REGENERATIVE BRAKING USING BUCKBOOST CONVERTER

Thesis submitted in partial fulfilment of the requirements for the degree of

Bachelor of Technology

In

Electronics and Instrumentation Engineering

By

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Under the supervision of

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CERTIFICATE

This is to certify that the work on the thesis entitled **Regenerative Braking using Buck-Boost Converter** by **Pragyan Priyanka Satapathy** is a record of original research work carried out under my supervision and guidance for the partial fulfilment of the requirements for the degree of **Bachelor in Technology** in the department of **Electronics and Communication** Engineering, **National Institute of Technology, Rourkela**. Neither this thesis nor any part of it has been submitted for the award of any degree elsewhere.

Place: NIT Rourkela

Date: May, 2014
Department

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Pragyan Priyanka Satapathy

(B.Tech in Electronics & Instrumentation Engineering)

ABSTRACT

A Buck Boost converter circuit has been designed and simulated to drive a dc motor for an electric vehicle. The design consists of an IGBT Buck-Boost converter, the battery pack in the Buck side and a capacitor in the Boost side. The main battery has the motor load connected to it. The design helps in improving the efficiency of the DC motor by using the bidirectional buck boost converter along with the battery pack and capacitor.It provides energy to the motor during acceleration and also facilitates the energy regeneration during braking or deceleration. The incorporation of the regenerative braking can improve the efficiency as much as 25% and therefore improve the driving range. During boost operation the converter transfers the energy from the capacitor to the battery(battery gets charged) while during regeneration converter works in buck mode and transfers energy from battery to capacitor(capacitor is charged).There are a number of options for DC DC converter such as Boost,Buck converter, Isolated/Non isolated Half bridge Buck Boost converter,Full Bridge converter and ,Cuk Converter.The isolated converters are preferred as they don't include transformers and hence increase the overall efficiency of the system along with reduction of size and weight of the system.

The converter can be made to operate in two different modes,Discontinuous Conduction Mode and Continuous Conduction Mode. The CCM is used for better utilization of semiconductor switches and passive components as well as enhanced efficiency.The DCM is used in applications with higher control needs because it provides low output current,low switching frequency and a faster response.But it leads to increased ripples.The converter's design parameters were set as per the equations governing its operation in the selected mode.

In the present work the converter switching is implemented by using IGBTs.A controlled PWM signal is applied to the IGBT switches. Thus the amount of energy transferred in both direction depends on the controlled duty cycle of the PWM signal.

The PWM signal has been generated by using STM32F107 ARM CORTEX M3 DEVELOPMENT BOARD for varying duty cycles.The ARM Cortex M3 processor is a 32 bit processor with many features such as RISC Core,operating at 72 MHz maximum frequency, 64 to 256 Kbytes of Flash memory,upto 64 Kbytes of SRAM, Low power– Stop,Sleep and Standby modes and 1 μs A/D converters (16 channels).

The ARM Cortex Kit is used to drive a DC motor with the help of a Motor driving IC. Varying duty cycles result in varying speeds of the DC motor.

A controller was designed to generate a controlled PWM signal input to the igbt switches.

The battery voltage is measured and an error signal is generated with respect to a reference voltage. This error is given as input to a PI controller and the controller generates a PWM switching pattern by using a comparator. The controller thus controls the amount of energy transferred to the capacitor.In present work the controller is designed and simulated for both the operating modes-Buck mode and Boost mode

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CHAPTER 1

INTRODUCTION

CHAPTER 1

INRODUCTION

1.1BACKGROUND

The gradual rise in demand for energy has led to an increase in fuel burning which in turn adversely affects the environment. Efficient use of energy and its conservation is highly essential due to the fact that one unit of energy conserved in the consumption level reduces the energy demand by 3 to 4 times. Moreover, such conservation through judicious utilization of energy can be achieved by less than one-fifth the price of fresh capacity formation. Energy efficiency can considerably contribute to our efforts to meet energy needs as well as decreasing fuel consumption. In electric vehicles, the regular braking systems convert kinetic energy into heat, mainly in the form of friction. This causes a huge amount of energy wastage. Regenerative braking is a mechanism that recovers energy.This energy reduces the speed of an object or vehicle by transforming its kinetic energy to a different form.But in case of regular braking systems extra kinetic energy is converted into heat through friction in the braking linings and wasted. Thus regenerative braking of an electric vehicle implemented with a bidirectional converter and capacitor can reduce the energy loss and also improve the overall efficiency of the system.

1.2MOTIVATION

By using a bidirectional DC DC converter, its possible to enhance the output voltage of the electrical storage systems to a higher level and hence decreasing the current output.This leads to power losses. It also provides reverse power flow in regenerative braking and thus efficiency increases. These characteristics of the DC DC converter make it a preferable choice for power transfer in electric vehicles and hence reducing the overall cost ,size and weight of the system along with increasing efficiency and achieving regenerative energy.The practical implementation of regenerative braking in electric vehicles, requires a battery pack in buck side and an ultra capacitor bank in the boost side of the Buck Boost converter. Ultracapacitor is a recent technology that provides 20 times more energy storage than regular electrolytic capacitors. They show improved performance in specific power than any other battery.They can be discharged and charged many times without much degradation of performance. These features when combined with regular electrochemical batteries make the transient performance of the electric vehicle better by enhancing the lifetime of the batteries. Rapid and abrupt discharge of battery during acceleration or rapid charge during deceleration can be dealt by using ultracapacitors.

1.3 CONTRIBUTION OF THE THESIS

The main goal of the present work is to design, model and simulate a Bidirectional DC DC Buck Boost converter with a battery pack at the buck side and a capacitor in the boost side. In accordance with this objective, the methodology for selecting an appropriate topology of the bidirectional DC DC converter has been presented and then the controller to generate a controlled PWM signal has been designed to meet the required specifications.

Some of the salient points of this thesis are:

1. Selection of a DC DC converter as per requirements
2. Determine the converter parameters as per the mode (CCM/DCM)
3. Design of a bidirectional Buck Boost Converter Model.
4. Design of a single controller during both the modes for controlled PWM

1.4 LITERATURE REVIEW

Different dc dc converter topologies have been studied and analysed and the comparison between them has been presented in [7,8]. The importance of the power electronics and dc dc converter in the hybrid electric vehicle technology is discussed and presented in [3, 5].The comparison between the various non isolated Bidirectional DC DC converters on the basis of their performance has been done in [9].The implementation of regenerative braking in electric vehicles using dc dc converter along with a control system is discussed in [1,2,6]. Here the power circuit is having two major components that is the Buck-Boost converter using IGBTs, and the ultracapacitor bank.The control system is implemented by using a microcontroller.Different methods of tuning a PID controller are presented in [4].The concepts of the soft switching techniques for increasing efficiency and reducing stress in devices is discussed in [11,12]. The single controller for controlled PWM generation in bidirectional DC DC converter is presented in [10].

1.5 ORGANIZATION OF THE THESIS

The thesis work has been organized as follows:

- Chapter 2: This chapter presents an idea about different DC DC con- verter topologies and the topology that is best suitable for the present desig
- Chapter 3:In this chapter,the circuit operation and the designing issues have been discussed. According to the given specifications and design objectives,the circuit has been designed.
- Chapter 4: In this chapter, a control strategy is discussed and the controller is designed and modelled for the converter circuit
- Chapter 5: This chapter presents the simulation waveforms along with the results and discussions. Also includes the future work and conclusion.

CHAPTER 2

SELECTING OF DC DC CONVERTER TOPOLOGY

CHAPTER 2

SELECTING OF DC DC CONVERTER TOPOLOGY

2.1 DC DC CONVERTER

Today most of the electronic devices require improved quality,low weight,small size, efficient and reliable power supplies. Energy regulators are based on current and voltage divider operation principle and hence are inefficient. Thus high power requirements make use of switch regulators. They use power electronics semiconductor switches like igbts or mosfets for on or off state. There is little power loss in these states because of low voltage across the switch when it is turned on and no current through the switch when turned off.Hence, switching regulators provide improved energy conversion efficiencies. Electronic processors of power of high frequency are used in dc dc converters. Thus, DC-DC converter can be defined as a circuit that converts DC voltage from one voltage level to another,that is it converts the unregulated DC input voltage to a controlled DC output voltage at a desired level.These DC-DC converters are used extensively today in many electronic gadgets such as laptop, mobile etc.All these devices have one power supply battery at a fixed level which is to be converted to a different voltage level.This helps in reducing the space and cost of extra batteries.

The various uses of dc dc converters:

- Conversion of the dc voltage input at one level into dc voltage output at another or same level
- for dc output voltage regulation against line variations and load disturbances
- to minimize dc output voltage ripple below a desired level
- to isolate the load from the input voltage
- to provide protection to the input voltage and the circuit from electromagnetic interference (EMI) or noise

The dc-dc converters are of two main types:

2.2 Resonant and soft-switching converters-Here switching transitions(on and off) occur in favourable conditions, that is, zero voltage or zero device current. This reduces the loss and stress associated with switching,leading to lower electromagnetic interference(EMI) and easier thermal management. The value of switching frequency is kept in the practically acceptable range to achieve high efficiency in the converter and at the same time limit its cost. These resonant converters have resonant tanks to create oscillatory sinusoidal current as well as voltage waveforms so that zero-current switching (ZCS) or zero-voltage switching (ZVS) conditions can be generated for the power switches. Decrease in switching losses leads to higher switching frequency.This increase in the switching frequency reduces the size and weight of the passive components like capacitors, inductors etc.Soft switching techniques used in power converters help in increasing energy conversion efficiency,also enhances the switching frequency and hence reduce the weight ,size and the cost of the passive components.They also reduce the electrical and thermal stresses in the switching devices.They also help in suppressing the EMI. Thus the power loss during switching is eliminated from the converter.Soft switching can be achieved by using resonant components such as snubber capacitor or inductor or by the use of the parasitic component of the converter. Soft switching is realized in the DC DC converter circuit by the addition of resonant switches consisting of a controlled semiconductor switch such as power MOSFET or an IGBT, an antiparallel freewheeling diode and a resonant capacitor or a resonant inductor. The condition of soft switching can be realized in the converter only if the resonant part of the switch has the capability to discharge itself at the time of switching. If the resonant capacitor or the inductor across the switches can reset themselves and acquire zero current or voltage at the time of the switching, soft switching is established. Thus operation under soft switching condition is possible by addition of external components. This method is useful particularly in high frequency operations but it also leads to conduction losses. Figure 2.1 shows the ideal and practical switching waveforms for switch voltage.

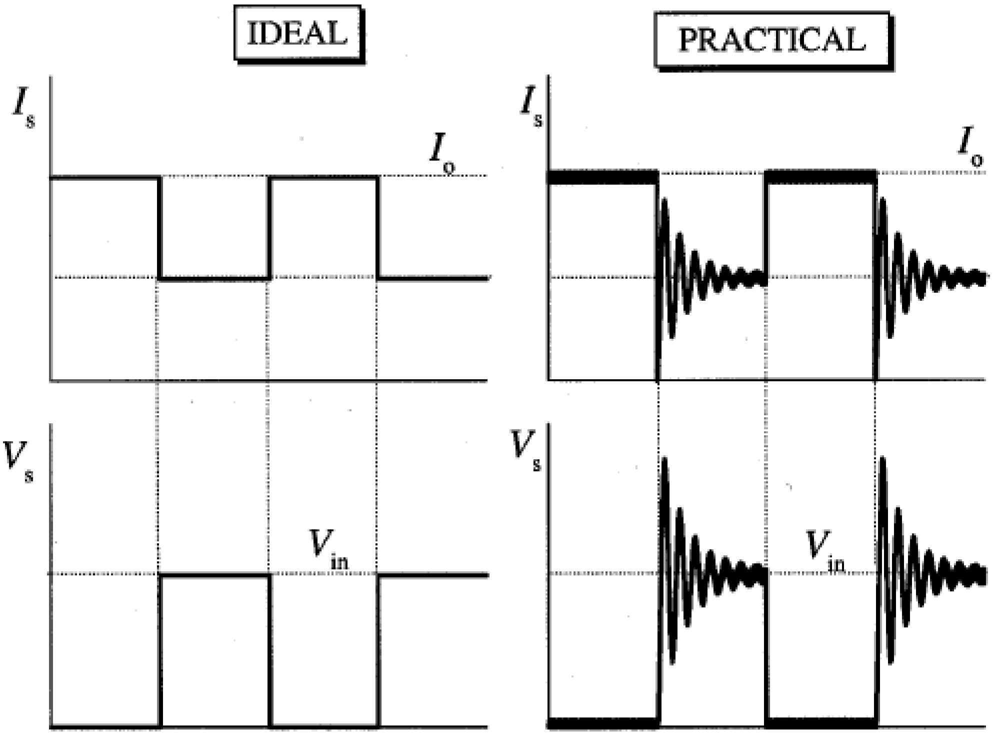

Figure 2.1: Ideal vs Practical switching waveform
Soft switching is of two types-

2.2.1 Zero Voltage Switching

In the Zero Voltage resonant switch, resonant capacitor is connected parallel across a switch to attain zero-voltage-switching (ZVS).For a unidirectional switch the capacitor voltage oscillates freely during both the half-cycles(positive as well as negative). This allows the resonant switch to work in the full wave mode. Connection of a diode anti-parallel to the one directional switch will cause the voltage of the capacitor to be set to zero by the diode in the negative halfcycle. The switch then works in halfwave mode.The goal of a Zero Voltage switch is to shape the switch voltage waveform with the help of resonant switch during off time which causes the switch to be turned on by creating a zero voltage.

