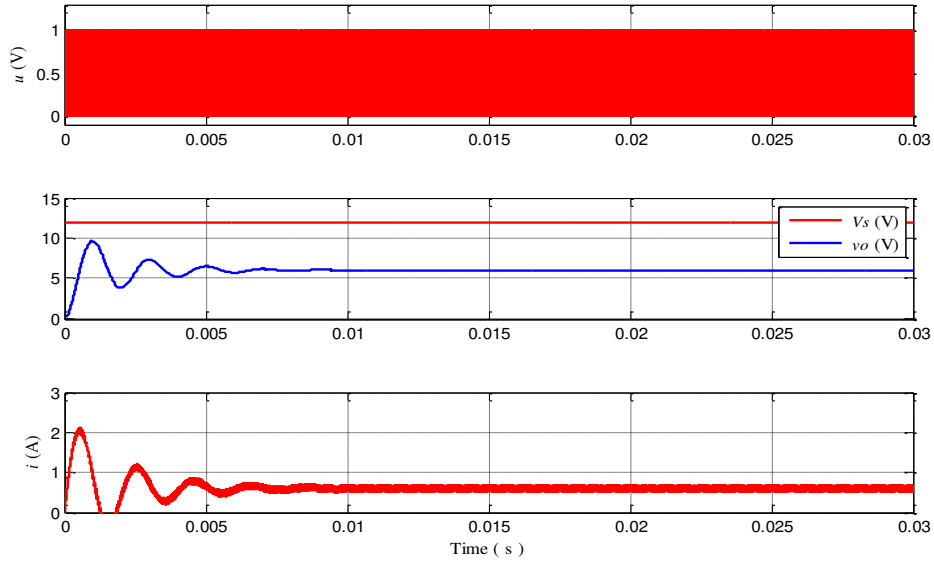


Figure 3.12 Simulation results for PWM (u), input ($V_s = 12$) and output voltage ($v_o = 6$), and inductor current at $V_{set}=2$, $R=10\Omega$, $C=100\mu f$ and $L=1mH$ during 0.03second.

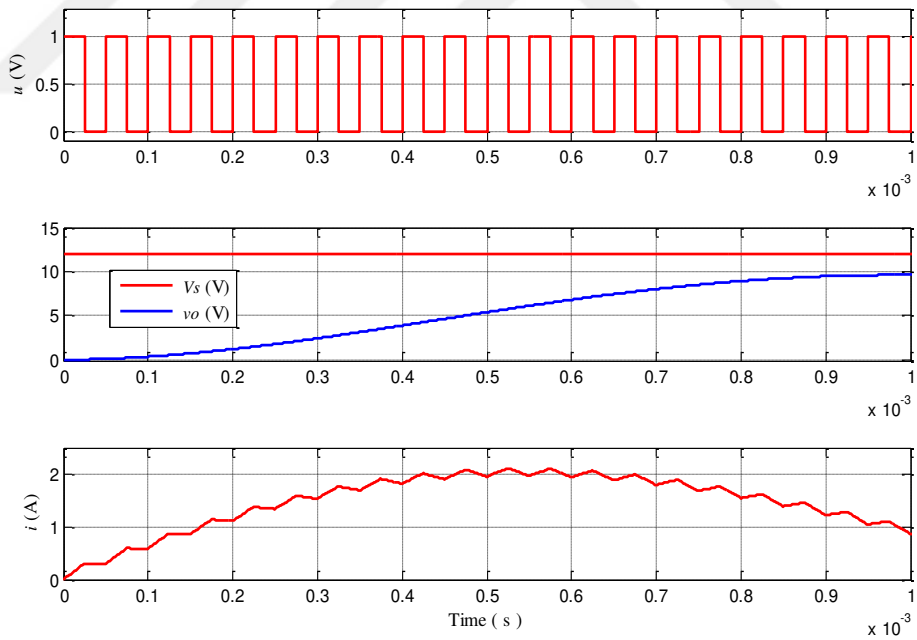


Figure 3.13 Simulation results for PWM (u), input ($V_s = 12$) and output voltage (v_o), and inductor current at $V_{set}=2$, $R=10\Omega$, $C=100\mu f$ and $L=1mH$ from 0 to 1ms.

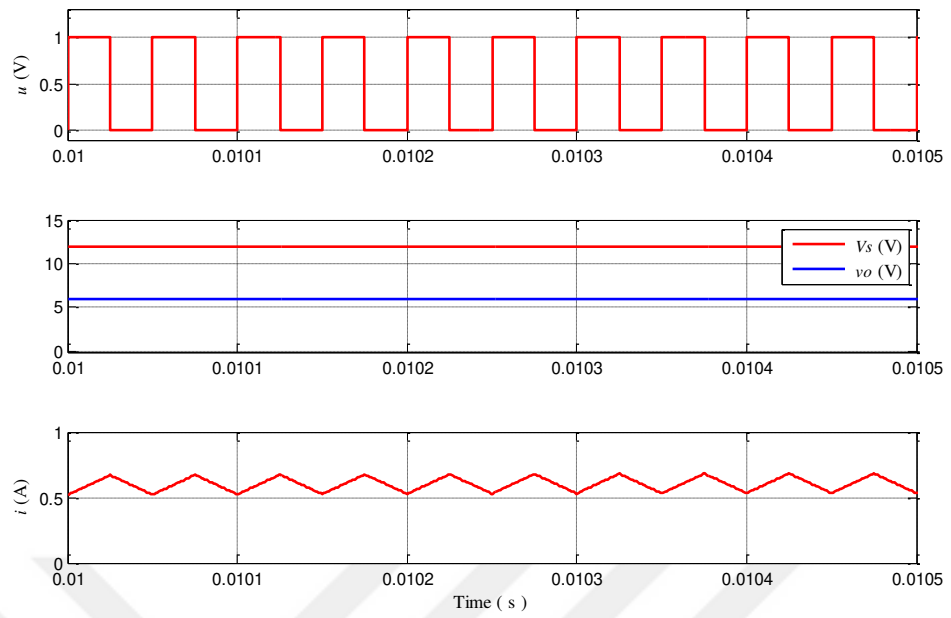


Figure 3.14 Simulation results for PWM (u), input ($V_S = 12$) and output voltage (v_o), and inductor current at $V_{set}=2$, $R=10\Omega$, $C=100\mu f$ and $L=1mH$ from 0.01s to 0.0105s.

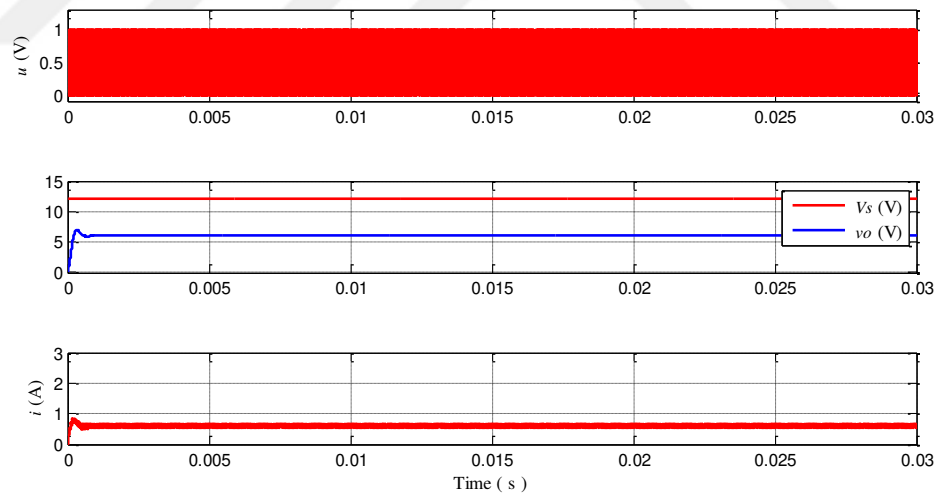


Figure 3.15 Simulation results for PWM (u), input ($V_S = 12$) and output voltage ($v_o = 6$), and inductor current at $V_{set}=2$, $R=10\Omega$, $C=10\mu f$ and $L=1mH$ during 0.03second.

