Speed Control and Regenerative Braking of Bidirectional DC-DC Converter

Fed Permanent Magnet DC Motor

A Thesis Submitted in partial fulfilment for the award degree of

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In

Electrical Engineering

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<u>Certificate</u>

This to certify that the thesis entitled "Speed Control and Regenerative Braking of Bidirectional DC-DC Converter Fed Permanent Magnet DC Motor", submitted to the National Institute of Technology Rourkela, Odisha by Prem **Sai Tirkey (111EE0239)** and **Naganaveen Kumar Chiruvolu (111ee0410)** for the award of Bachelor of Technology in the Department of Electrical Engineering is the bonafide record of research work carried by them under my supervision and guidance.

……………………………………………..

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This thesis mainly emphasis on speed control and regenerative braking of PMDC motor fed by a bidirectional DC-DC converter. The main objective is to increase the efficiency of the motor and also the power flow in both directions which also further improves efficiency during regenerative braking mode. Different types of bidirectional DC-DC converters have been studied. As we all know that during the buck mode operation of converter regenerative braking occurs which in turn charges the battery whereas in boost mode the battery supplies the required power to run the motor. So out of all the present bidirectional DC-DC converters we have opted for half bridge non-isolated bidirectional DC-DC converter because it is cheap, less number of components and due to its low weight. In order to decrease the switching losses we have implemented International rectifiers (IR2110), in which the input is a pulse and its outputs are two pulses complimentary to each other of required period through which MOSFET can be triggered. So for further reduction in losses we have optimized all the values of inductor, capacitor by zero voltage techniques so as to achieve the required specifications. All the parameters discussed in the thesis have been controlled and simulated during both the operations and are verified with theoretical results.

BDC ………………………………………………………….. Bidirectional dc-dc converters

DC ………………………………………………………...……………..Direct current

HEV …………………………………………….…….…………Hybrid electric vehicles

UPS………………………………………………………………Uninterruptible power supplies.

IBDC ……………………………………………………………………………… Isolated BDC

AC-link …………………………………………………………..Alternating current link

PMDC motor …………………………………………………Permanent magnet DC motor

PID controller ……………………………...…Proportional, integral and derivative controller

ZVRT………………………………….. Zero voltage crossing resonance switching technique

NBDC converter ………………………………………………Non-isolated DC-DC converter

CCM ....continuous conduction mode

DCM …………………………………………………………discontinuous conduction mode

MOSFET……………………………………….metal–oxide–semiconductor field-effect transistor

1.1 INTRODUCTION

Bidirectional dc-dc converters (BDC) [1] [4] have got a ton of consideration as of late and it is the progressive exploration work because of the expanding need for the systems with the ability of bidirectional transfer of energy between two dc buses and switched mode DC-DC converters are one of the least difficult and are simple electronic circuits which can change from one level of electrical voltage into another by switching activity in both directions. Alongside customary uses in dc engine drives, new utilizations of BDC is energy stockpiling in renewable energy frameworks, hybrid electric vehicles (HEV) [2] [7] and UPS. Because of changing nature of renewable energy resources similar to wind and sun powered, makes them inadmissible for only source of power and at same time interest for renewable energy systems due consumption of fossil fuel is expanding over the past decade. An optimal answer for this issue is to utilize an energy storing system with the renewable energy source for consistent power supply and keep up a smooth and constant power stream to the load. Thus batteries and super-capacitors are the most widely recognized and efficient storing devices from low to medium-power range. A dc-dc converter is constantly needed to permit transfer of energy between input storage system and whatever remains of system. So, this type of converters should be capable of bidirectional capacity of power flow with adaptable control in every working mode. In HEV applications, BDCs links various dc voltage systems and exchange energy between them. Profoundly effective with lightweight, little less in size in its structure and high unwavering quality are some essential viewpoint for the BDC utilized as a part of such an application which can be attained considerably by half bridge BDC. During normal mode in a line UPS, the UPS yield terminals are joined with the grid and energy is bolstered back to the inverter dc buses and charge the batteries through a BDC. If there is any break of power supply then the battery bolsters the inverter dc buses through BDC yet in opposite direction of power flow. The study, pattern, design of parameters and adjustment of switching converters are the principle calculates that needs to be weighed in planning a BDC. Numerous control techniques are utilized for controlling the switch method of DC-DC converters and the straightforwardness controller structure is dependably sought after most mechanical with superior applications. For each control technique we have their particular benefits and downsides, and their adequacy is dictated by the utilization and where it is associated.