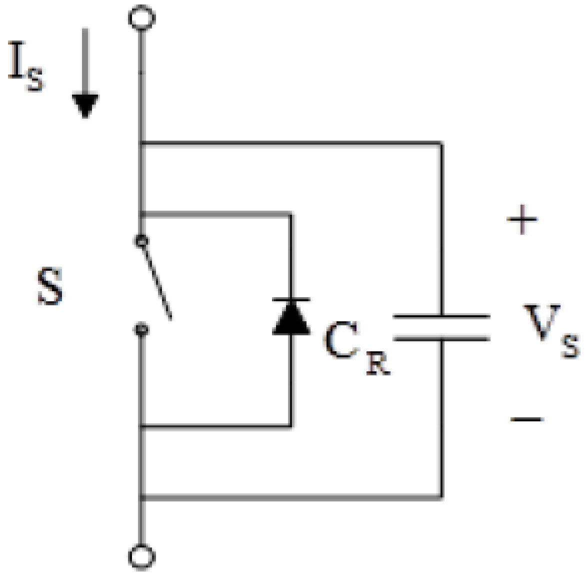

Figure 2.2: Zero voltage resonant switch

2.2.2 Zero Current Switching

In Zero Current resonant switch, the power switch S has an inductor connected in series with it to get zero-current-switching. In case of a unidirectional switch, the switch current can oscillate only in positive halfcycle and thus resonant switch works in half-wave mode. Connection of an antiparallel diode with the one directional switch causes switch current to flow in both the directions and thus the resonant switch will operate in full-wave mode.When turned on,the current in the switch increases gradually from zero.Oscillation of current occurs due to the resonance in between capacitor and inductor.The goal of the switch is the shaping of the waveform of switch current in the conduction period to provide a condition of zero current which causes the switch to be turned off.

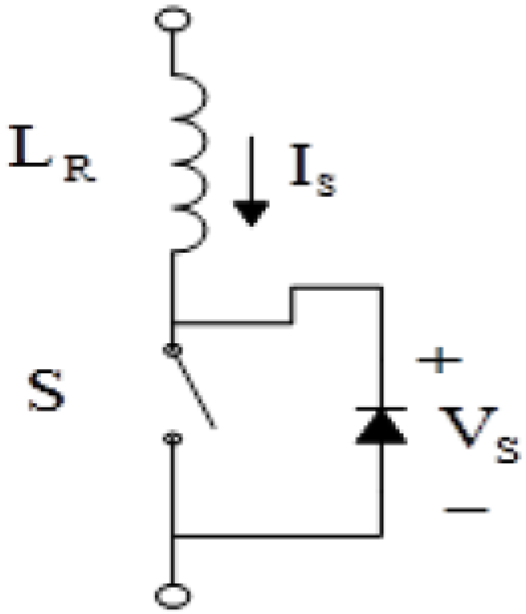

Figure 2.3: Zero current resonant switch

2.3 Hard-switching pulse width modulated (PWM) converters-

PWM converters have lesser number of components and higher efficiency. The operate at a constant frequency.They require a relatively simpler control system.Integrated circuit controllers for hard switching converters are also commercially available.These converters also allow large conversion ratios for both boost and buck operations.But the major drawback of PWM controlled dc-dc converters is that PWM rectangular current as well as voltage waveforms lead to both turn-off and turn-on losses in semiconductor devices.This reduces the practical operating frequencies by hundreds of kilohertz.Also the PWM rectangular waveforms produce electromagnetic noise.

2.3.1 Step-Down (Buck) Converter

The buck converter circuit can be seen in Fig 2.4. Output waveforms of the converter can be seen in Fig2.5. Here it has been assumed that the inductor current is always positive.If switch is turned on, the diode becomes reverse biased(no current).When switch is turned off, the diode becomes forward biased and conducts,thus providing uninterrupted current in the inductor.

As per to Faraday’s law, voltage time product of inductor in steady-state is zero. In case of the buck converter

$(V_s-V_o)DT=-V_o(1-D)T$

DC Voltage transfer function, $M_v=V_o/V_s=D$

Filter inductance at the boundary of
DCM(discontinuous conduction mode) and CCM(continuous conduction mode) is given by

$L_b=(1-D)R/2f$

For Inductor value less than above,the converter goes to CCM mode

In CCM mode the inductor current includes a dc current and a triangular ac component superimposed to it.Most of this ac component flows through the filter capacitor as ac current,which produces a voltage ripple in the output load voltage. To reduce the ripple voltage value below a required value called ripple voltage, the filter capacitance C should be more than the below mentioned value.

Cmin=(1-D)Vo/8VrLf^2

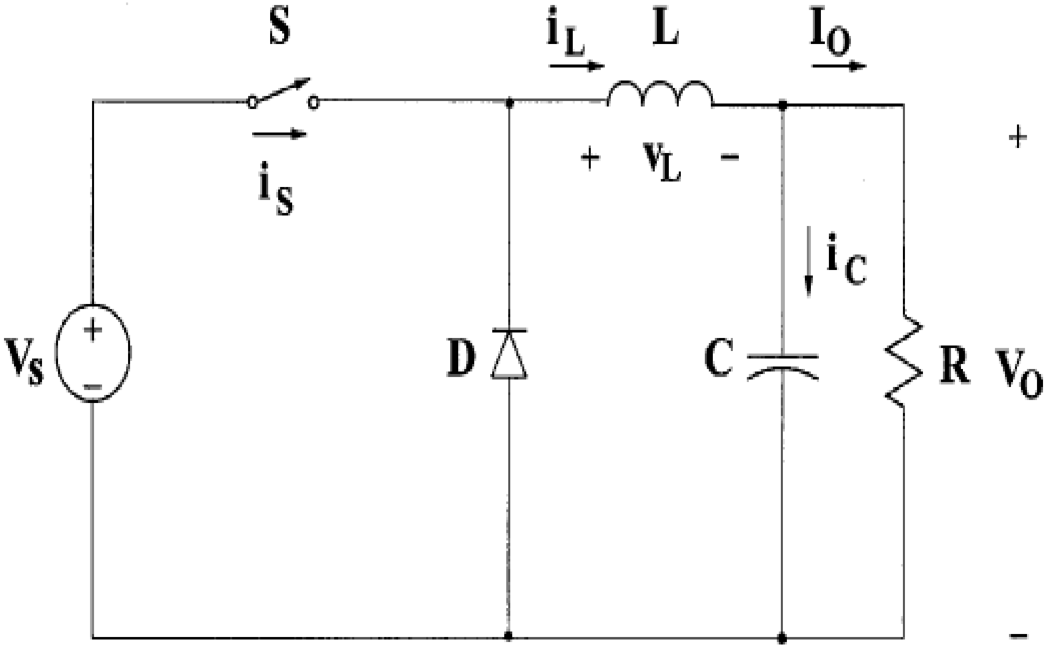

Figure 2.4: Buck Converter circuit

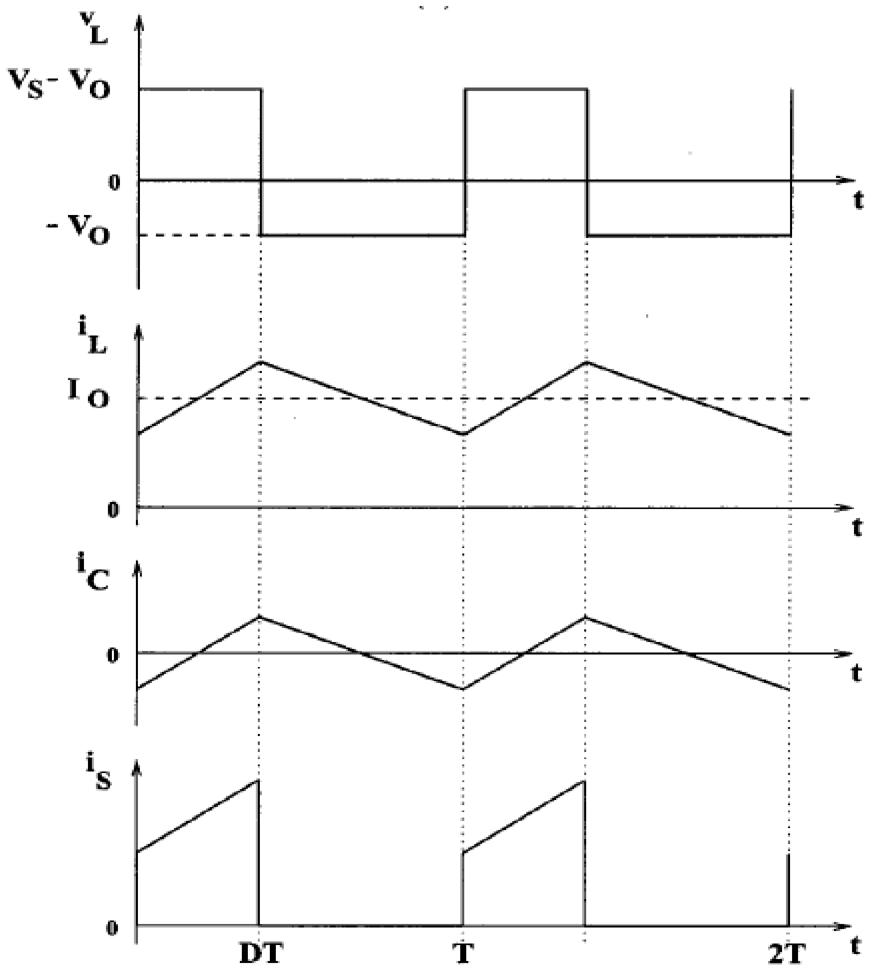

Figure 2.5: Output waveforms for the buck converter circuit

2.3.2 Step-Down (Boost) Converter

Fig 2.6 shows a PWM controlled boost converter(step down). It includes a dc input voltage , filter inductor, controlled switch,filter capacitor,diode and load resistance . When the switch is turned on, the diode is reverse biased and the current in the inductor increases linearly.If the switch is off, the energy is extracted from the inductor and transferred via the diode to the output RC circuit.
According to Faraday’s law, for inductor in boost mode

VsDT=(Vo-Vs)(1-D)T

DC Voltage transfer function Mv=Vo/Vs=1/(1-D)

Thus the output voltage is higher than the input voltage(boost operation) all the time.The boundary value of inductor is given by

Lb=(1-D)^2DR/2f

The converter works in CCM mode if inductor value is less than above value.

The current in the output RC circuit is not continuous in this case.Thus, a large filter capacitor is needed here as compared to that of buck converters in order to limit the output voltage ripple.

When diode is reversed biased, the filter capacitor must discharge through the load resistor. The filter capacitance has the lowest value resulting in voltage ripple Vr which is given by

Cmin=DVo/VrRf

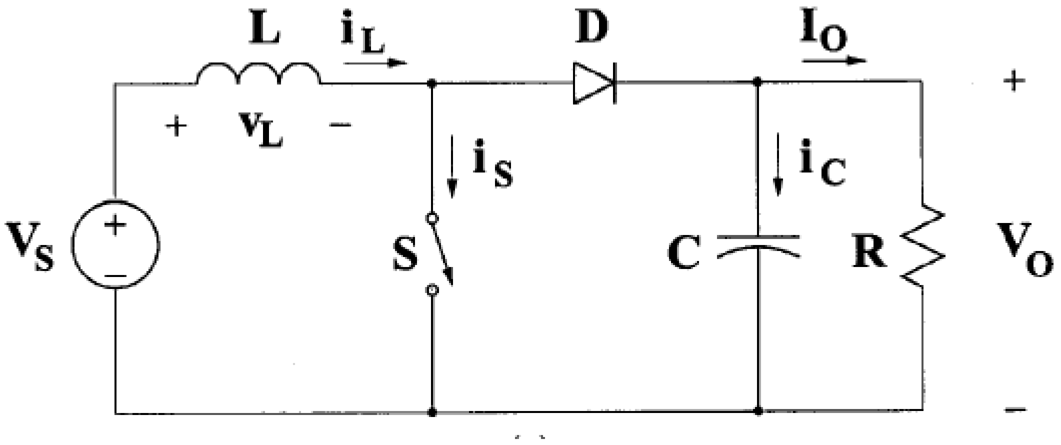

Figure 2.6: Boost Converter circuit

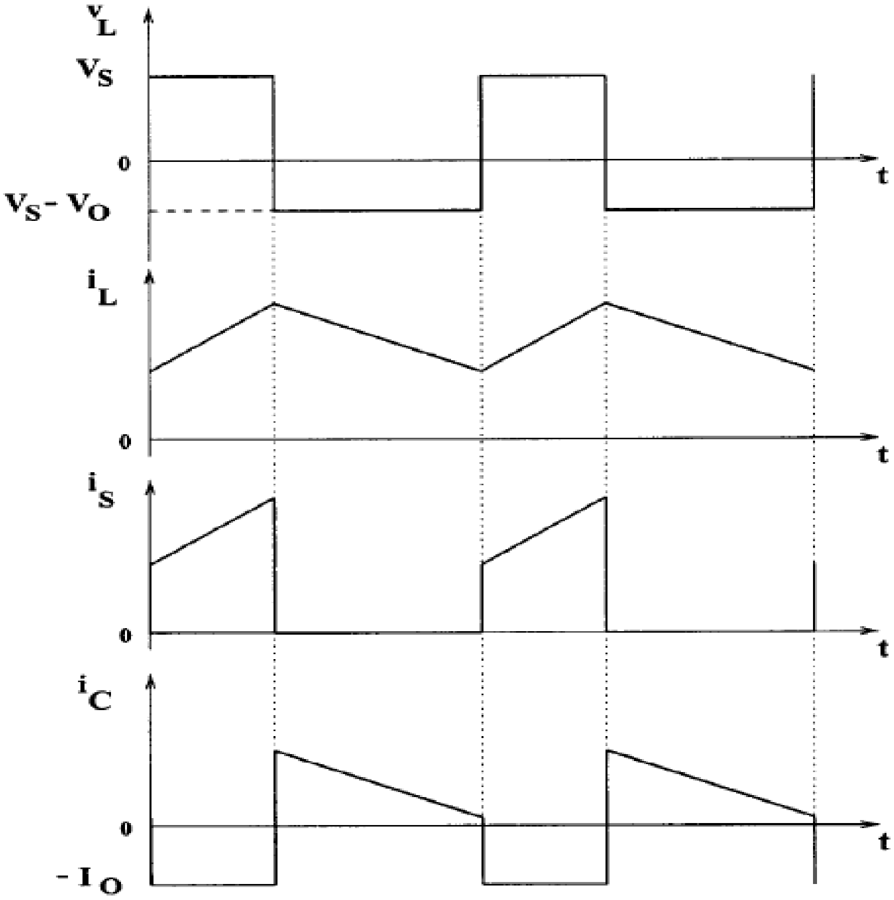

Figure 2.7: Output waveforms for the boost converter circuit

2.3.3 Non Isolated Buck Boost Converter

A non isolated or no transformer topology of a dc dc converter can be seen in Fig 2.8.If switch is turned on,current in inductor rises and the diode becomes reverse biased. If the switch is off, the diode becomes forward biased and conducts and inductor current flows.
The waveforms for buck-boost converter are shown in Fig 2.9. The steady state zero voltage-second product for the inductor is given by

$VsDT=-Vo(1-D)T$

Transfer function for DC voltage,$Mv=Vo/Vs=-D/(1-D)$

Here with respect to the ground,the output voltage is negative.The converter works in buck mode when Duty Cycle of the PWM applied to switch is less than 50% and works in boost mode when Duty Cycle is greater than 50%.