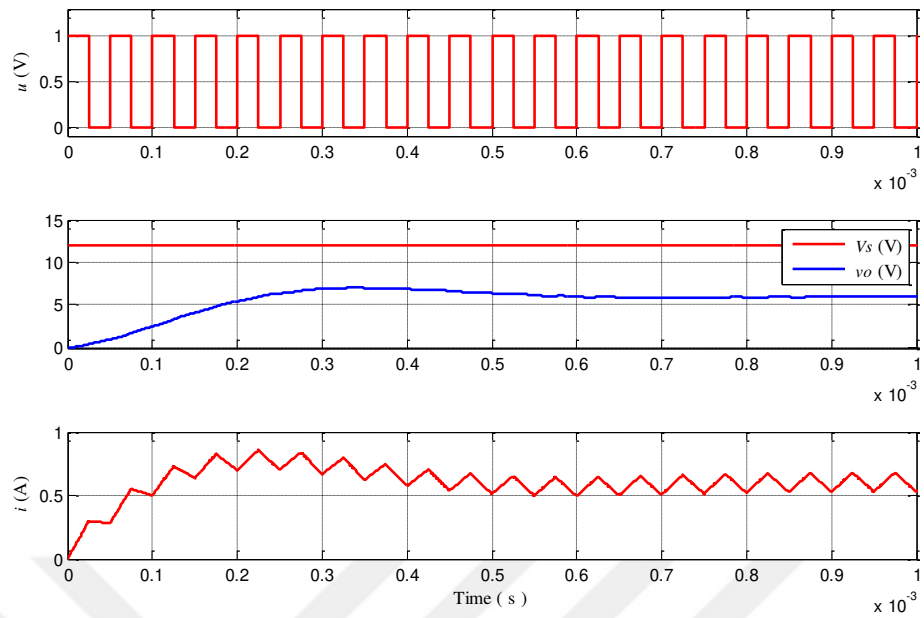


Figure 3.16 Simulation results for PWM (u), input ($V_s = 12$) and output voltage (v_o), and inductor current at $V_{set}=2$, $R=10\Omega$, $C=10\mu f$ and $L=1mH$ from 0 to 1ms.

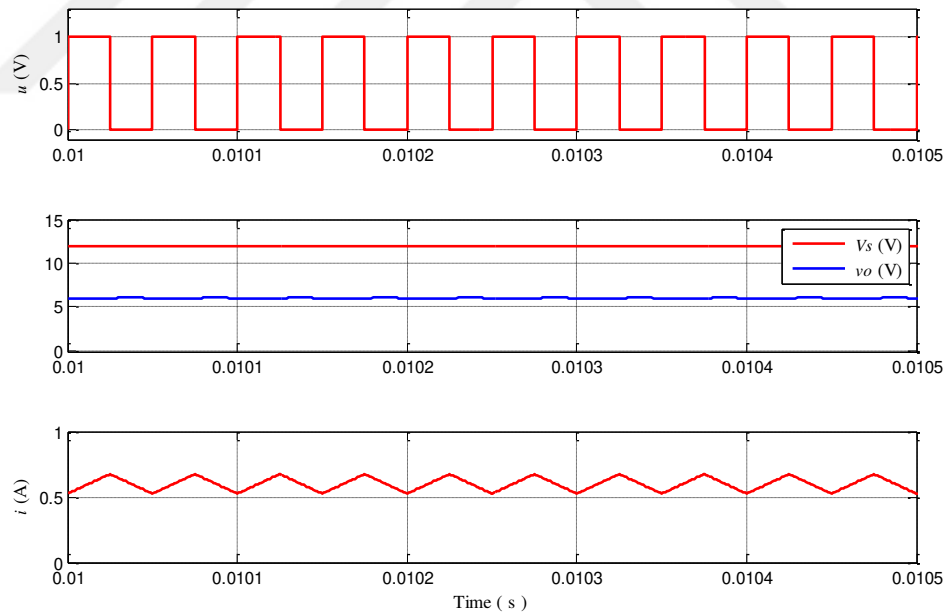


Figure 3.17 Simulation results for PWM (u), input ($V_s = 12$) and output voltage (v_o), and inductor current at $V_{set}=2$, $R=10\Omega$, $C=10\mu f$ and $L=1mH$ from 0.01s to 0.0105s.

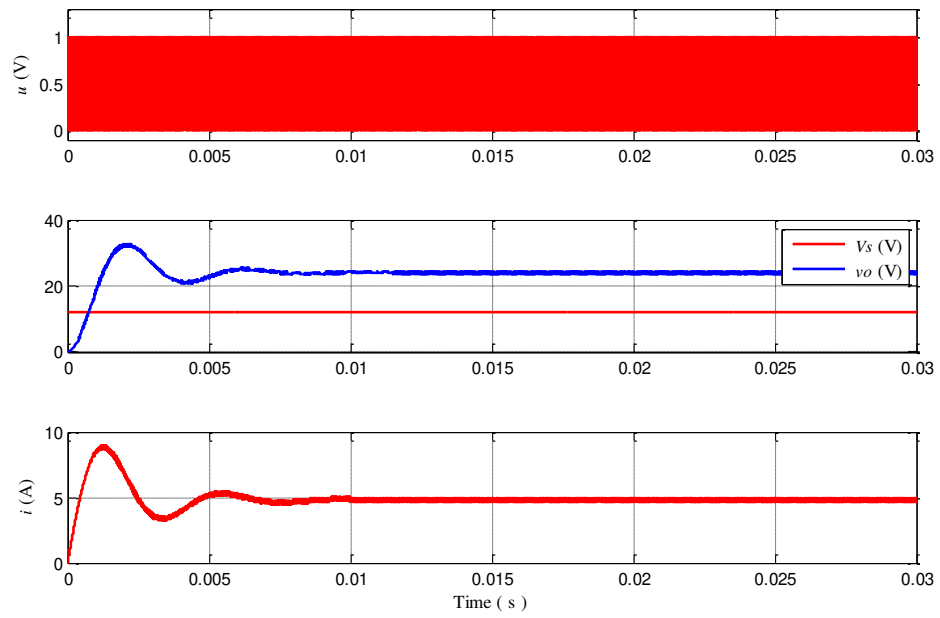


Figure 3.18 Simulation results for PWM (u), input ($V_s = 12$) and output voltage ($v_o = 24$), and inductor current at $V_{set}=6$, $R=10\Omega$, $C=100\mu f$ and $L=1mH$ during 0.03second.

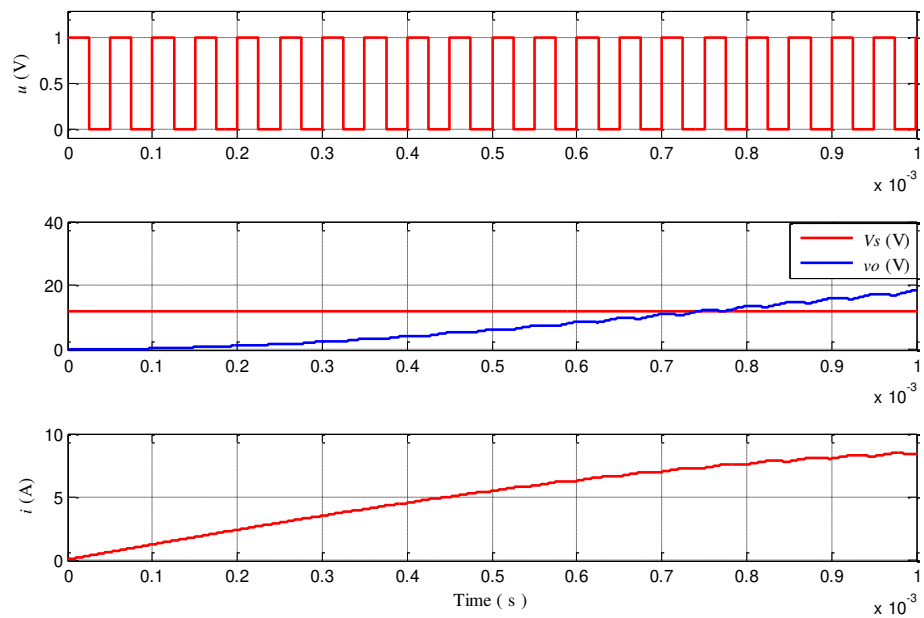


Figure 3.19 Simulation results for PWM (u), input ($V_s = 12$) and output voltage (v_o), and inductor current at $V_{set}=6$, $R=10\Omega$, $C=100\mu f$ and $L=1mH$ from 0 to 1ms.

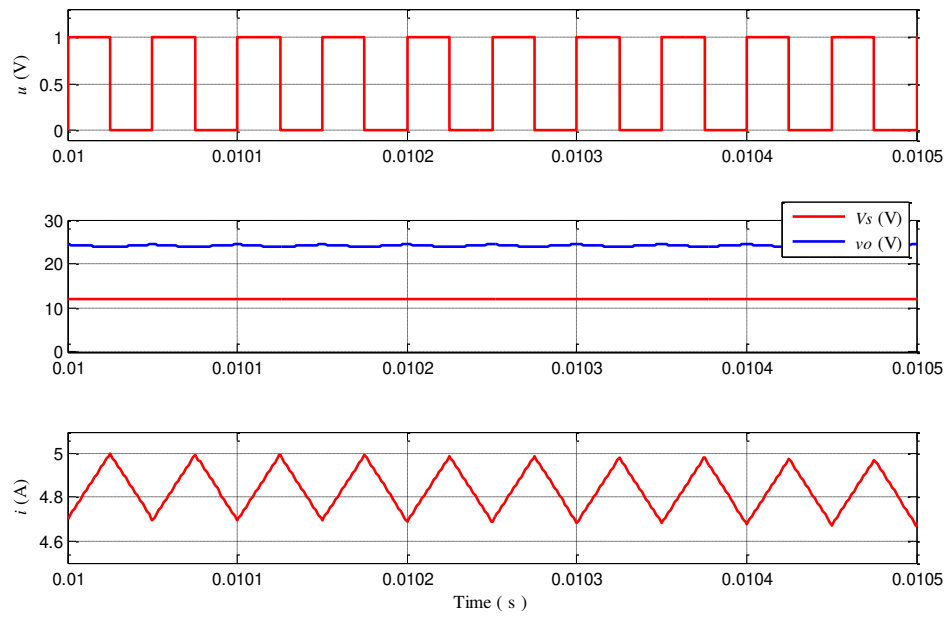


Figure 3.20 Simulation results for PWM (u), input ($V_s = 12$) and output voltage (v_o), and inductor current at $V_{set}=6$, $R=10\Omega$, $C=100\mu f$ and $L=1mH$ from 0.01s to 0.0105s.