BDCs are of two types: non-isolated and isolated [3]. Non-isolated BDCs (NBDC) are simpler due to absence of transformer than isolated BDCs (IBDC) and their efficiency is also high.

However, galvanic isolation is required in many applications and mandated by different standards. The complexity of IBDCs stems from the fact that an AC-link must be present in their structure in order to enable power transfer via a magnetically isolating media, i.e. a transformer. For each outlining of item or simply exploring different algorithms regarding different calculations and plans, simulation is done before the genuine physical usage. Different instruments are accessible for developing and reenacting electrical and electronic circuits, including Math Works Sim Power Systems. It is conceivable to evade this by speaking to the framework as a mathematical model.

1.2 OBJECTIVE

The main objective of the work is to study the various converter circuit and to plan the bidirectional dc-dc converter circuit to run the PMDC and subsequently can control it in a productive way by enhancing the proficiency and diminishing the errors. For speed control of PMDC motor we used the non-isolated half bridge DC-DC bidirectional converter using PID controller and complementary switching. Furthermore, utilize the above for the usage and configuration simulation is done.

1.3 MOTIVATION

In this digitally occupied era, control and automation is major emerging field in electrical system and we had studied control system in our courses So, the essential target of this work is to plan, show and mimic the Bidirectional DC-DC converter fed PMDC engine. As per this target, the technique for selecting a fitting topology of the bidirectional DC-DC converter has been exhibited.

1.4 LITERATURE REVIEW

The clarification behind enhancing the benefit and to minimize the mistakes we have been utilized IEEE search paper ([1] to [7]), numerous online inquiry paper and Wikipedia to learn, outline and examination. We have specified the different research paper [1] to , taking into account this we planned and contemplated our work. The topological study to drive and to inspect between them has been displayed. The part, likewise, the essential of the power equipment and dc- dc converter was overviewed and cleared up. The examination between the various NBDC on the reason of their execution has been done. The power stage and the ZVRT exchanging was introduced. A high and low side MOSFET driver IR2110 controlled bidirectional DC -DC converter was shown.

2.1 INTRODUCTION

The DC-DC Converter shift the input DC voltage and current to a sought yield DC voltage or current due to this property it is called DC equivalent to AC transformer having continuously changing turn ratio. DC-DC converters due to application lossless switch give proficient change of DC voltage starting with one level then onto next. The bi-directional dc-dc converter in motor drives for HEVs [2] is utilised to control the both motoring and regenerative braking operations. For motoring operations of motor drive, a dc-dc converter change the motor current keeping in track to take after the torque reference signal and for the power flow to be reversed, to recuperate the vehicle kinetic energy from wheel in the battery by method for motor drive regenerative braking operations. This paper manages with the analysis of bi-directional converter topologies. Each of them permits stepping the battery voltage level either up or down with or without changing the polarity.

2.2 CLASSIFICATION OF BIDIRECTIONAL DC-DC CONVERTERS

Depending on their structure BDC are classified [3] as follows:

- Non-isolated Bidirectional DC-DC converter (NBDC).
- Isolated Bidirectional DC-DC converter (IBDC).

2.3 NON-ISOLATED BIDIRECTIONAL DC-DC CONVERTER TOPOLOGIES AND ITS OPERATIONS

The basic switch mode DC-DC converters such as buck and boost converters (and their derivatives) do not have bidirectional power flow capability. This limitation is due to the presence of unidirectional biased diodes in their structure which prevents reverse current flow. Generally, a unidirectional dc-dc converter can be turned into a bidirectional converter by replacing the diodes with a controllable switch in its structure and connecting a diode across switch in reverse to the power flow.so we have in Fig. 1.1 which shows the half bridge BDC from a basic buck and boost converter. Similarly bidirectional CUK and Buck-Boost cascade converter can be derived from their respective unidirectional converter shown in figure 2.2.