The inductor value at the boundary in between the CCM and DCM is

$Lb=(1-D)^2R/2f$

Filter Capacitor for Ripple Voltage Vr is given by,

$Cmin=DVo/VrRf$

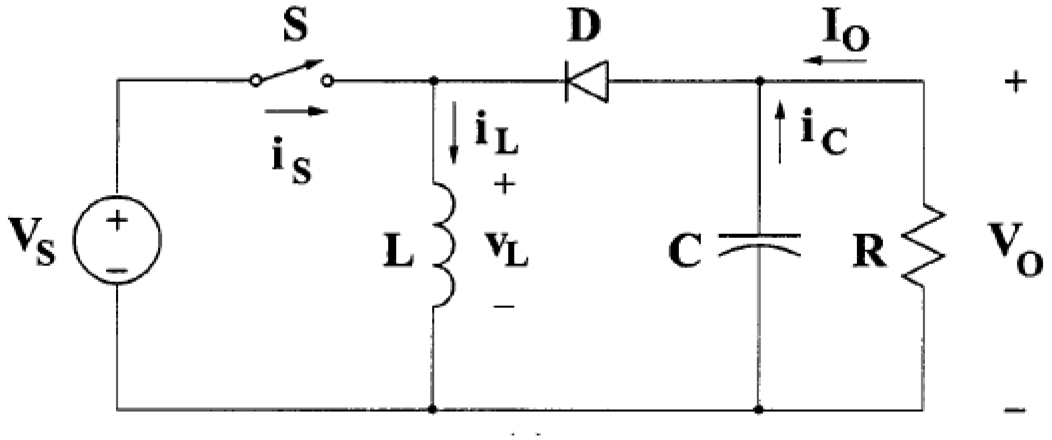

Figure 2.8: BuckBoost Converter circuit

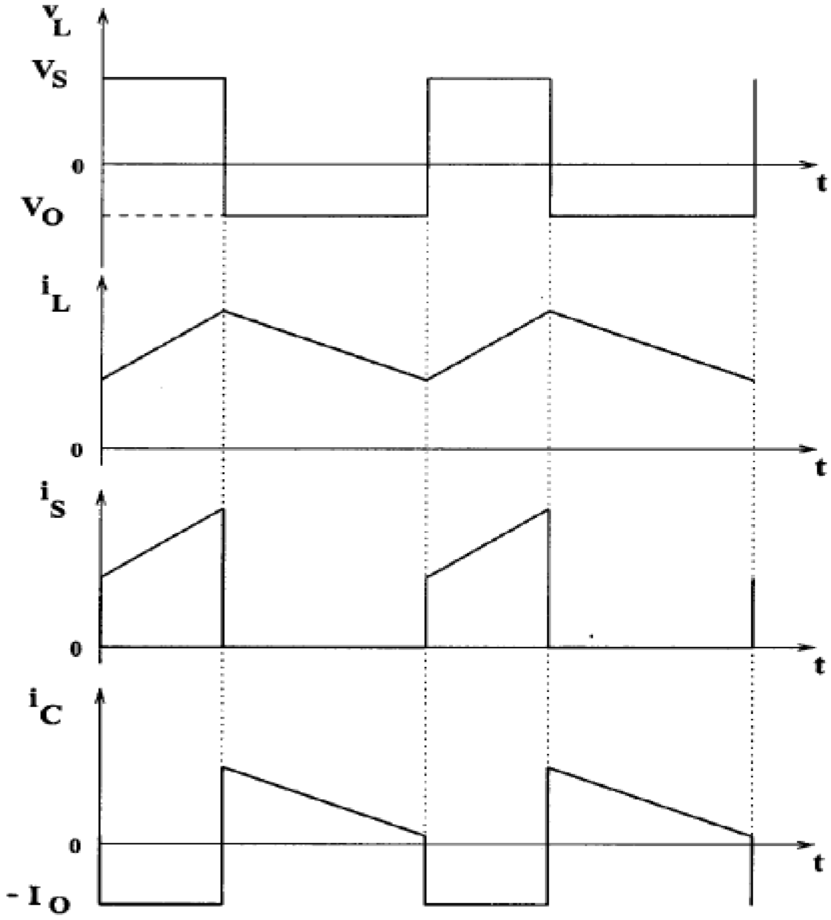

Figure 2.9: Output waveforms for the buckboost converter circuit

2.3.4 Cuk Converter

The Cuk converter circuit can be seen in Fig 2.10.If switch is on, diode becomes reverse biased and inductor L2 current discharges the capacitor C1.
If switch is off,diode causes conduction of currents of both inductors L1 and L2.But the capacitor C1 charges by the inductor current L1 only.

Transfer function for DC voltage,Mv=Vo/Vs=-D/(1-D)

This is equivalent to the voltage transfer function of buck boost converter. Boundaries in between the DCM and CCM give the following inductor values

For L1- Lb1=(1-D)R/2Df

For L2- Lb2=(1-D)R/2f

Filter Capacitance , Cmin =(1-D)Vo/8VrL2f^2

Ripple voltage(peak – peak) in the capacitor C1, Vr1=DVo/C1Rf

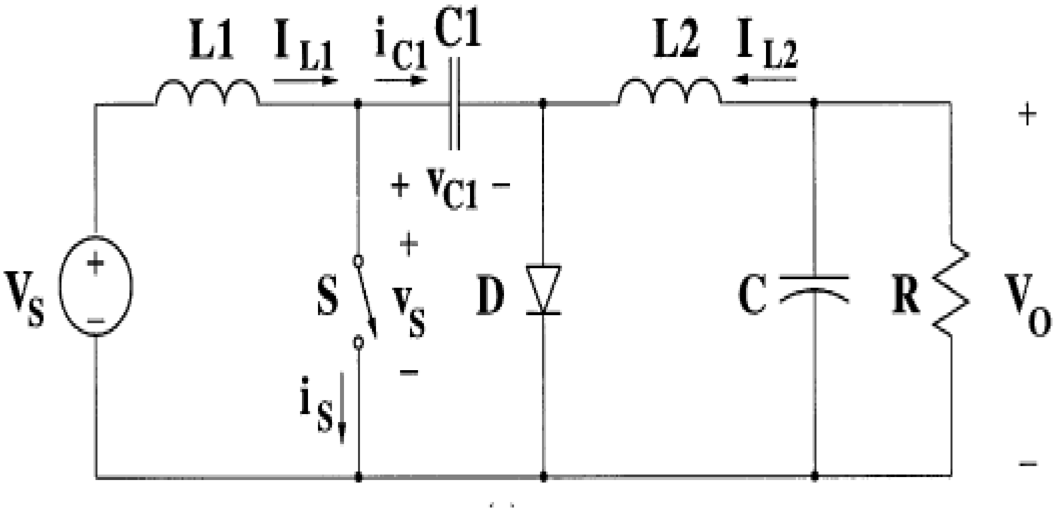

Figure 2.10: Cuk Converter circuit

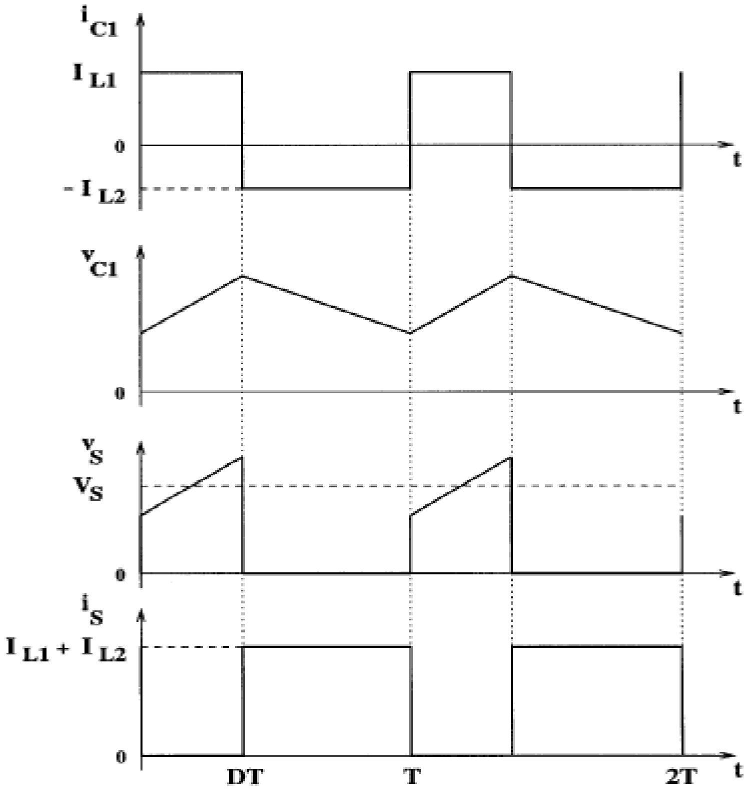

Figure 2.11: Output waveforms for the cuk converter circuit

2.3.5 Half Bridge Non Isolated Buck Boost Converter

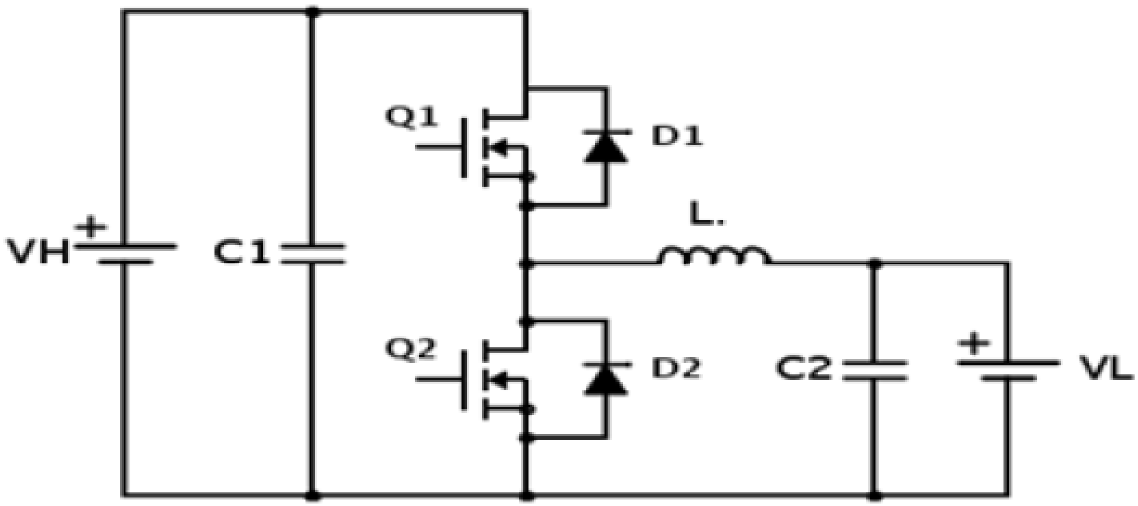

Figure 2.12: Half bridge non isolated buck boost converter circuit

When the Buck and the Boost converters are connected antiparallel across each other , the resulting circuit is similar to the Boost and Buck discussed.But it also provides bidirectional current flow as shown in fig 2.12.

Above circuit has two different modes-buck and boost mode.Switching between these two modes can be done by using the MOSFET switches.The switches Q1 or Q2 along with the anti-parallel diodes D1 or D2 ,acting as freewheeling diode,either increases or reduces the voltage level depending on the mode.The operation of the above circuit can be explained in the given two modes as follows:

Mode 1 (Boost Mode): In this mode switch Q2 and diode D1 starts conducting depending on the duty cycle.The switch Q1 and diode D2 are off(reverse biased) throughout.This mode can further be divided into two stages depending on the conduction of the switch Q2 and diode D1 as shown in the Fig and Fig.

Stage 1 (Q2-on, D2-off ; Q1-off, D2-Off): In this mode Q2 is on and short circuited.Hence,the lower voltage battery charges the inductor and the inductor current increases linearly until Q2 is off.Also as the diode D1 is reversed biased in this mode and the switch Q1 is off, no current flows through the switch Q1.