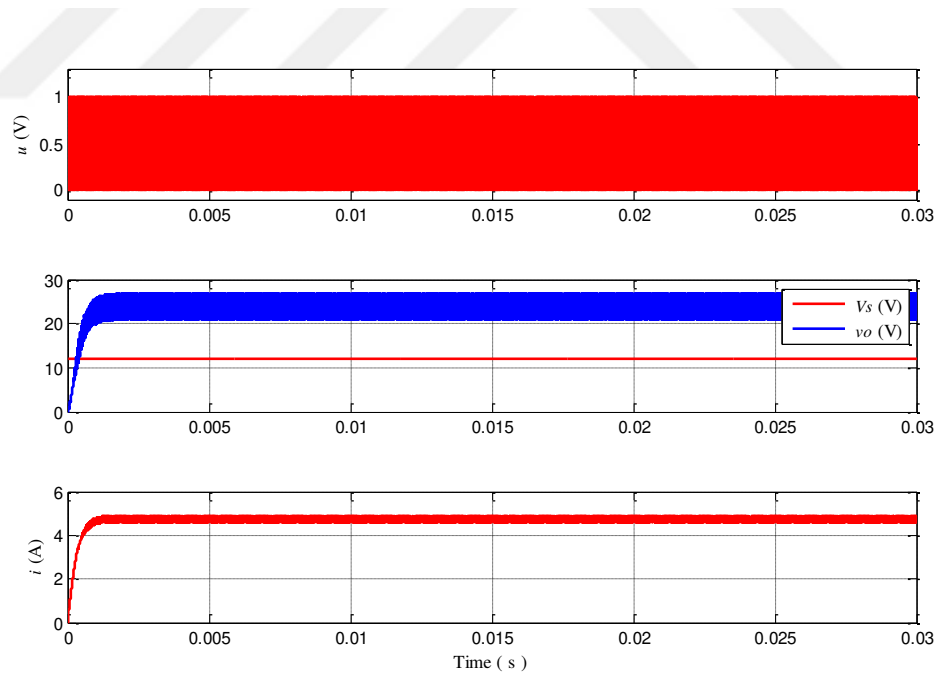


Figure 3.21 Simulation results for PWM (u), input ($V_s = 12$) and output voltage (v_o), and inductor current at $V_{set}=6$, $R=10\Omega$, $C=10\mu f$ and $L=1mH$ during 0.03second.

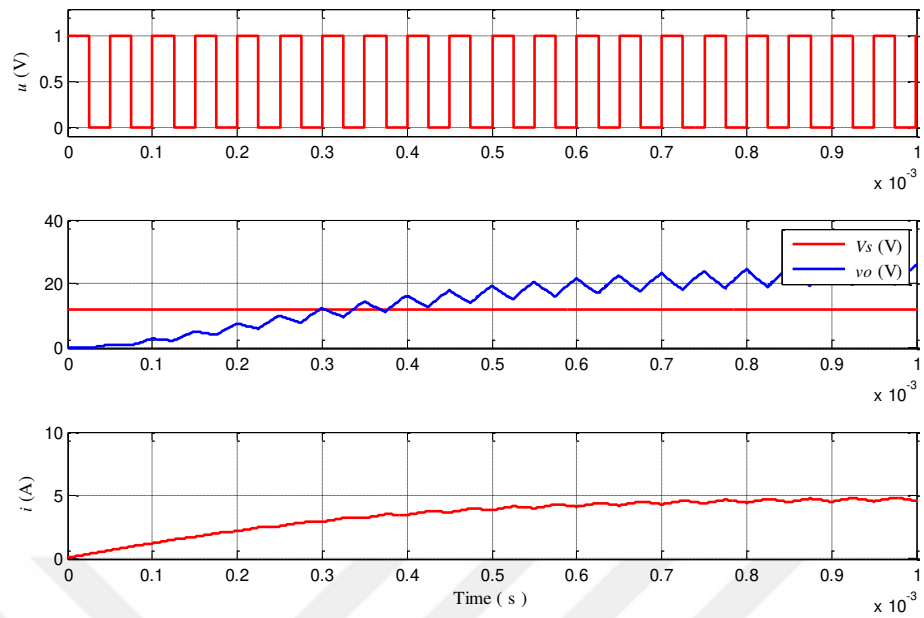


Figure 3.22 Simulation results for PWM (u), input ($V_s = 12$) and output voltage (v_o), and inductor current at $V_{set}=6$, $R=10\Omega$, $C=10\mu f$ and $L=1mH$ from 0 to 1ms.

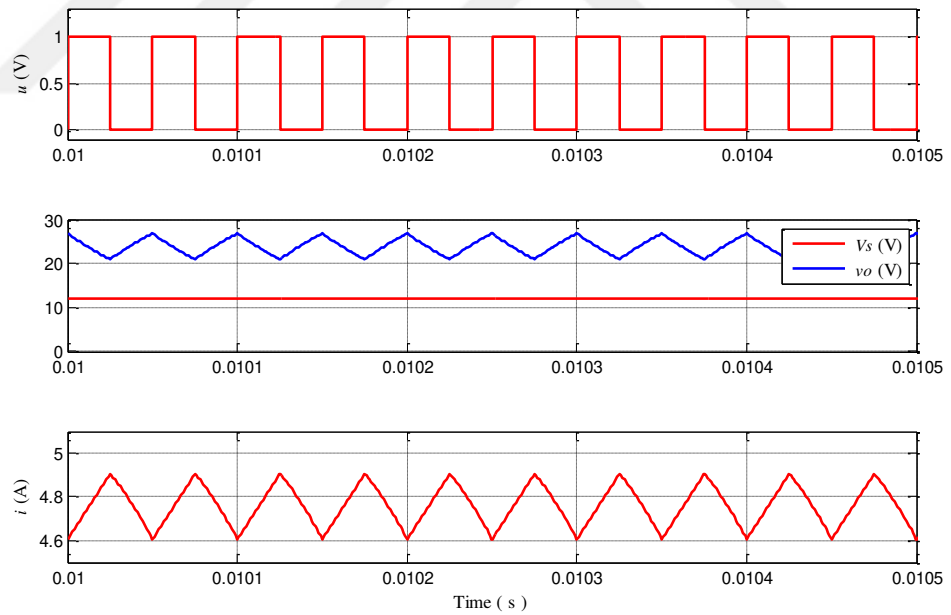


Figure 3.23 Simulation results for PWM (u), input ($V_s = 12$) and output voltage (v_o), and inductor current at $V_{set}=6$, $R=10\Omega$, $C=10\mu f$ and $L=1mH$ from 0.01s to 0.0105s.

CHAPTER 4

GENERATE PWM FOR THE BUCK-BOOST CONVERTER USING PIC18F4550 MICROCONTROLLER

4.1 Introduction

Two stages of DC to DC converters are used for producing positive regulated output voltage. The first stage of DC to DC converter is buck converter while second stage of DC to DC converter is boost converter. The buck converter (first stage) is made as a source of the boost converter (second stage). To generate the PWM signals for the two stages, a PIC 18F4550 microcontroller is used to control these two stages. The PIC 18F4550 microcontroller must be programmed such as the buck converter operates in buck mode when the output voltage needs to be less than the input voltage while the boost converter is made in OFF state. When the output voltage needs to be greater than the input voltage, the PIC 18F4550 microcontroller must be programmed such as the boost converter operates in boost mode while the buck converter is made in ON state.

4.2 Double Stages Buck-Boost Converter

Block diagram of double stages buck and boost converters based on PIC18F4550 is shown in Figure 4.1. Whole system can be divided into four blocks. First block is concerned with the conversion of two signals one of them is incoming signal from output voltage (feedback voltage (FB)) while the other is reference voltage (V_{ref}) into the PIC18F4550 level voltage (5V). The second block is concerned with conversion of the analog to digital signal, as well as processe the digital signal to produce two PWM signals (PWM0 (G1) and PWM1 (G2)). This is done by using PIC18F4550 microcontroller.