The limitations associated with the half bridge NBDC are:

• It can step-up or step-down input voltage only from one direction. In technically, this may give the value of voltage ratio which is $d = \frac{Vout}{Vin}$, which may be either smaller or greater than unity in one direction or other.

• When the voltage proportion gets to be substantial, this structure gets to be unfeasible.

To improve the above limitation, other IBDC have been proposed like buck-boost converter, buck-boost cascade, Cuk and sepic-zeta. The buck-boost or Cuk converters may be implemented when we have the difference magnitude of two dc bus voltages to be is very small and the value of voltage ratio should be near to unity is required.

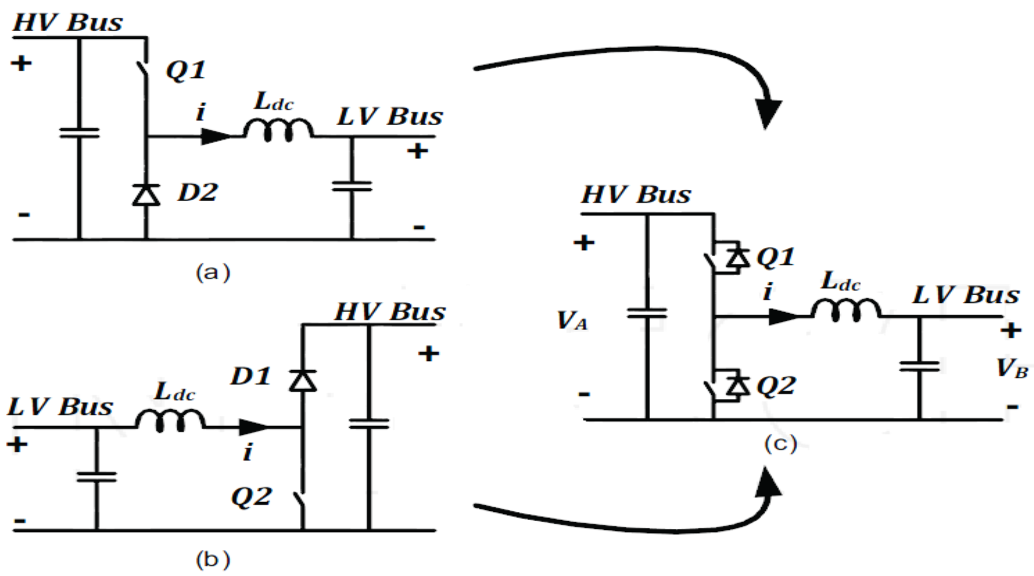

Fig. 2.1 (a) Buck converter (b) Boost converter (c) Half bridge converter.

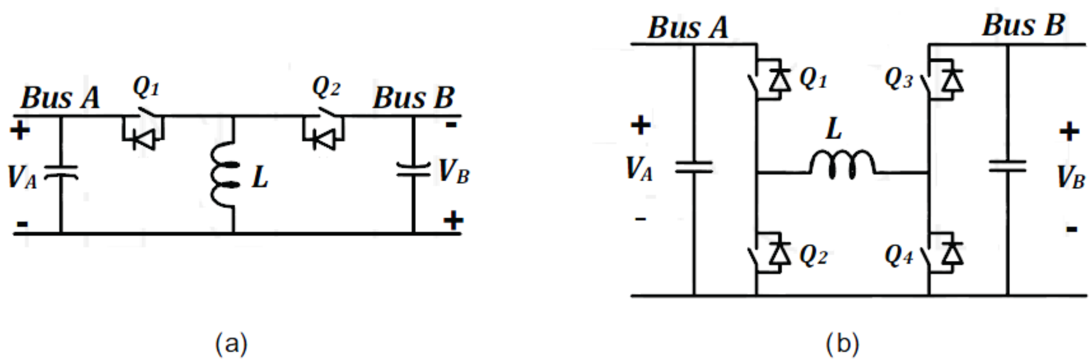

Fig. 2.2 (a) Bidirectional buck-boost and (b) two back-to-back connected Buck-Boost cascade.