Stage 2 (Q1-off, D1-Off; Q2-off, D2-on): In this mode Q2 and Q1 both are off and opened circuited. As the current flowing through the inductor cannot change instantaneously, the polarity of the voltage across it is reversed and thus it acts in series with the input voltage. Therefore the diode D1 is forward biased and the inductor current charges the output capacitor C2 to a higher voltage. Thus the output voltage increases.

Mode 2 (Buck Mode): In this mode switch Q1 and diode D2 enters into conduction depending on the duty cycle.The switch Q2 and diode D1 are off all the time. This mode is divided into two stages depending on the conduction of the switch Q1 and diode D2 as shown in the Fig and Fig.

Stage 1 (Q2-on, D2-off; Q1-off, D2-Off): In this mode Q1 is on and Q2 is off.The higher voltage battery will charge the inductor and the output capacitor will get charged by it.

Stage 2 (Q1-off, D1-off; Q2-off, D2-on): In this mode Q2 and Q1 both are off. Again since the inductor current cannot change instantaneously, it gets discharged through the freewheeling diode D2. The voltage across the load is stepped down as compared to the input voltage.

2.4 CONVERTER’S PARAMETERS DESIGNING

2.4.1 SYSTEM PROPOSED

In the present design,the non isolated half bridge buck boost converter has been used due to the following reasons:

- no transformer winding(as its non isolated),hence system is of low weight
- it is used for high power applications
- reduces the cost as well as size of the system
- lower input and output current ripple

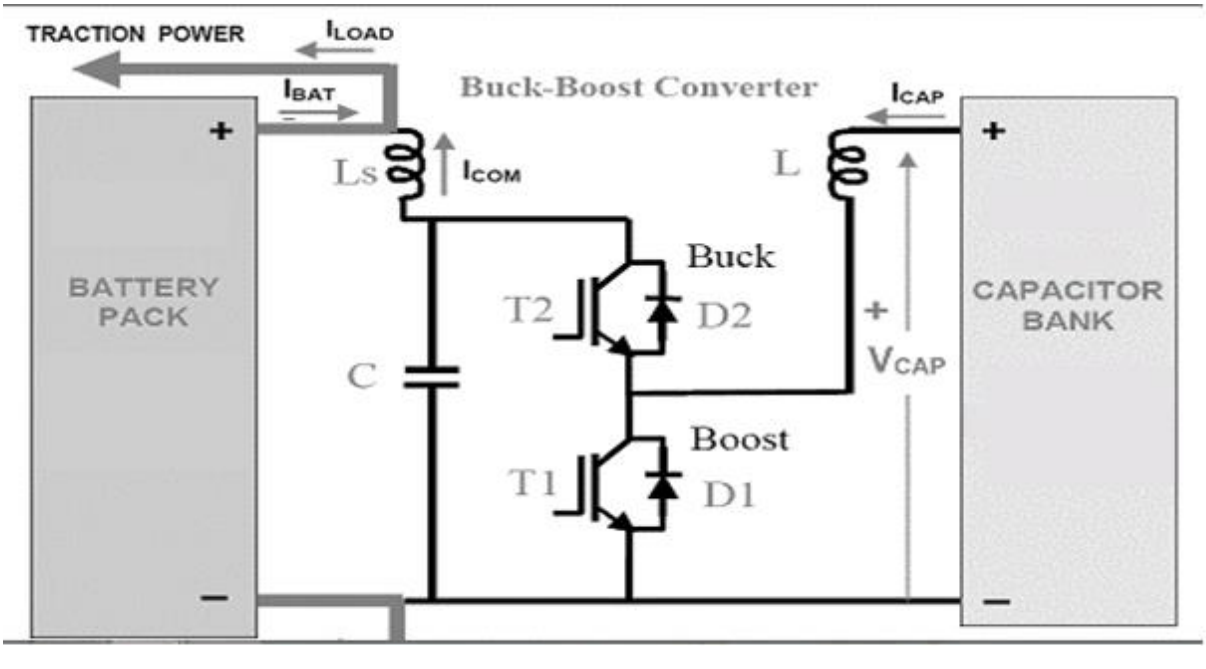

Figure 2.13: The designed buckboost circuit

The Bidirectional DC DC converter can operate in the discontinuous as well as continuous conduction mode as well as at the edge of discontinuous as well as continuous mode. The effect of converter's work at these three conduction modes affects its efficiency and performance. In CCM mode the current in inductor is always positive (never zero).If the switching frequency f is low and average output current is low due to high resistance, the converter operates in the discontinuous conduction mode (DCM).

During acceleration the **Boost operation** takes place,in which **T1** is turned on and off in a controlled duty ratio to transfer desired energy from the capacitor to the battery pack. When **T1** is ON,energy is stored in the inductor **L** from the capacitor.During the OFF state of **T1**, the energy is transferred to **C** from the inductor, through the diode **D2**.This energy then goes into the battery pack. In order to soften the current pulses of to the battery,the inductor **Ls** is used.
During deceleration the **Buck operation** takes place,in which the converter transfers energy to the capacitor from the battery.This operation is done with a controlled Pulse Width Modulated(PWM) input signal on **T2**. If **T2** is turned ON, the energy is transferred to the capacitor from main battery, and inductor **L** stores some part of this energy. If **T2** is turned OFF, energy is transferred to the capacitor from inductor **L**.

2.4.2 CALCULATIONS-

INDUCTOR SELECTION-

The selection criteria is to have the full (rated) load current operating under
DCM/CCM boundary condition.
The equations for inductor current in the buckboost mode and in DCM mode are the following:
The smallest value of inductor required to operate the converter in CCM mode is called as critical inductance value. For the buck and boost converter the critical inductance value is dependent on the steady state duty ratio, load resistance and switching value.
The equation for boost mode to determine the critical inductance is given by:

$$L_{cr,boost} = (T(1-D)^2DR)/2$$

And $$V_o/V_s = 1/(1-D)$$

The equation for buck mode to determine the critical inductance is given by:

$$L_{cr,buck} = (T(1-D)R)/2$$

And $$V_o/V_s = D$$

Therefore the value of the converter inductor should be less than the value given by:

$$L = \min((L_{cr,boost}),(L_{cr,buck}))$$

Where T=Time Period
D=Duty Cycle
R=Load Resistance

For the simulated circuit ,T=2ms,D=0.6,Vbat=12V,Vcap=5V

With the above values,we get L=1mH

Filter Capacitance $C=(DV_oT)/V_r$

With ripple voltage Vo/Vr=1%,T=2ms,D=0.6,we get C=0.1mF.
In the proposed system,the nominal battery voltage is set at 13V and in boost mode the initial capacitor voltage is set at 10V.

CHAPTER 3

CONTROLLER DESIGN

CHAPTER 3
CONTROLLER DESIGN

3.1 INTRODUCTION

PI CONTROLLER

Proportional-integral(PI) controllers are commonly used in industrial control systems because it has only two tuning parameters that has to be tuned for the desired controlled output.A PI controller takes the input signal as the error signal. This error signal is difference of desired external reference signal and measured control variable.

The controller reduces the error by manipulating control inputs.It consists of two constant parameters that has to be tuned namely KP ,the proportional term and KI the integral term. Here KP depends on the current value of the error, and KI depends on the accumulation of the errors in past.

The transfer function for a PI control is given by:

G(s)=M(s)/E(s)=Kp+Ki/Ti(s)

Characteristics of the PI controllers are :

- They can remove the steady-state error of the step response (due the presence of the integral action)
- But they have the disadvantage of reset windup

Fig shows an ideal PI controller

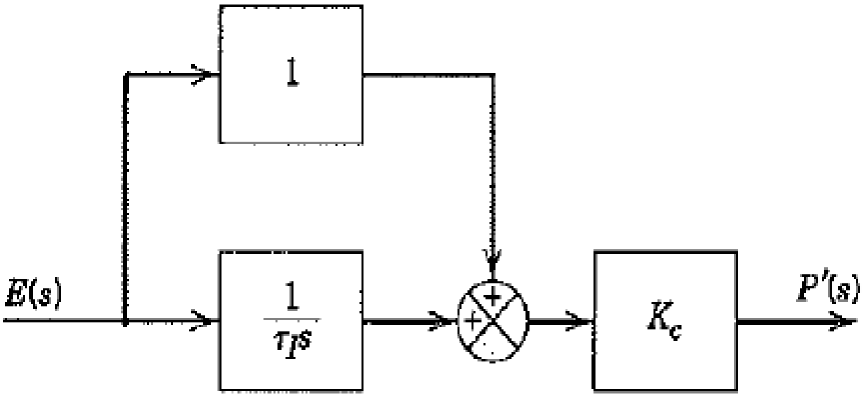

Figure 3.1: An ideal PI controller circuit

3.2 CONTROL STRATEGY

A dc-dc converter should give a regulated dc output voltage irrespective of load variations and input voltage fluctuations.The parameters of the converter may vary with time,pressure,temperature etc. Therefore, the control of the output voltage should be done in a closedloop using negative feedback.The widely used closed-loop control techniques for PWM dc-dc converters are the current mode and voltage mode control, which are shown in Fig.3.2 and Fig.3.3.

3.2.1 Voltage-mode control

Here the converter output voltage is measured. The difference of measured voltage and external reference voltage is given as output by the error amplifier. The error amplifier is then given as input to a controller, which generates a controlled voltage. This voltage is compared to a constant amplitude sawtooth waveform. The comparator then generates a PWM signal that is supplied to the gates of controlled switches in the Buck Boost converter. The duty cycle of the PWM signal is determined by the controlled voltage. The frequency of swatooth waveform is equal to the frequency of PWM. A major advantage in case of voltage-mode control technique is that its implementation of harware is not complex and is flexible.In the present design,Voltage mode control has been used as the control strategy.

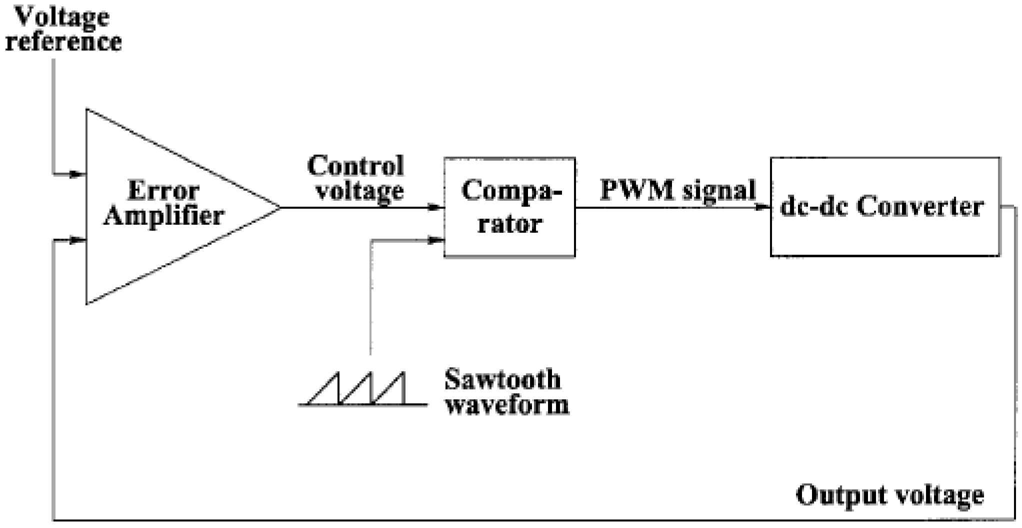

Figure 3.2: Voltage mode control technique for dc dc converter

3.2.2 Current-mode control

Here an extra secondary control loop carries the inductor current and this is converted into its analog voltage and is compared with the controlled voltage.In this case,the sawtooth waveform is not used.Instead the voltage-mode control technique is used by the converter.This current considerably affects the dynamic performance of the converter,which shows some features of the current source. The output current signal of PWM Buck Boost converters is either the average of the output inductor current like in Cuk and Buck converters or is the product of the average inductor current and depends on the duty cycle. In actual designing of current-mode control, it is possible to measure the maximum current in inductor in place of average inductor current.As the maximum inductor current is same as maximum switching current value, the switch current is used in the secondary loop.This helps in simplification of the current sensor.

Also the maximum inductor or switch current depends directly on the input voltage. Therefore, the secondary loop implements the input voltage feed forward method in case of current mode.

The major advantage of the current mode control is the option of input voltage feed forward.It also limits the maximum switching current and ensures equal current division in modular converters.It also causes decrease in the dynamic order of the converter.But the major drawback of current-mode control technique is its complexity.Also it involves compensation of voltage that is controlled by ramp signals to prevent the controller from being unstable.