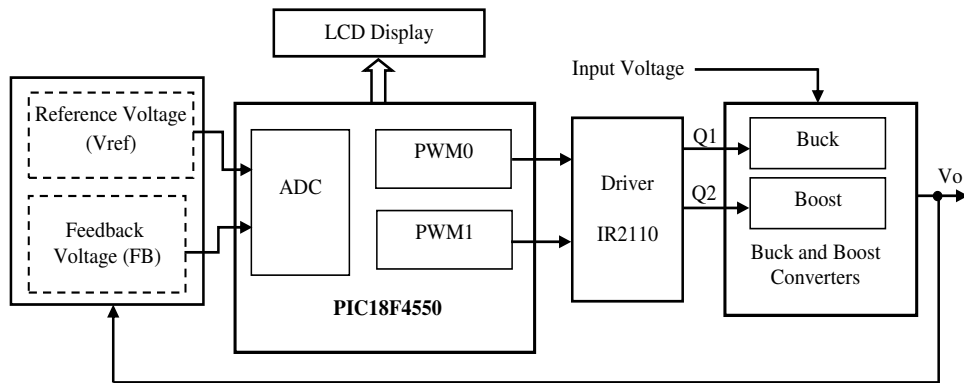


Figure 4.1 Block diagram of buck-boost converter based on PIC18F4550.

The analog voltages (V_{ref} and FB) are continuously displayed on LCD. Third block is driver which amplified the PWMs signals coming from PIC18F4550 to drive two MOSFET transistors. The fourth block is the power stages (buck and boost converters) which receives the input voltage and produces output voltage (V_o) according to the two signals coming from driver (IR2110).

4.3 PIC 18F4550 microcontroller

PIC18F4550 microcontroller is a type of microcontroller produced by the Microchip. The pin diagram of PIC18F4550 is shown in Figure 4.2 while the block diagram of PIC18F4550 is shown in Figure 4.3 [24].

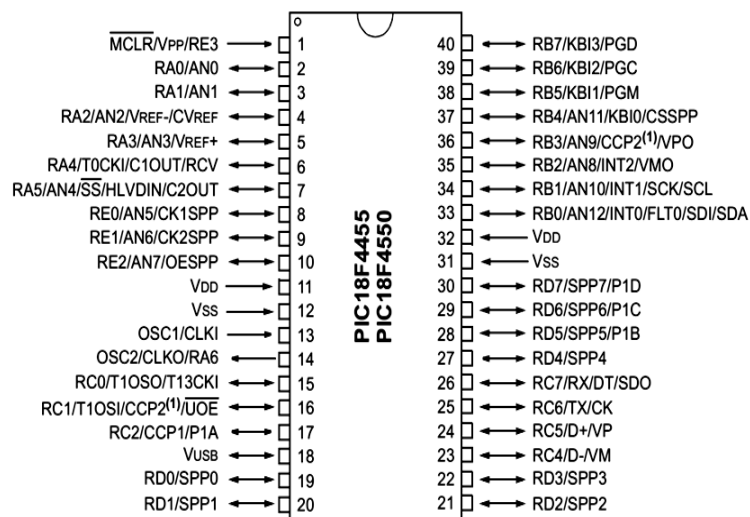


Figure 4.2 Pin diagram of PIC18F4550.

PIC18F4550 has the following features [24,25]:

- 40 pin with 5 I/O ports. Ports A, B, C and D are 8bit while port E 4bit.
- Operating frequency range DC – 48 MHz.
- Program memory: 32768 Bytes, RAM: 2048 Bytes and data EEPROM memory 256 Bytes.
- Two output modules of PWM.
- Number of timers: 4(TMR0 with 8-bit or 16-bit modes, TMR1 with 16-bit readable and writable 8-bit registers (TMR1H and TMR1L), TMR2 with 8-bit, and TMR3 with 16-bit readable and writable 8-bit registers (TMR3H and TMR3L)).
- A/D Converter: 13 channel with 10 Bit.

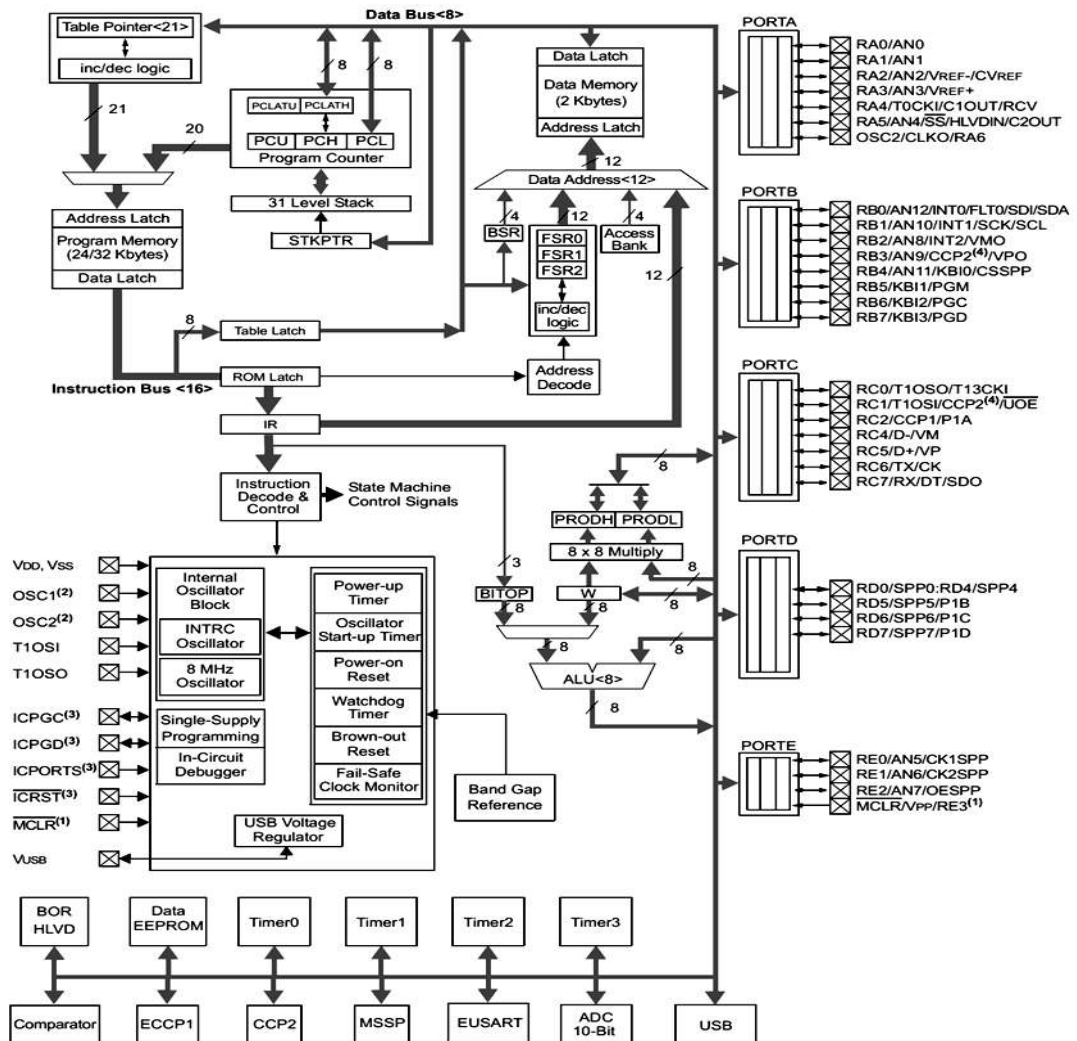


Figure 4.3 PIC18F4550 (40-pin) block diagram

4.4 Generate PWM signal using PIC 18F4550 microcontroller

The general way to generate a PWM signal is by comparing a sawtooth waveform with a fixed DC voltage level as shown below in Figure 4.4 in this mode. If the waveform value is greater than the DC compare level then the output is set high, or else the output is low. The duty cycle of a PWM Waveform is given by:

$$duty\ cycle = \frac{T_{on}}{T_{on} + T_{off}} \times 100\% \quad (4.1)$$

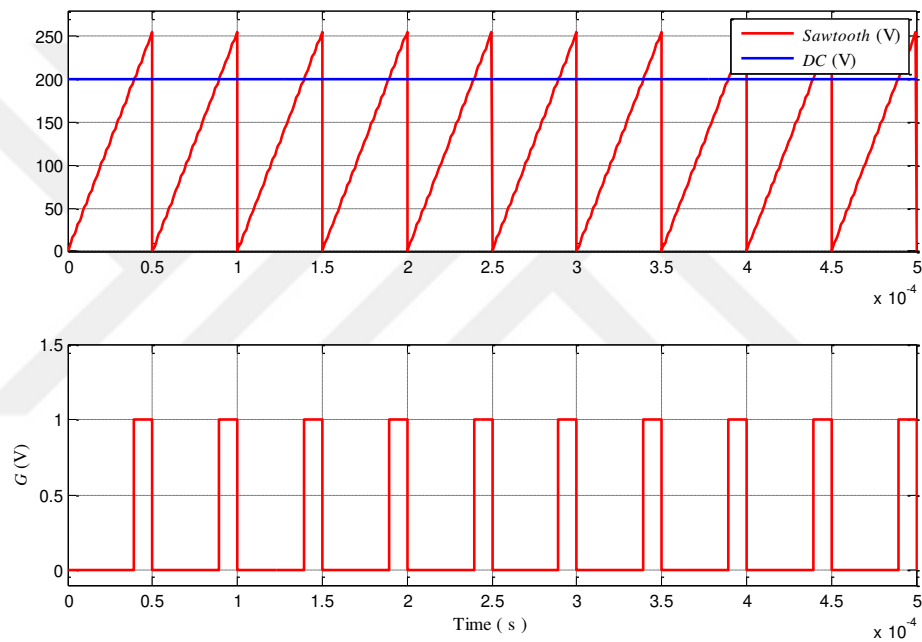


Figure 4.4 Generate PWM signals.

PIC18F4550 microcontroller has two CCP (Capture/Compare/PWM) modules. Each module contains a 16-bit register, which can operate as a 16-bit Capture register, a 16-bit Compare register or a PWM duty cycle register. The two standard CCPx modules (CCP1 and CCP2) operate as PWM modes. Each PWM module is associated with a control register (CCPxCON) and a data register (CCPRx). The data register is comprised of two 8-bit registers: CCPRxL (low byte) and CCPRxH (high byte). Figure 4.5 shows a block diagram of the CCPx module in PWM mode.

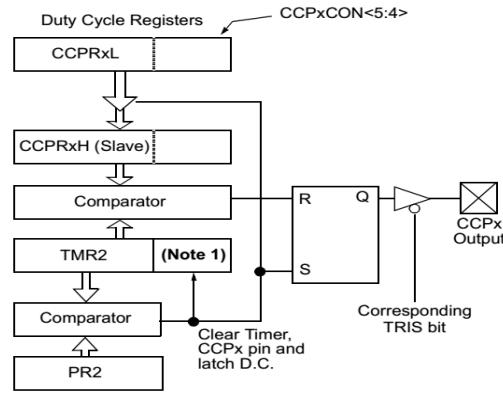


Figure 4.5 Block diagram of the CCP module in PWM mode.

In the figure 4.5, PR2 register is used to set the period of the PWM, CCPRxL register and CCPxCON is used to set the duty cycle of the PWM. In 8-bit counter, TMR2 register operates as up counter from 0 to 255 (operates as a sawtooth waveform) and CCPRxL register operated as a fixed DC voltage level. When the counter is less than the set of the PWM value, the pin outputs of the CCPx is a HIGH; when the counter is greater than the set PWM value, the pin outputs the CCPx is a LOW. The A PWM output in Figure 4.6 has a time base (period) and a time that the output stays high (duty cycle). The frequency of the PWM is the inverse of the period (1/period).

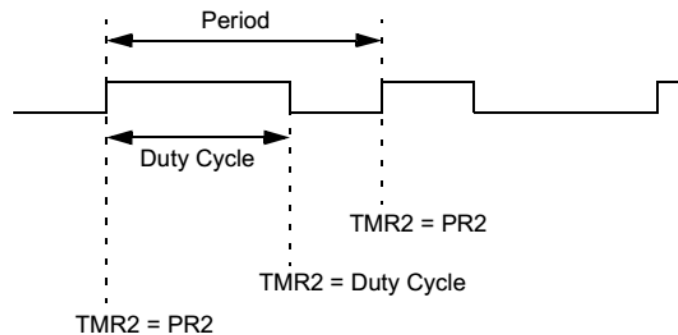


Figure 4.6 PWM output using PR2 and TMR2 registers.

The PWM period is specified by writing to the PR2 register. The PWM period can be calculated using the following formula [24]:

$$PWM \text{ Period} = [(PR2) + 1] \times 4 \times T_{osc} \times (TMR2 \text{ Prescale Value}) \quad (4.2)$$

Where PR2 is a timer2 Period Register, T_{osc} is the period of the clock source frequency. PWM frequency is defined as:

$$PWM\ frequency = \frac{1}{PWM\ Period} \quad (4.3)$$

In buck-boost converter design, the frequency of the PWM is designed to be 20 kHz. Therefore, the PWM Period = $1/20\text{kHz} = 50\mu\text{s}$. In this design, an external crystal XTAL of 48 MHz is chosen which represents the clock source frequency. Then period of the clock source frequency is $T_{osc} = 1/48\text{MHz}$. According to the datasheet of PIC18F4550 there are only three values for 2 Prescale Value . These are 1, 4, and 6. In this design, the TMR2 Prescale Value is set to be 4.

Using equation (4.2) to calculate the value of PR2 register:

$$PR2 = \frac{50\mu\text{s}}{4 \times (1/48\text{MHz}) \times 4} - 1 = 149$$

When TMR2 is equal to PR2, the following events occur on the next increment cycle:

- TMR2 register is cleared
- The CCPx pin (CCP1 or CCP2) is set.

Because PIC18F4550 microcontroller has two output modules of PWM, this will help to control the two transistors (Q1 and Q2), one for the buck and the second for the boost converters. The microcontroller (PIC18F4550) is programmed using flowcode to operate at 20 kHz output frequency and has the capability to control both buck and boost converters to regulate the output voltage according to the input voltage and the load variation.

The two output signals of PIC18F4550 (PWM0 and PWM1) have low current drive. Therefore IR2010 is used for achieving the requirements of MOSFET gate drive. The driver IR2010 has the capability to drive high and low side switches with maximum output current reach up to 2A.

4.5 Strategy of Working PIC18F4550 Microcontroller

At starting, PIC18F4550 microcontroller is designed to operate as soft start to prevent inrush current such that the transistor (Q2) turned OFF while the transistor (Q1) is driven using PWM0 (G1) signal with duty cycle starting from zero and increasing up to desired output voltage (if the output less than input voltage).

If the output needs to be greater than input voltage, the soft start begins such that the transistor (Q2) turned OFF while the transistor (Q1) is driven using PWM0 (G1) signal with duty cycle starting from zero and increasing up to 100%. At 100% duty cycle of PWM0 (G1) signal, the transistor (Q1) is turned ON all the time while the transistor (Q2) is drove using PWM1 (G2) signal with duty cycle starting from zero and increasing up to desired output voltage. The PWM1 (G2) signal is designed such that to make the maximum duty cycle 50% in order to prevent saturation in inductor (L1).

4.6 Flowcode for Programming PIC18F4550 Microcontroller

Many languages and programs are used for writing and programming the microcontroller such as: 1) low level language (Assembly language), 2) high level language such as BASIC, FORTRAN, PASCAL, C, Mikro C, Mikro BASIC, MPLAB and advanced graphical programming languages such as Flowcode.

Flowcode is a program which is designed to simplify those new to microcontroller programming to design complex program with little information of other programming languages. It depends on drag and drop flowchart symbols onto the window of PC. The flowchart symbols contains dialog box. The dialog box must be filling when prompted. Then Flowcode compiles the flow chart into HEX code. Picflash programmer is used for downloading the HEX code into the microcontroller (PIC18F4550) which executes the program. Figures 4.7 to 4.12 represent the flowcharts written in Flowcode for programming the microcontroller (PIC18F4550) to generate two PWM signals (PWM0 and PWM1) for driving the power stage of the buck and boost converters. Figure 4.7 represents the main program of Flowcode to program PIC18F4550 microcontroller which contains the following flowchart symbols:

- 1- Call component micro for the following operations: a) starting LCD display, b) enabling PWM0, d) enabling PWM1, e) setting zero duty cycle for PWM0 and f) setting zero duty cycle for PWM1.
- 2- Setting variables for the following operations:
 - a- Variable (i) is used as counter used for the duty cycle of PWM0. This variable (i) is used for making the duty cycle of PWM0 increasing step by step to make transistor (Q1) operates as buck soft starting.

- b- Variable (j) is used as counter used for the duty cycle of PWM1. This variable (j) is used for making the duty cycle of PWM1 increasing step by step to make transistor (Q2) operates as boost soft starting.
 - c- Variable (a) represents the maximum of the period register of PWM0 and PWM1.
 - d- Variable (b) represents the half of the period register of PWM1.
 - e- Variables (Vref and FB) represent the two analogue input signals for ADC0 and ADC1 of PIC18F4550.
- 3- Interrupt which is used for enabling the timer interrupt 0 (TMR0). The TMR0 is set such as an interrupt subroutine (INT00) is called every 23437.5Hz.
 - 4- Loop for printing the results on LCD which contains the following operations:
 - a- Call component macro for specifying the printing location.
 - b- Call component macro for printing string.
 - c- Call component macro for printing number.

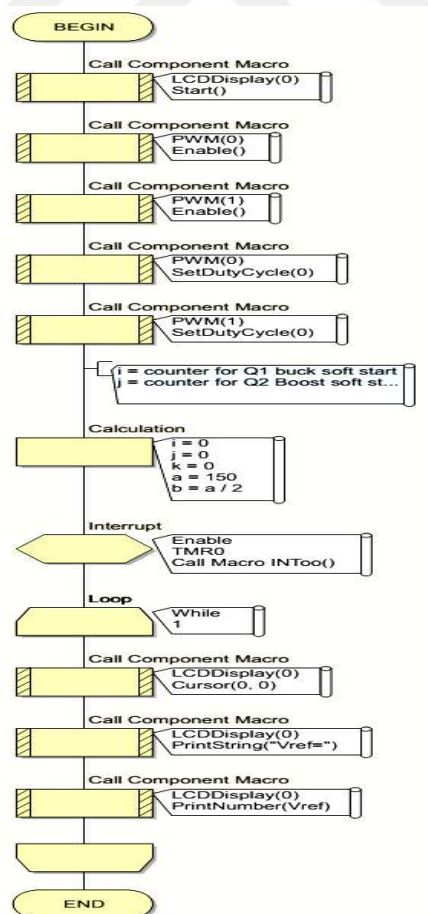


Figure 4.7 Main program using Flowcode to program PIC18F4550 microcontroller.