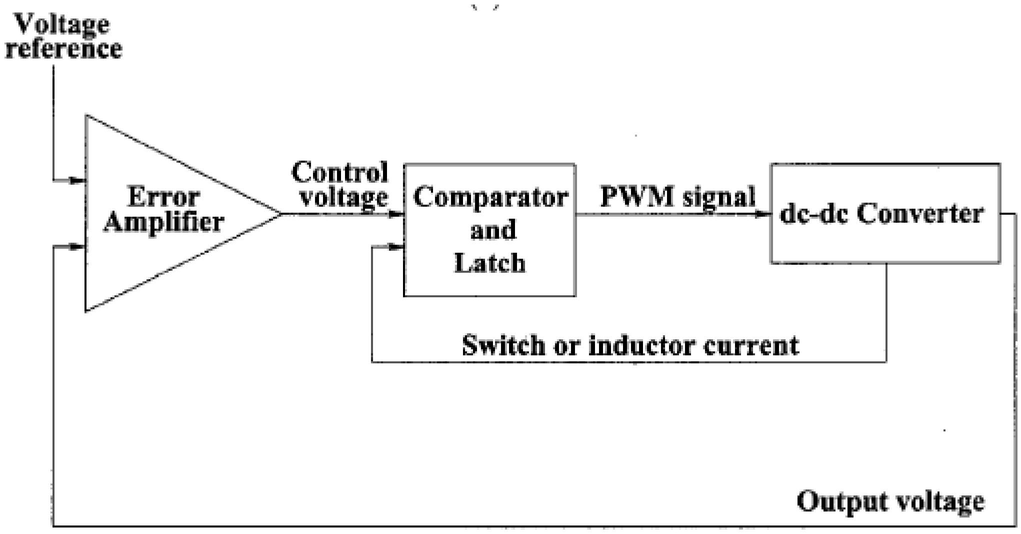

Figure 3.3: Current mode control technique for dc dc converter

3.3 CONTROLLER TUNING

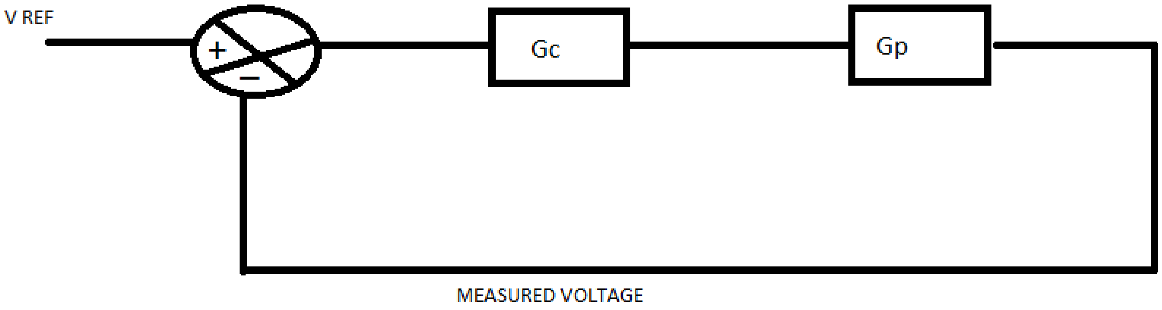

Figure 3.4: Closed loop feedback control for generating controlled PWM signal

In the present design a PI controller has been used to control the output voltage of the BuckBoost converter and generate a controlled PWM signal input to the igbt switch. Here the measured voltage is the filter capacitor voltage connected across the battery pack.An error signal is generated from the measured voltage and reference voltage and fed as input to the controller.The controller output generates a PWM signal by using a comparator.A controller has been designed for the proposed system for boost operation.The initial capacitor voltage is 10V while the nominal battery voltage is set as 8.5V

Gc represents the transfer function of a PI controller.

$Gc(s)=Kp+Ki/s$

Where Kp=steady state gain for proportional control

Ki= steady state gain for integral control

Gp represents the transfer function of the process during boost mode.In the designed circuit,during boost mode,the process represents a RL filter.

Hence, $Gp(s)=1/(s+R/L)$

where L=filter inductance and R=resistance in series with inductance

The equivalent transfer function of the negative feedback system is given by,

$G(s)=Gc(s)Gp(s)/(1+Gc(s)Gp(s))$

Substituting the transfer function equations for both controller and process in the above equation,we get

$G(s)=(Kps+Ki)/(S^2+(R/L+Kp)s+Ki)$

A general second order transfer function is given by,$G'(s)=wn^2/(s^2+2Twns+wn^2)$

Where wn=natural frequency,T=damping ratio

Comparing the equations for G(s) and G'(s),we get

$Ki=wn^2$; and $Kp+(R/L)=2Twn$

Let the Rise Time be set as 0.6s.

Now,rise time $Tr=1.8/wn$

Putting the value of Tr in the above equation,we get wn=3

Assumin T=.707 and putting the above obtained value of wn,we get the PI tuning parameters as follows:

Ki=9 and Ki=0.3

CHAPTER 4

SIMULATION AND RESULTS

CHAPTER 4

SIMULATION AND RESULTS

4.1 Closed loop Simulation of a Buck Boost converter with the designed values was done in the Matlab Simulink. The simulation results were found satisfactory and as expected. The various waveforms are as follows:

1.**BUCK OPERATION**-Duty cycle of PWM to switch-30% for input voltage 12V

Result:output voltage 5V, Ripple factor=Vr/Vo=1%

R=10ohm,Lb=25H,C=30uF,f=100kHZ

Output voltage(V) vs Time(seconds) waveform

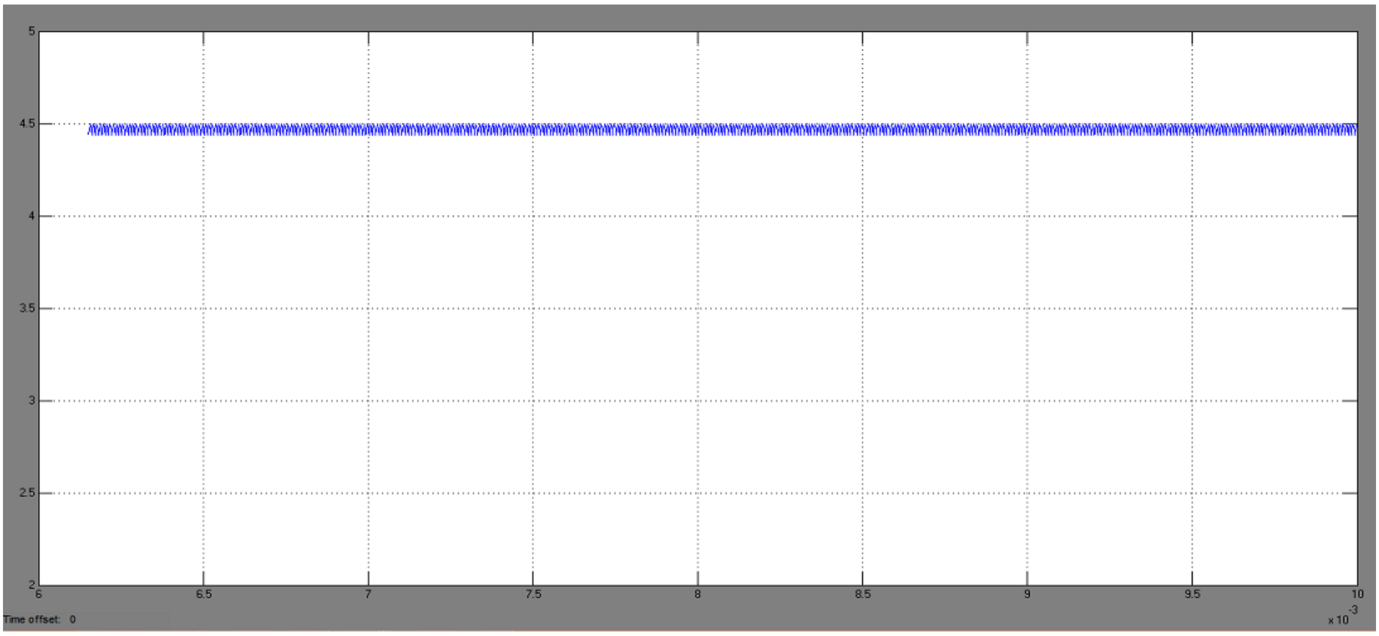

Figure 4.1: Output voltage waveform for buck mode

2.**BOOST OPERATION**-Duty Cycle-66% for input voltage 12V

Result-output voltage 24V, Ripple factor=Vr/Vo=1%

R=10ohm,Lb=6uH,C=70uF,f=100kHZ

Output voltage(V) vs Time(seconds) waveform

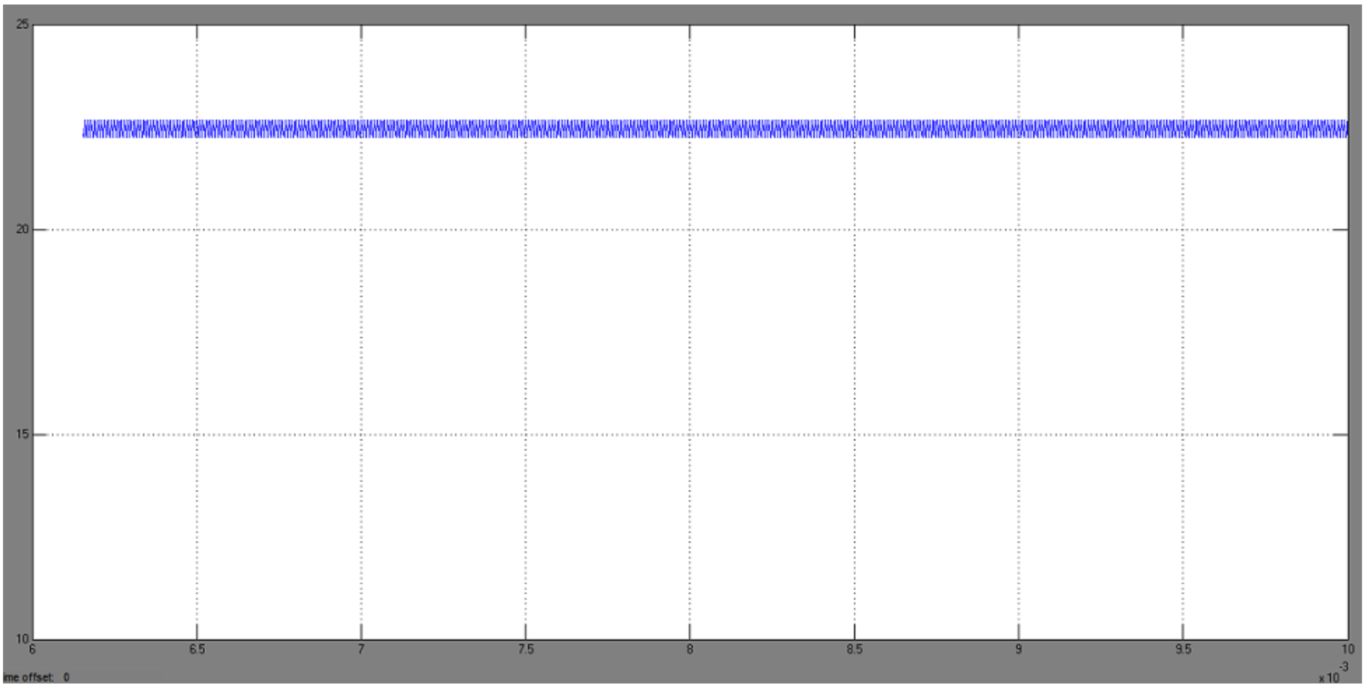

Figure 4.2: Output voltage waveform for boost mode

4.2 PWM Waveform generation of varying duty cycles using **STM32F107 ARM CORTEX M3 DEVELOPMENT BOARD.**

The various waveforms are as follows:

RESULT:INPUT PORT A,PIN 1:DUTY CYCLE -25%
PIN 3:DUTY CYCLE - 50%
PIN 4:DUTY CYCLE – 80%

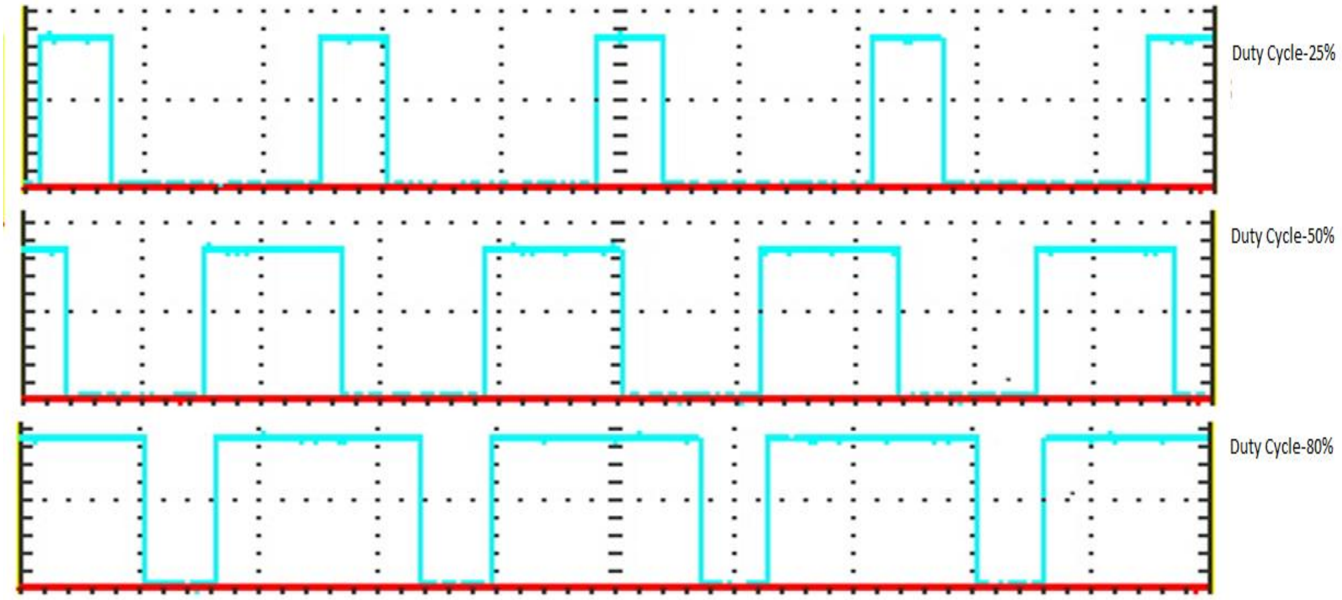

Figure 4.3: PWM waveforms for varying duty cycles

4.3 Closed loop Simulation of a Bidirectional Buck Boost converter with Battery pack and capacitor(without controller) was done in the Matlab Simulink. The simulation results were found satisfactory and as expected. The various waveforms are as follows:

4.3.1 **BOOST MODE-**

1.**PWM SIGNAL VS TIME (SECONDS) WAVEFORM-**

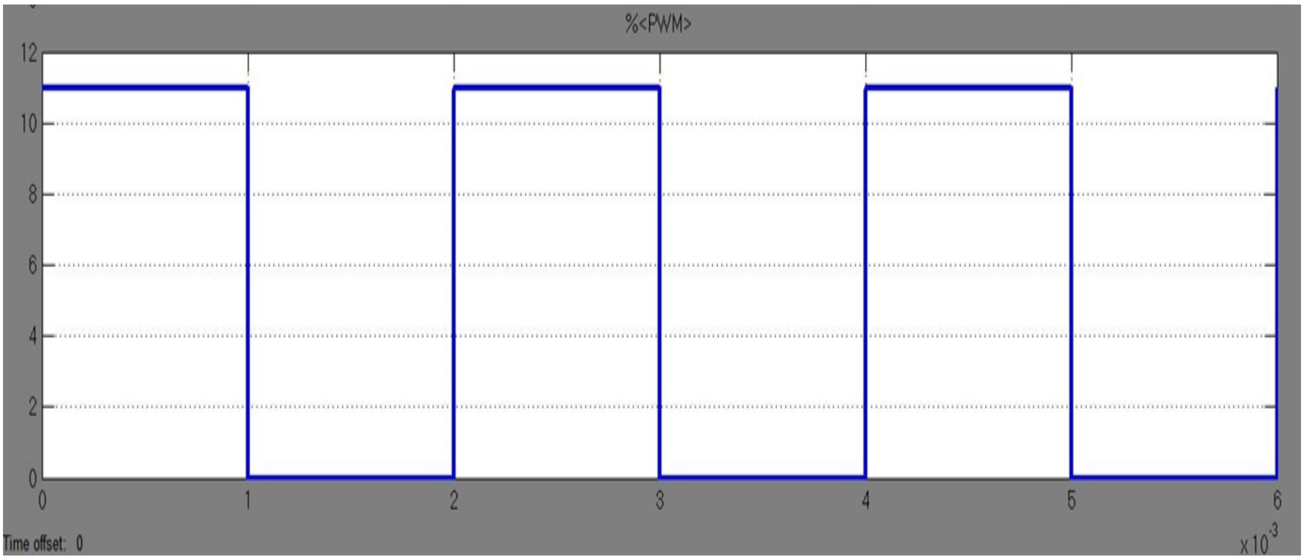

Figure 4.4: PWM waveform for the boost converter

Amplitude of the signal is 11V
Time period-2ms

2.**BATTERY VOLTAGE(Vbat) vs TIME(SECONDS) WAVEFORM-FOR GIVEN PWM SIGNAL**

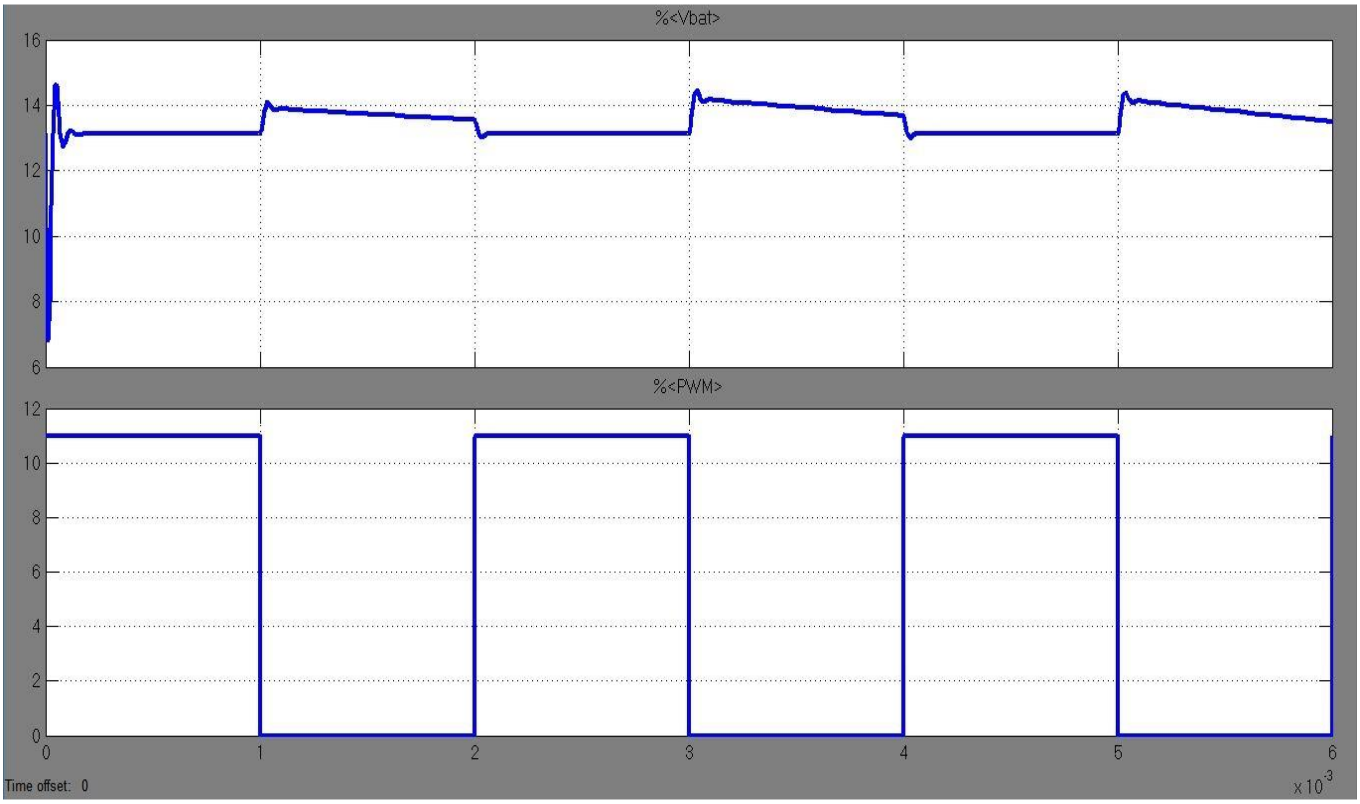

Figure 4.5: Battery voltage waveform(boost mode)

The nominal battery voltage is set at 13V.When T2 is on, the battery current is zero, hence battery voltage remains constant.But when T2 is turned off,the inductor energy is transferred to the battery pack,hence its voltage increases.

3. **BATTERY CURRENT(Ibat) vs TIME(SECONDS) WAVEFORM-FOR GIVEN PWM SIGNAL**

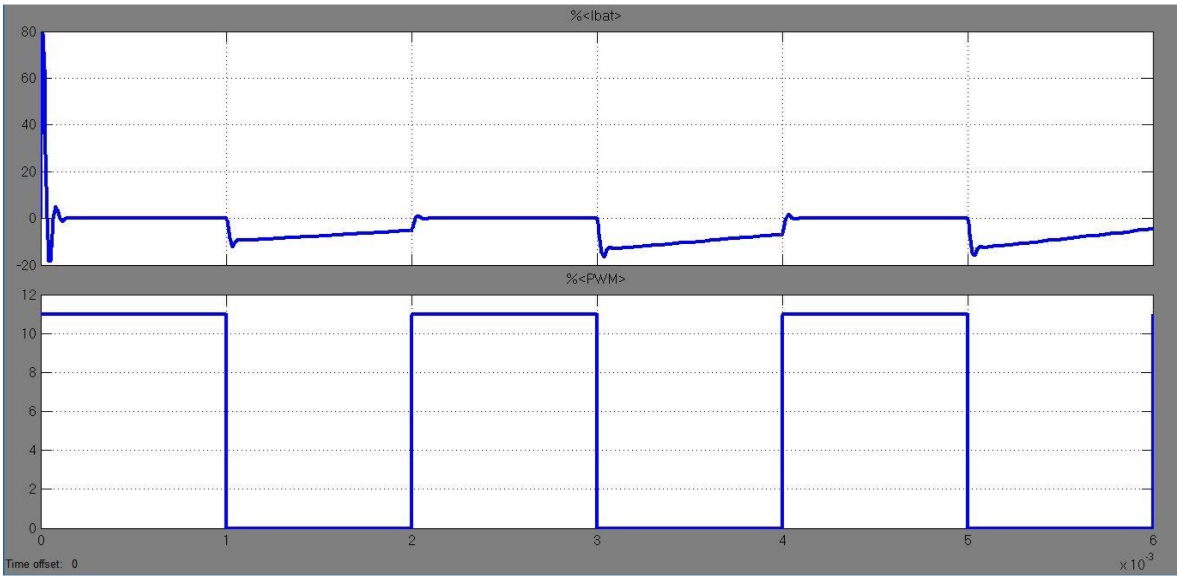

Figure 4.6: Battery current waveform(boost mode)

When T2 is on, the battery current is zero, as .But when T2 is turned off,the inductor energy is transferred to the battery pack,hence current increases.The negative current indicates that the flow of current is from capacitor towards the battery.

4. **CAPACITOR VOLTAGE(Vcap) vs TIME(SECONDS) WAVEFORM-FOR GIVEN PWM SIGNAL**

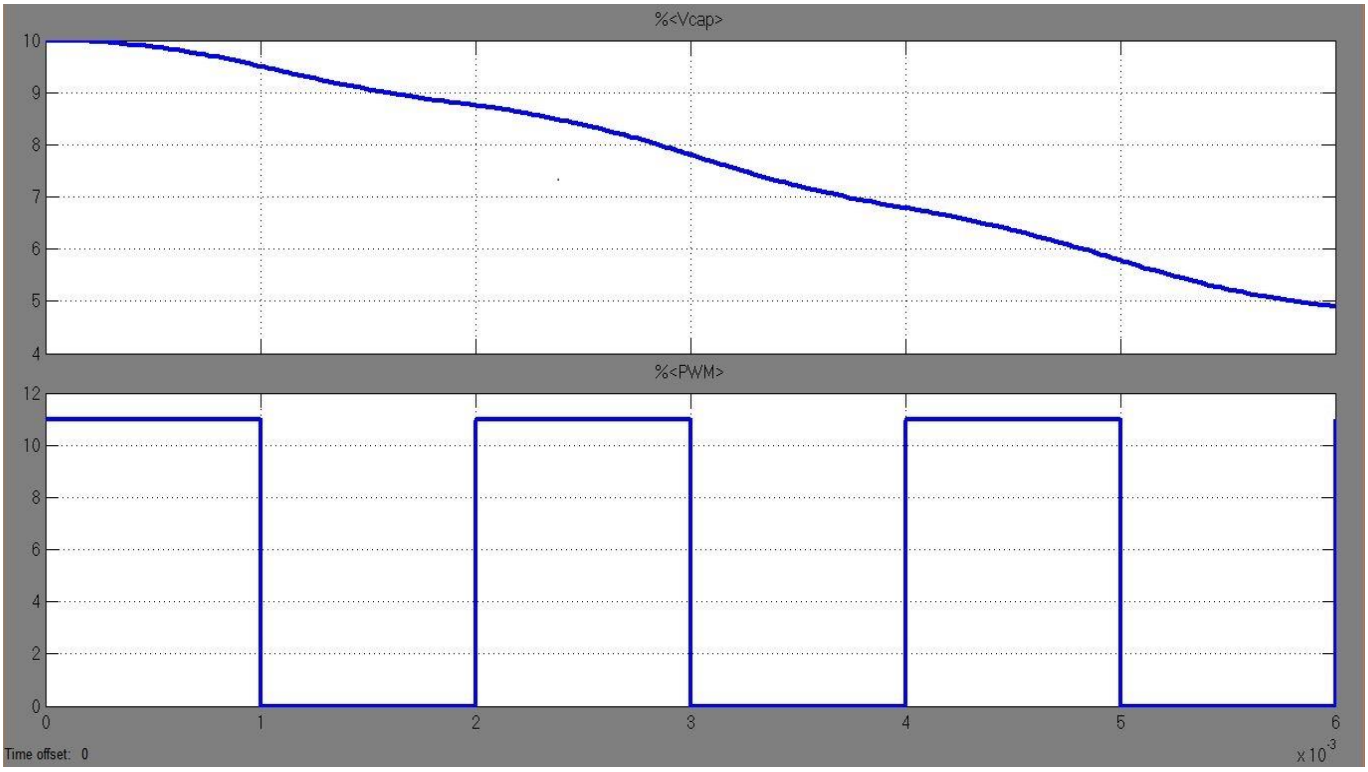

Figure 4.7: Capacitor voltage waveform(boost mode)

As the energy is transferred from capacitor to battery, the capacitor discharges and its voltage reduces from 10V(initial value of capacitor voltage) to 5V.