Figure 4.8 represents the interrupt subroutine for (INT0) using timer interrupt 0 (TMR0). This subroutine contains the following flowchart symbols:

- 1- Call component micro for reading analogue signal at ADC0 and storing data in variable (FB). Where FB is the feedback of the output voltage.
- 2- Call component micro for reading analogue signal at ADC1 and storing data in variable (Vref). Where Vref is the reference voltage.
- 3- Four (IF) statements and four subroutine (Cond0, Cond1, Cond2 and Cond3).
- 4- Call component micro for setting the duty cycle of PWM0.
- 5- Call component micro for setting the duty cycle of PWM1.

Figures 4.9 to 4.12 represent the subroutines for Cond0, Cond1, Cond2 and Cond3 respectively.

According to the first IF statement ($V_{ref} < 127 \ \&\& \ FB < V_{ref}$), if the answer is yes, the Cond0 subroutine is called as shown in Figure 4.9 This subroutine makes variable (i) increase step by step from zero up to 150 which makes the duty cycle (PWM0) of Q1 increase step by step also to smoothly increase the output voltage from zero up to desired output voltage. During this time, variable (j) is set to be zero to make the duty cycle of Q2 (PWM1) zero also, which makes Q2 in OFF state. This condition make converter operates as buck converter.

According to the second IF statement ($V_{ref} > 127 \ \&\& \ FB < V_{ref}$), if the answer is yes, the Cond1 subroutine is called as shown in Figure 4.10. This subroutine makes variable (i) increases step by step which makes the duty cycle of Q1 (PWM0) increases step by step also until $i = 150$ which makes Q1 in ON state. After that time, variable (j) is set to be increasing step by step (up to 75 which equals to 50% duty cycle) which makes the duty cycle of Q2 (PWM1) increases step by step also. This condition make converter operates at starting as buck converter and at the end as boost converter. This method helps to reduce the inrush current.

According to the third IF statement ($V_{ref} < 127 \ \&\& \ FB > V_{ref}$), if the answer is yes, the Cond2 subroutine is called as shown in Figure 4.11. This subroutine calculates the difference between two signals (FB and Vref). The difference between two signals (FB and Vref) is subtracted from variable (i) and stored in variable (i) which makes the variable (i) decrease which makes the duty cycle of Q1 (PWM0) decrease. During this time, variable (j) is set to be zero to make the duty cycle of Q2 (PWM1) zero

also, which makes Q2 in OFF state. This condition make converter operates as buck converter with regulated process.

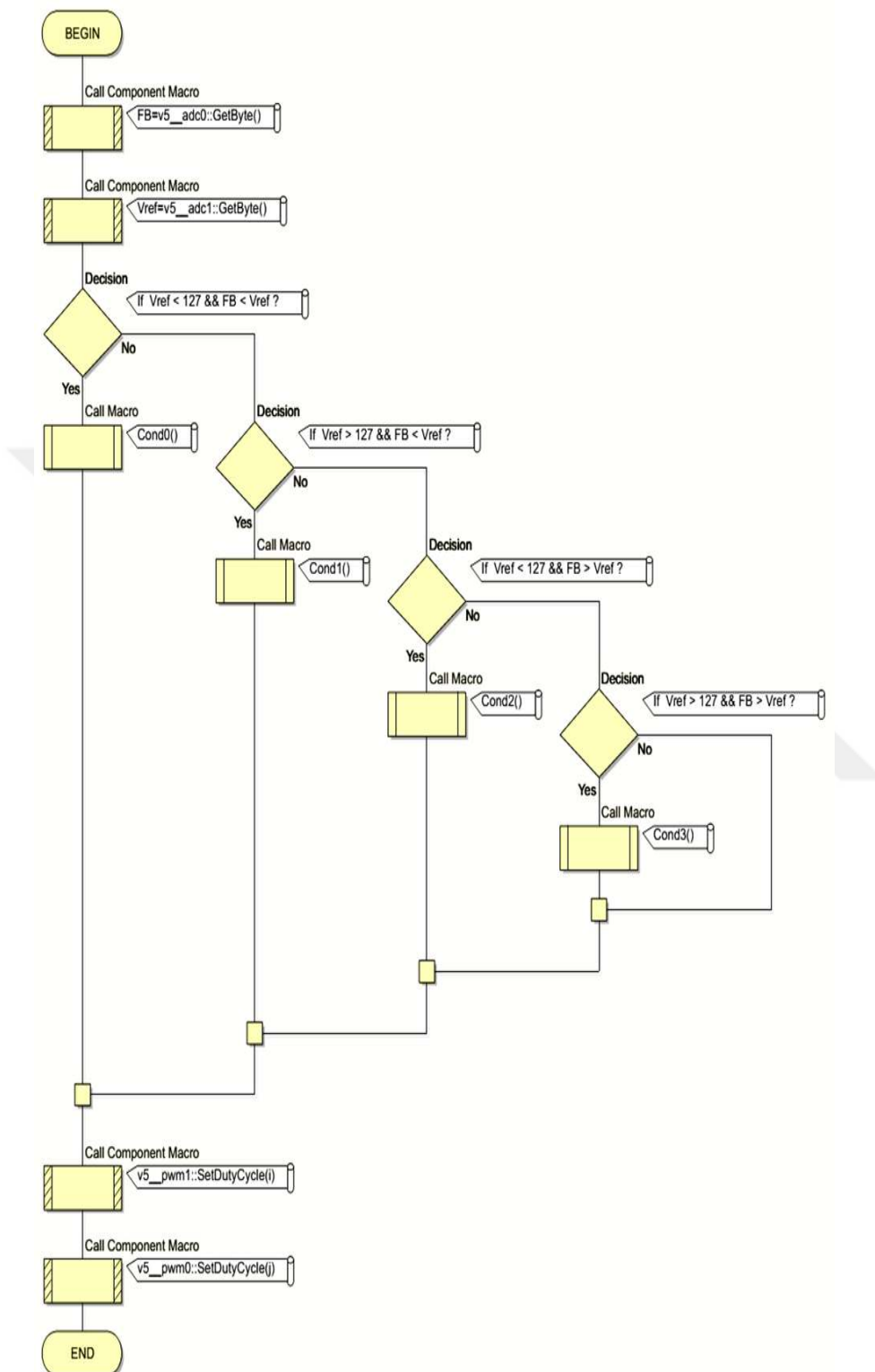


Figure 4.8 Interrupt subroutine for (INT0) using timer interrupt 0 (TMR0).

According to the fourth IF statement ($V_{ref} > 127 \ \&\& \ FB > V_{ref}$), if the answer is yes, the Cond3 subroutine is called as shown in Figure 4.12 This subroutine calculates the difference between two signals (FB and V_{ref}). The between two signals (FB and V_{ref}) is subtracted from variable (j) and stored in variable (j) which makes the variable (j) decrease which makes the duty cycle of Q2 (PWM1) decrease and reduce the output voltage. During this time, variable (i) is set to be 150 to make the duty cycle of Q1 (PWM0) 100%, which makes Q1 in ON state. This condition make converter operates as boost converter with regulated process.

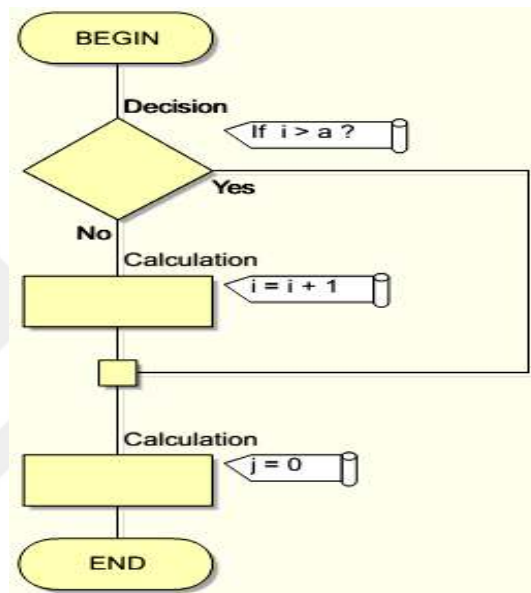


Figure 4.9 Subroutine for (Cond0).

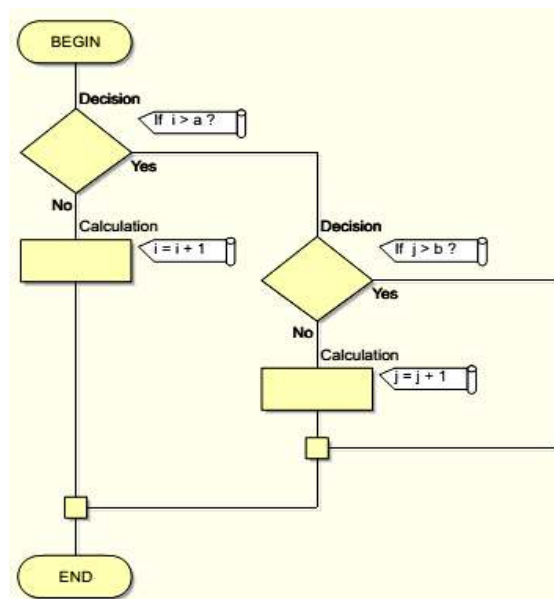


Figure 4.10 Subroutine for (Cond1).

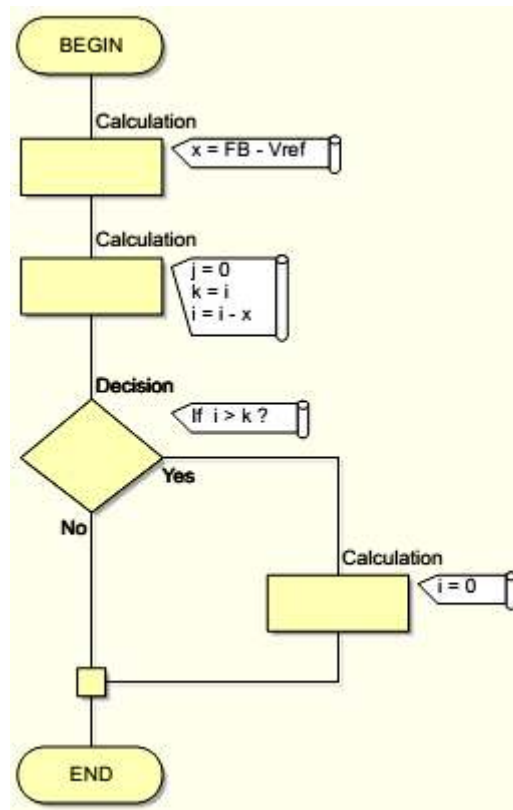


Figure 4.11 Subroutine for (Cond2).

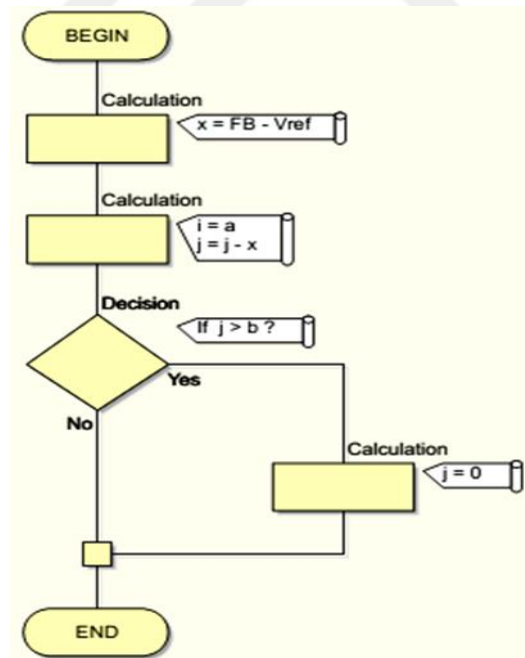


Figure 4.12 Subroutine for (Cond3).

CHAPTER 5

DESIGN AND IMPLEMENTATION OF THE BUCK-BOOST CONVERTER USING PIC 18F4550 MICROCONTROLLER

5.1 Connection of PIC18F4550 Microcontroller

In order to make the PIC18F4550 microcontroller operates properly, PIC18F4550 must be provided with a power supply, reset signal and clock signal as shown in Figure 4.1. PIC18F4550 family is available as both standard and low voltage devices and it operates at different power supply voltages.

A regulated power supply with 5V DC is the most suitable. Figure 5.1 shows a cheap series positive regulator LM7805 which provides a quite enough current (1A) with very good voltage stability in order to make the PIC18F4550 microcontroller with related components operate normally. Also, a logic 1 (VCC) must be applied on the reset pin (MCLR (pin1)) in order to make PIC18F4550 operate properly. A push button switch is connected between GND and the reset pin (MCLR (pin1)). This helps the PIC18F4550 microcontroller to manually restart it if there is a wrong. By pushing this switch (Reset button), a zero voltage is applied on the pin 1 (MCLR) which makes the PIC18F4550 microcontroller starts its execution program from the beginning. To make pin 1 from being in logic 1 (VCC voltage), a resistor with 10k Ω is inserted between the 5V DC.

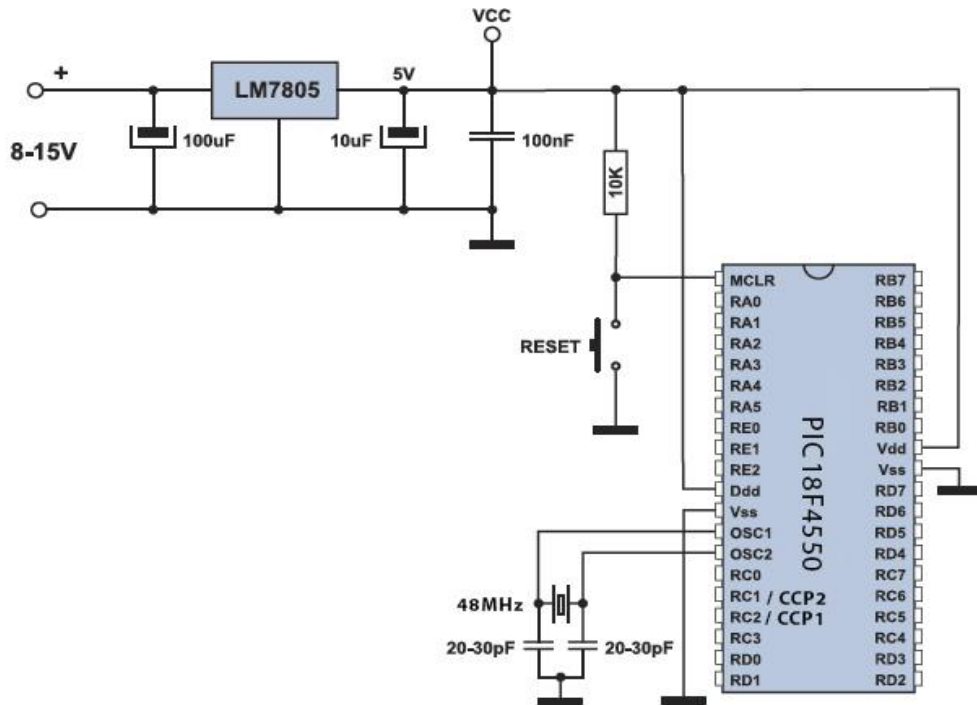


Figure 5.1 Necessary Connection of PIC18F4550.

5.2 Selection the speed of the PIC4550 Microcontroller

Even microcontroller has a built-in oscillator, it can operate with external components which make the microcontroller operation more stable and determine its speed. Depending on components in use and their operating frequencies, the oscillator can be run in four different modes:

PIC 18F4550 microcontroller can be clocked in several ways. These methods are:

- 1) Crystal clock (crystal/resonator)
- 2) RC clock
- 3) Internal clock

The oscillator pins of PIC 18F4550 microcontroller are the OSC1 and OSC2 pins. PIC18F4550 microcontroller can be operated in twelve oscillator modes. In this design, a high-speed crystal/resonator with PLL enabled (HSPLL) mode is chosen where a crystal oscillator with 48MHz is connected to the OSC1 (pin13) and OSC2 (pin14) pins of the microcontroller to establish oscillation.

5.3 Double Stage Buck and Boost Converters Circuit Design Using PIC18F4550

Double stages of buck and boost converters are used as shown in Figure 4.2. This configuration is used for achieving wide positive output voltage range. The first DC to DC converter represents a conventional buck converter and operates when the output voltage needs to be less than input voltage (V_s). The second DC to DC converter represents a conventional boost converter and operates when the output voltage needs to be greater than input voltage (V_s). The heart of this design is PIC18F4550 microcontroller.