5. CAPACITOR CURRENT(Icap) vs TIME(SECONDS) WAVEFORM-FOR GIVEN PWM SIGNAL

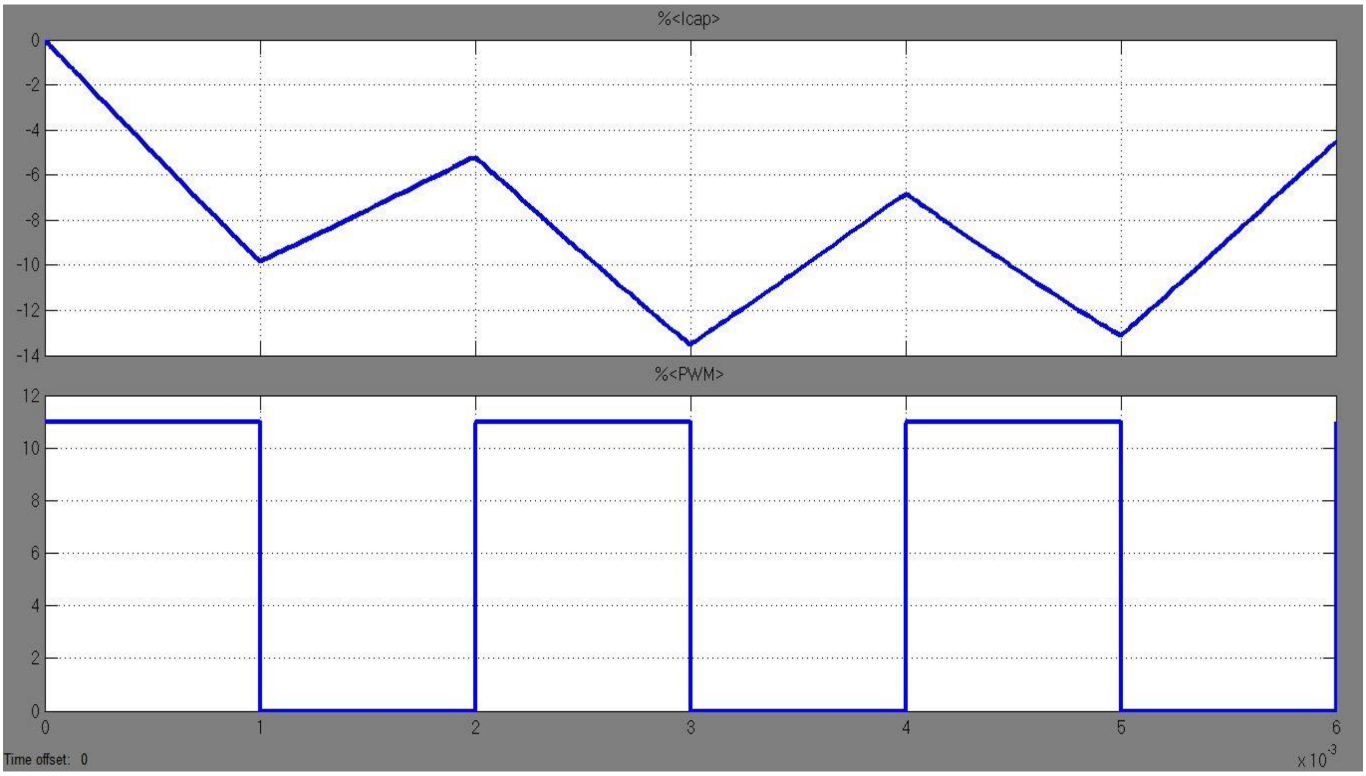

Figure 4.8: Capacitor current waveform(boost mode)

When T2 is on,the inductor current increases.When turned off,the inductor energy is transferred to the battery,hence its current reduces.

4.3.2 BUCK MODE

1. PWM SIGNAL VS TIME (SECONDS) WAVEFORM-

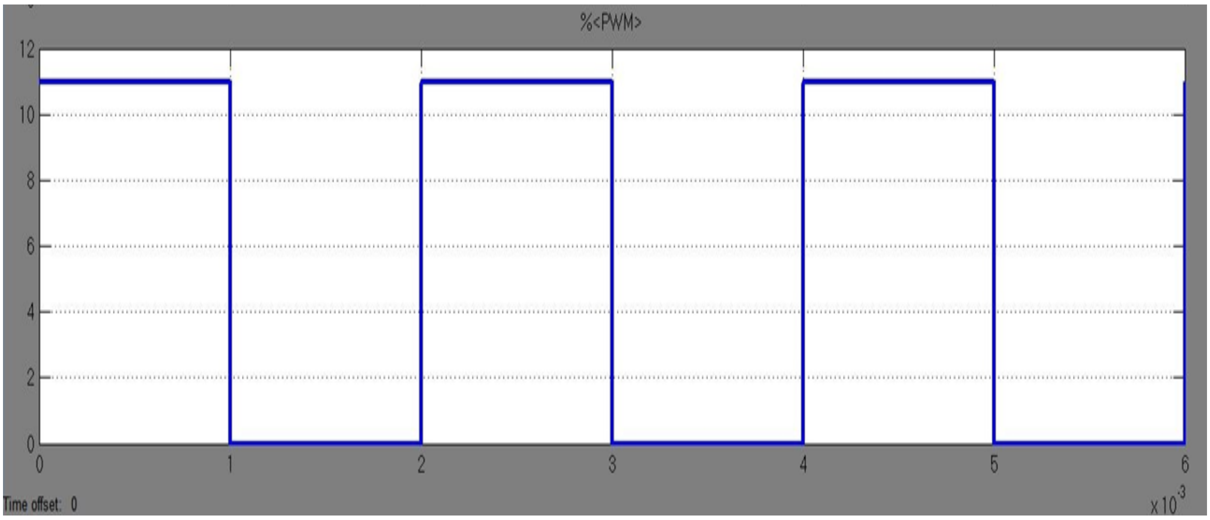

Figure 4.9: PWM waveform for the buck converter

2.**BATTERY VOLTAGE(Vbat) vs TIME(SECONDS) WAVEFORM-FOR GIVEN PWM SIGNAL**

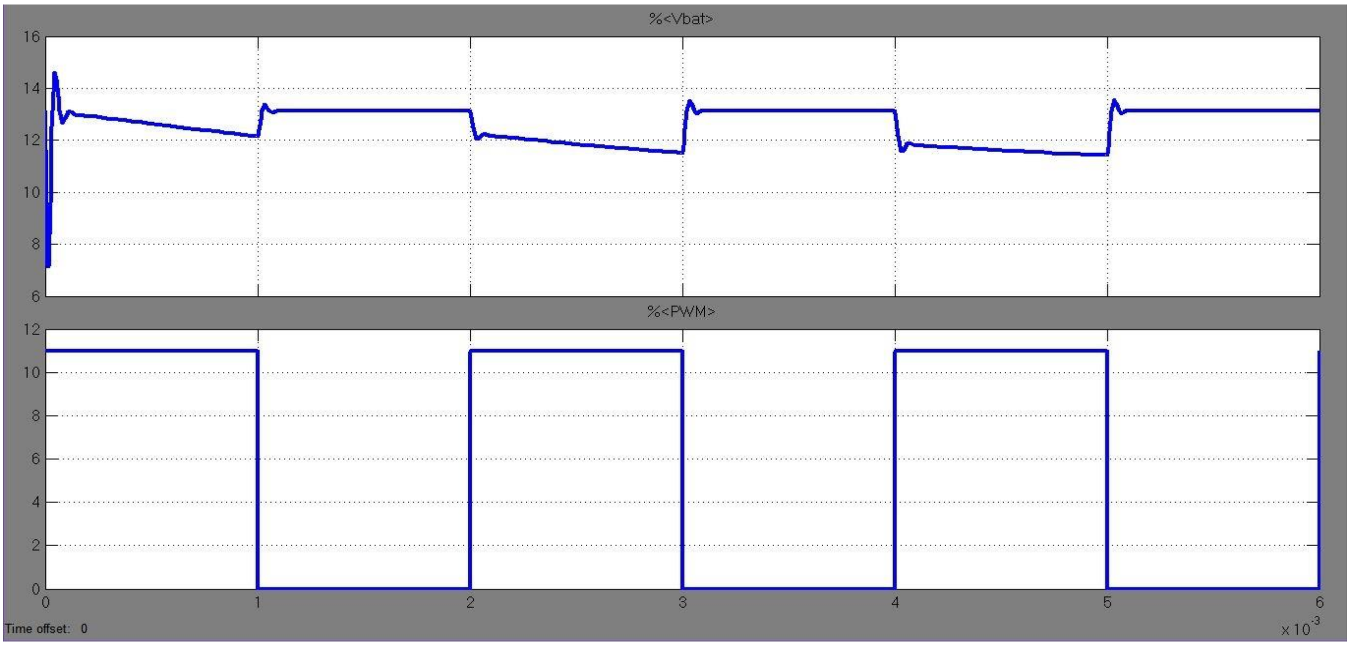

Figure 4.10: Battery voltage waveform(buck mode)

3. **BATTERY CURRENT(Ibat) vs TIME(SECONDS) WAVEFORM-FOR GIVEN PWM SIGNAL**

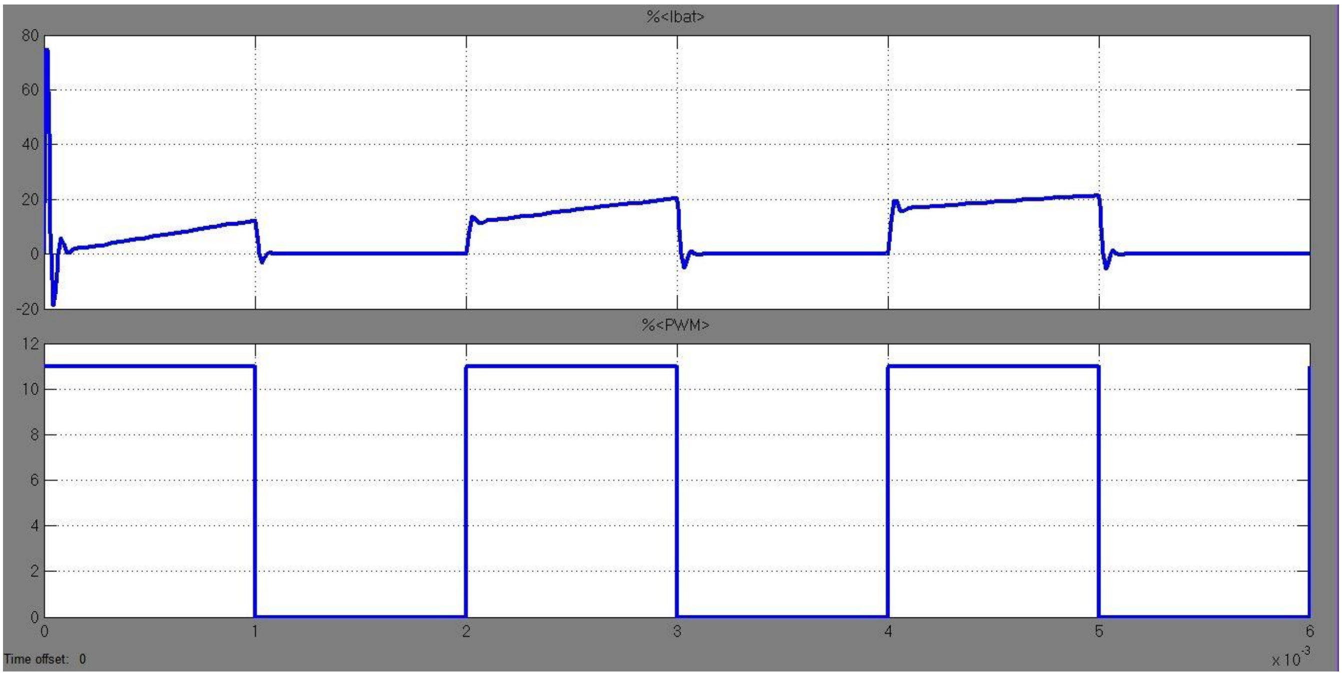

Figure 4.11: Battery current waveform(buck mode)

4. CAPACITOR VOLTAGE(Vcap) vs TIME(SECONDS) WAVEFORM-FOR GIVEN PWM SIGNAL

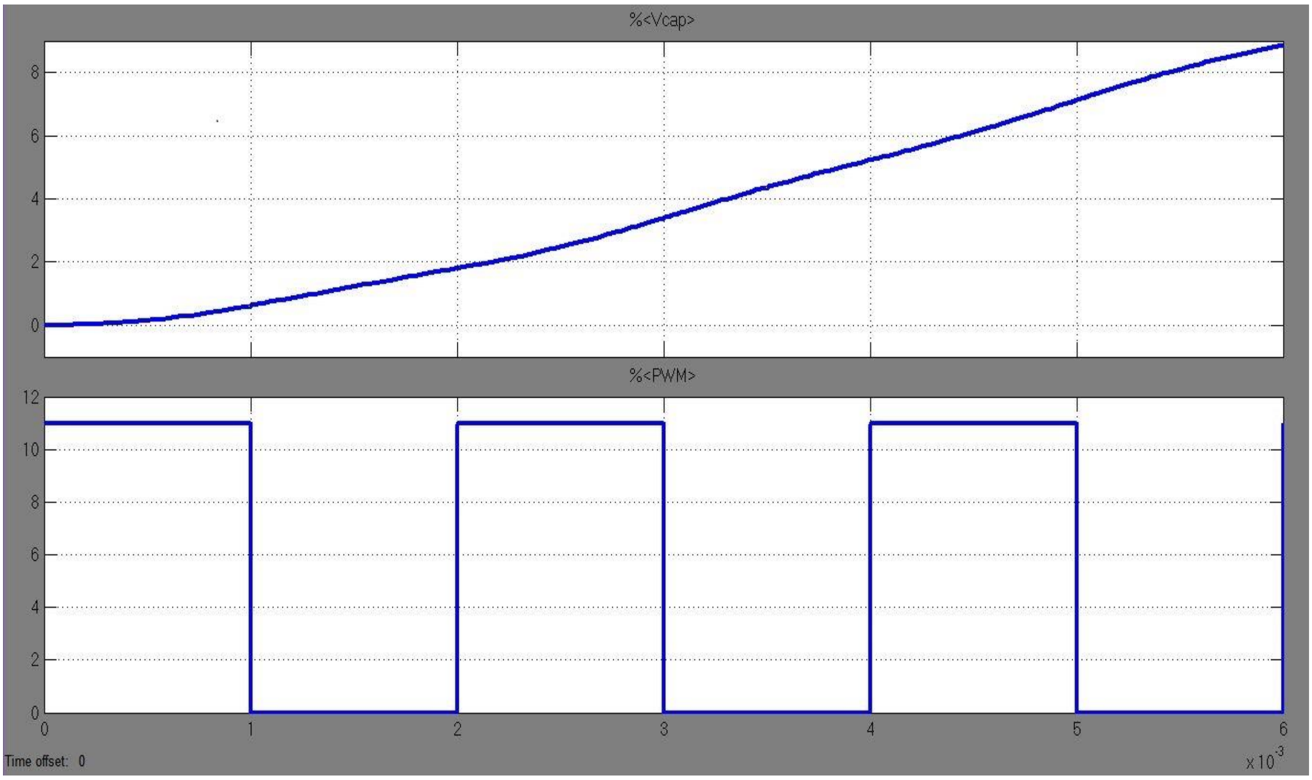

Figure 4.12: Capacitor voltage waveform(buck mode)