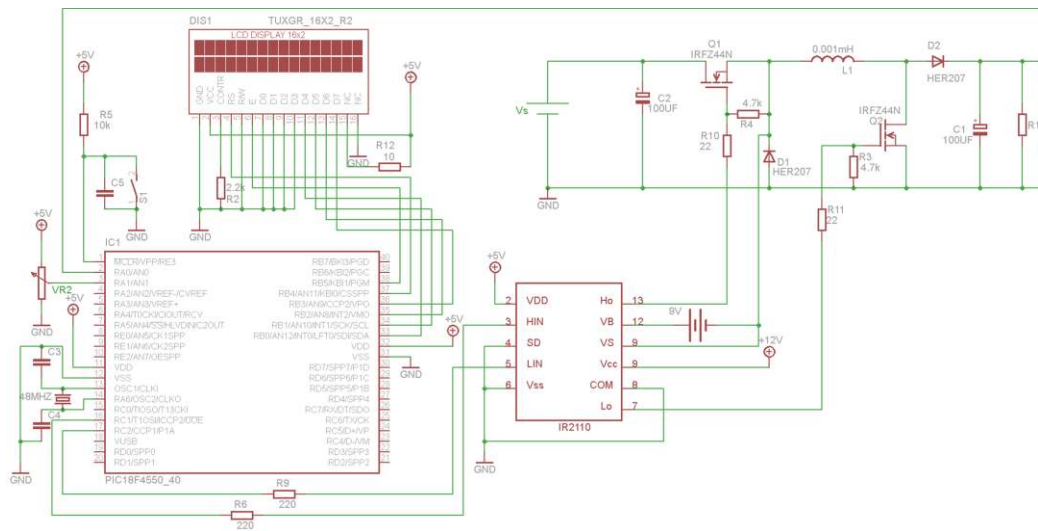


Figure 5.2 Double stages buck and boost (buck-boost) converter using PIC 18F4550 microcontroller.

5.4 Description of the Buck-Boost Converter Circuit

The PIC18F4550 produces two output signals (PWM1 (CCP1) and PWM0 (CCp2)) on pin 17 and pin 16 respectively. These two outputs have low current drive. Therefore IR2110 [26, 27] is used as a high speed, high current power MOSFET driver with capability of 2A peak sink and source currents. PWM0 signal is amplified using IR2110 to produce gate drive (G1) for driving transistor Q1 while PWM1 signal is amplified to produce gate drive (G2) for driving transistor Q2. The variable resistor (VR1) represents the feedback resistor to feedback a part of the output voltage (FB) while the variable resistor (VR2) represents the reference voltage (V_{ref}).

5.5 Experimental Results

The circuit shown in Figure 5.2 has been implemented as shown in Figure 5.3. The implemented prototype operates at a frequency 20 kHz with input voltage range (15-20) V and output voltage range (3-30) V. The gate voltage ($G1$) and inductor current (I_L) for buck mode are shown in Figure 5.4 and Figure 5.5. Figure 5.4 represents the buck mode signals with duty cycle 0.2 and output voltage equals to 2.4V while Figure 5.5 represents the buck mode signals with duty cycle 0.8 and output voltage equals to 9.6V. Figure 5.6 represents the gate voltage ($G2$) and inductor current (I_L) for boost mode.



Figure 5.3 a prototype of the buck-boost converter.

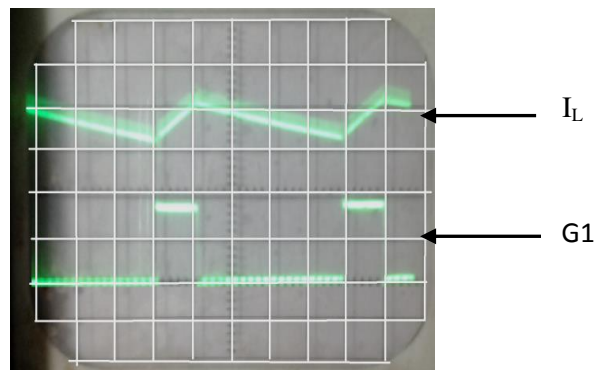


Figure 5.4 Buck mode signals with input voltage 15V, duty cycle 0.2 and output voltage equals to 3V ($G1=2V/div$, $I_L=0.1V/div$, Time base= $10\mu s$).

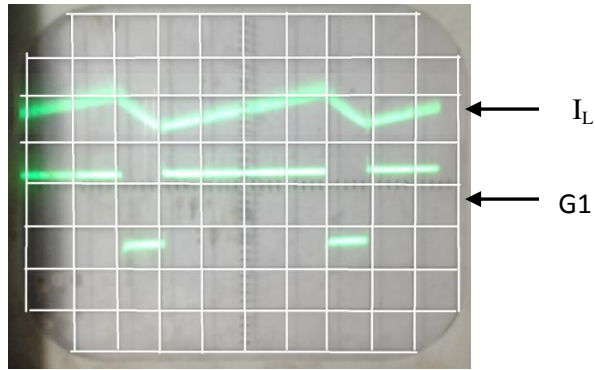


Figure 5.5 Buck mode signals with input voltage 15V, duty cycle 0.8 and output voltage equals to 12V ($G1=2V/div$, $I_L=0.2V/div$, Time base= $10\mu s$).

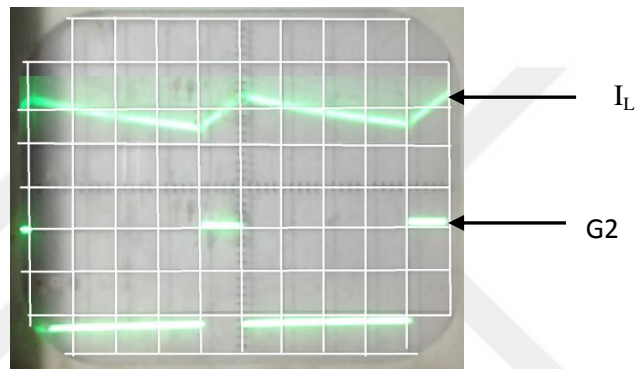


Figure 5.6 Boost mode signals with input voltage 15V, duty cycle 0.2 and output voltage equals to 18.75V ($G1=2V/div$, $I_L=0.5V/div$, Time base= $10\mu s$).

In the design, the prototype has the capability to control the output voltage regardless input voltage and load variation. Also in buck mode, the output current flows only in Q1 while in boost mode, the output current flows in both Q1 and Q2. This means that this configuration is series buck and boost converter. To overcome this case, a parallel buck and boost converter must be use as shown in Figure 5.7 in parallel buck and boost converter, the load current flows in Q1 only in buck mode and in Q2 only in boost converter.

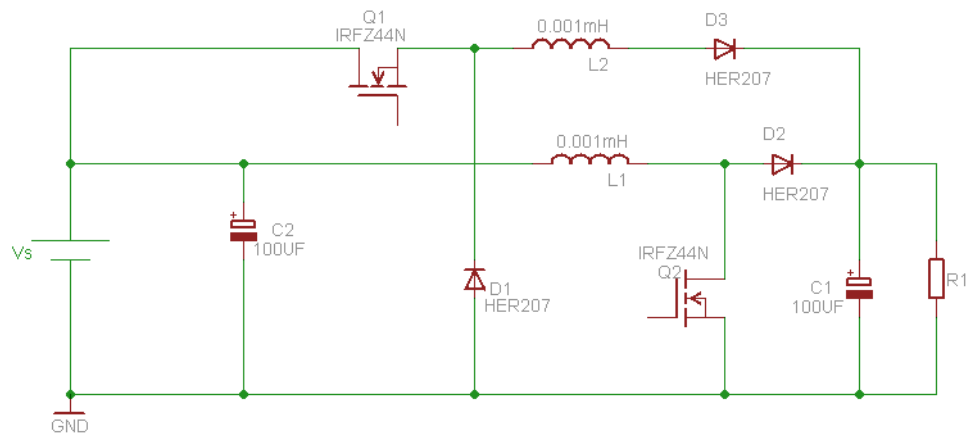


Figure 5.7 Improved circuit of buck-boost converter (parallel buck and boost convertre)

CHAPTER 6

CONCLUSIONS AND SUGGESTIONS FOR FUTURE WORK

6.1 Conclusions

In this thesis the buck-boost converter has been designed, simulated and implemented. The prototype was designed to operate at PWM frequency 20kHz with input voltage range (15-20) V and output voltage range (3-30) V. From this work the following conclusions have been reported:

- 1- The experimental and simulation results show good agreement.
- 2- The prototype has the capability to control the output voltage regardless input voltage and load variation.
- 3- Because of using PIC 18F4550 microcontroller, the circuit has ability to implement interleaved strategy when there is a need to increase the output power.
- 4- In buck mode, the output current flows only in Q1.
- 5- In boost mode, the output current flows in both Q1 and Q2. This means that this configuration is series buck and boost converter. To overcome this case, a parallel buck and boost converter must be use. In parallel buck and boost converter, the load current flows in Q1 only in buck mode and in Q2 only in boost converter.

6.2 Suggestions for Future Works

In this research, the buck-boost converter based on PIC18F4550 can produce output voltage below, above or equal the input voltage with high efficiency. But the disadvantage of this configuration is that in boost mode, the current flow in two transistors (Q1 and Q2). This case can be avoided by adopting the configuration shown in Figure 5.7 which is leaved for future work. In this figure the buck converter stage must be operated only in case of the output voltage less than the input voltage

while the boost converter stage is made in OFF state always. In case of the output voltage need to be greater than the input voltage, the boost converter stage must be operated only while the buck converter stage is made in OFF state always. This will increase the efficiency of the overall buck-boost converter but increase also cost and the size of the converter because of adding another inductance (L_2) and diode (D_3).



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