5. CAPACITOR CURRENT(Icap) vs TIME(SECONDS) WAVEFORM-FOR GIVEN PWM SIGNAL

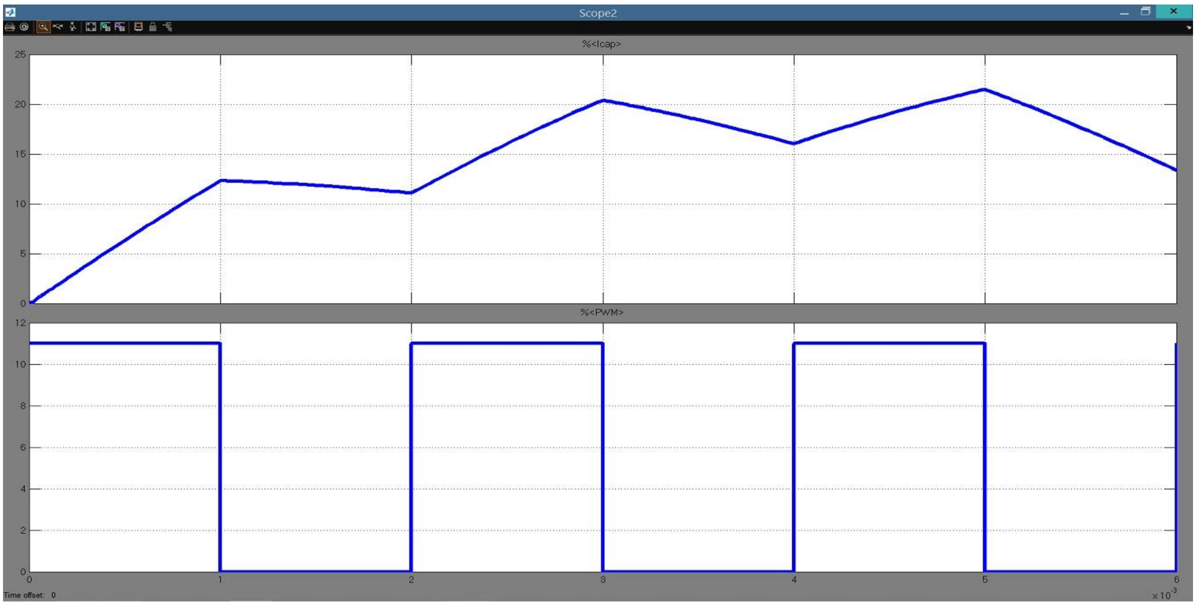

Figure 4.13: Capacitor current waveform(buck mode)

4.4 Closed loop Simulation of a Bidirectional Buck Boost converter with Battery pack and capacitor with PI controller was done in the Matlab Simulink. The simulation results were found satisfactory and as expected. The various waveforms are as follows:

BOOST MODE

1.**BATTERY DISCHARGING AFTER 0.5 seconds due to the applied load**

BATTERY VOLTAGE(Vbat) vs TIME(SECONDS)

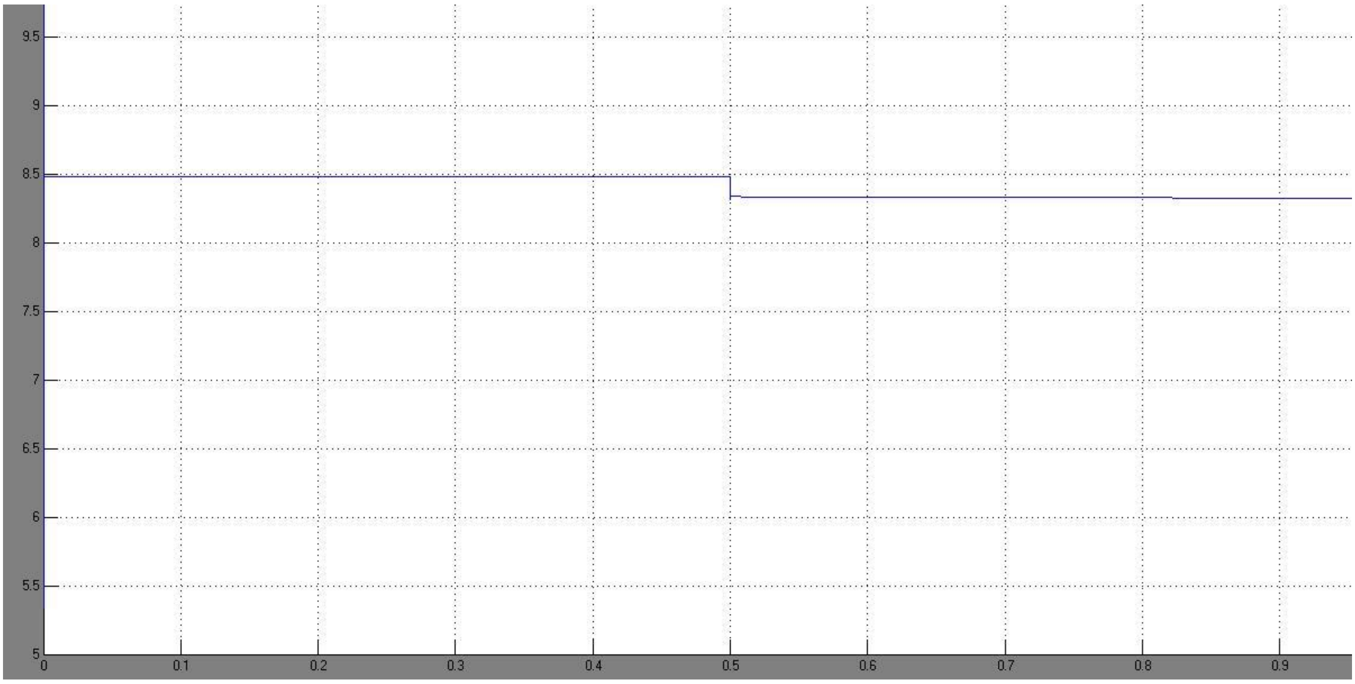

Figure 4.14: Battery discharging waveform due to applied load

The battery voltage reduces from its nominal value of 8.5V to 8.3V after 0.5 seconds due to a load applied to the battery pack.Hence the battery discharges.

2.**BATTERY CHARGING(BOOST MODE)-**

BATTERY VOLTAGE(Vbat) vs TIME(S)-

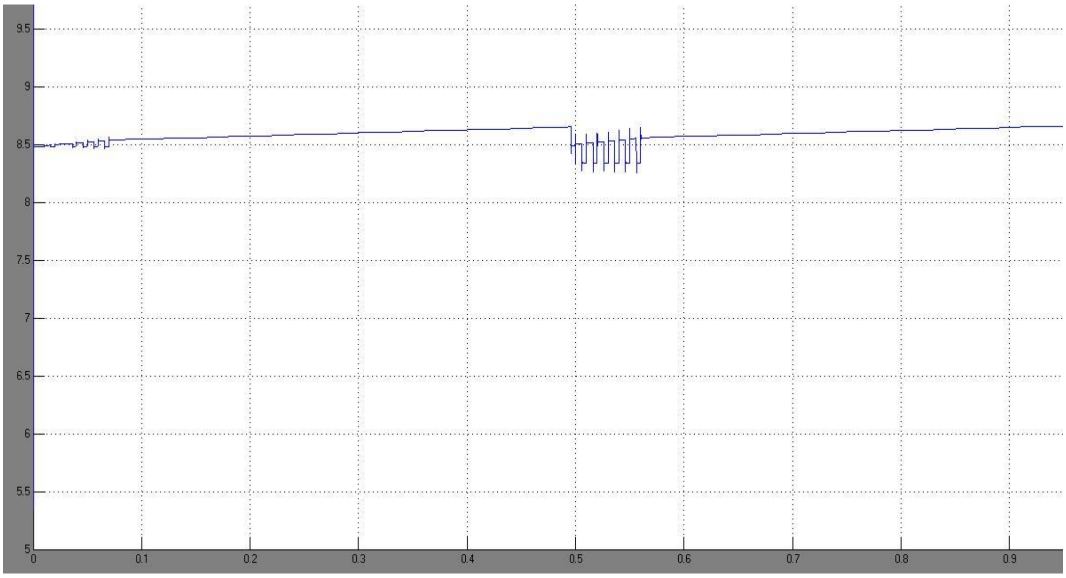

Figure 4.15: Battery voltage waveform(boost mode)

When controlled PWM is applied to T2 (boost mode), the battery charges after 0.5seconds and its voltage increases due to the transfer of energy from capacitor.

3.**CAPACITOR DISCHARGING AFTER 0.5seconds**

CAPACITOR VOLTAGE(Vcap) vs TIME(SECONDS)

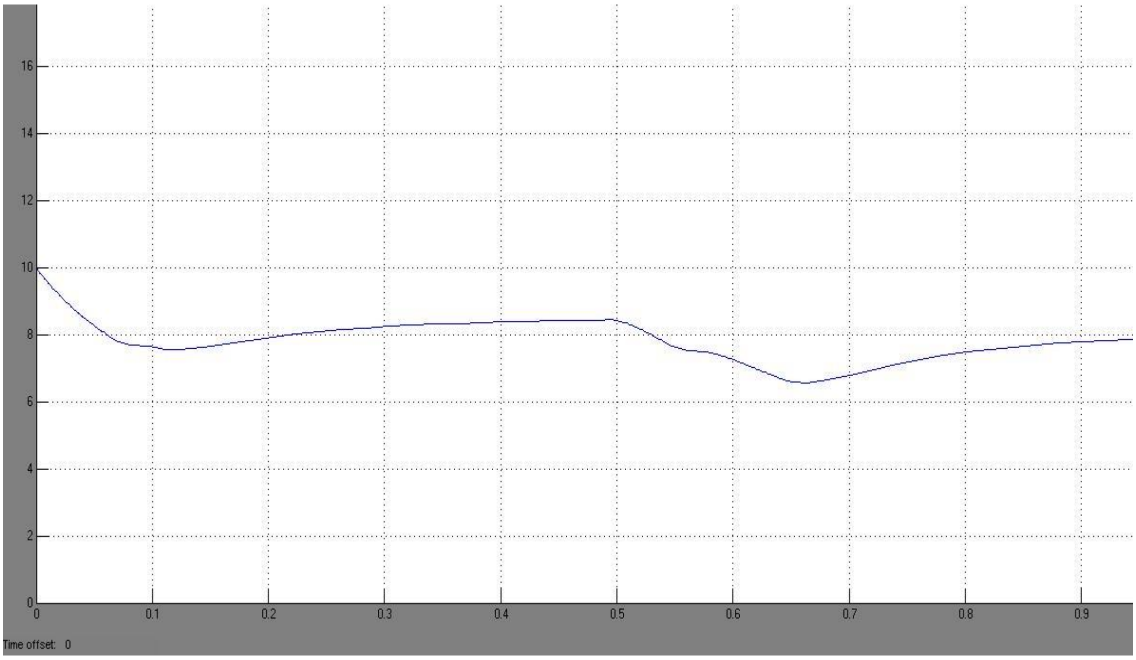

Figure 4.16: Capacitor voltage waveform(boost mode)

The capacitor discharges after 0.5seconds(hence the decrease in voltage) but again starts charging due buck mode operation.

4.5 CONCLUSION

The above design can be used to drive a motor for an electric vehicle. During regenerative braking,the motor acts as a generator,with current flowing in the opposite direction.This motor drives the electric vehicles.During braking,the motor operates as a generator and the load output voltage is the output voltage of the motor.Braking takes place by energy transfer in a controlled manner to the load .The proposed system when used with motor load provides higher decelerations and accelerations of the electric vehicle with minimum power losses, and minimum degradation of battery.The system uses an IGBT Buck-Boost converter,a main battery pack to drive the motor,a capacitor to store energy and system controller measures the converter output voltage and generates a controlled PWM. Electrochemical batteries can be incorporated in the system to improve the overall performance of the electric vehicle during transient time and also to enhance lifespan of batteries. Thus, fast charging during regenerative braking or sudden and fast battery discharge during acceleration can be overcome.

4.6 FUTURE WORK

For proper hardware implementation of the proposed design, a good control strategy is required to measure the battery charge, battery current,speed of the motor, the instantaneous value of currents in both load and capacitor and original capacitor voltage to generate the PWM signal for semiconductor switches. If motor speed increases(acceleration),the capacitor is kept discharged by the control system. If motor is static, the capacitor is charged to its maximum voltage. If motor speed is medium,the capacitor is kept at medium voltage in order to allow decelerations or accelerations in the future.When motor accelerates, controller must transfer energy from capacitor. In the opposite situation (regenerative braking),the controller transfers energy from battery pack. This control strategy can be implemented using a microcontroller.

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