2.3a. HALF BRIDGE CONVERTER

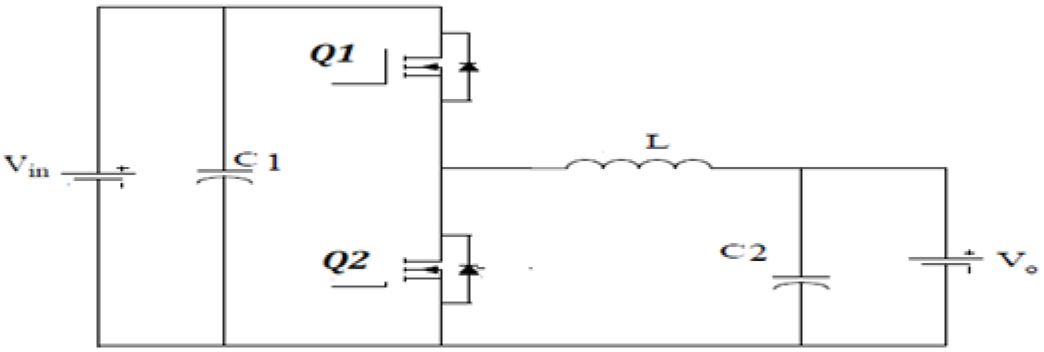

Figure 2.3 Half bridge converter

Buck Operation:

During buck mode [1] of operation, i.e.at the point when the power is exchanged from the high voltage (V_{in}) to the low voltage (V_{out}) side, *Q1* is on while switch *Q2* is kept off and circuit get to be as indicated in figure 2.4. For analysis of circuit we assumed-

- The components will be treated as ideal ones i.e. switching losses are disregarded. .
- The value of V_O will be constant through the operation i.e. the ripple value of output voltage is zero.
- Consistent steady state operation of circuit can be visualized i.e. the inductor current more than one cycle in will continue as before.

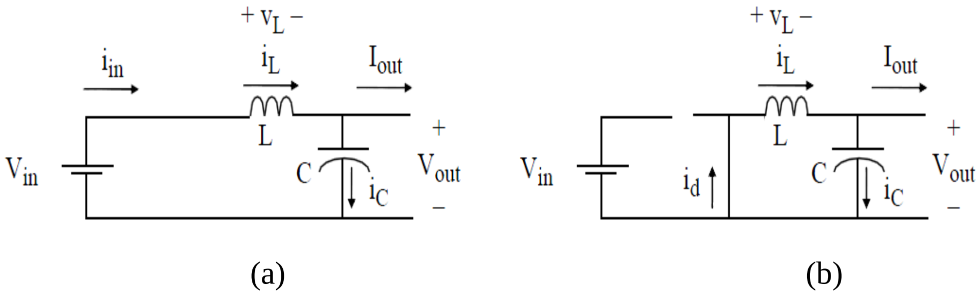

Figure 2.4 (a) Switch Q1 on and Q2 off for DT seconds. (b) Both switch Q1, Q2 off and D_2 gets forward biased for DT to T seconds.

When the switch *Q1* is closed, then diode D_2 get reverse biased and open. Then

$$\frac{di_L}{dt} = \frac{v_L}{L} = \frac{V_{in} - V_{out}}{L}, \quad 0 \le t \le DT \qquad (1)$$

Furthermore the inductor will get charged. At the point when the switch *Q1* and *Q2* are kept off, as the diode will be in forward so biased mode the current i_L will continue to flow in the diode D_2.

$$\frac{di_L}{dt} = \frac{v_L}{L} = -\frac{V_{out}}{V_{in}}, \text{DT} \le t \le T \qquad (2$$

As the inductor will be discharging we have the voltage waveform as shown in Figure 2.5.

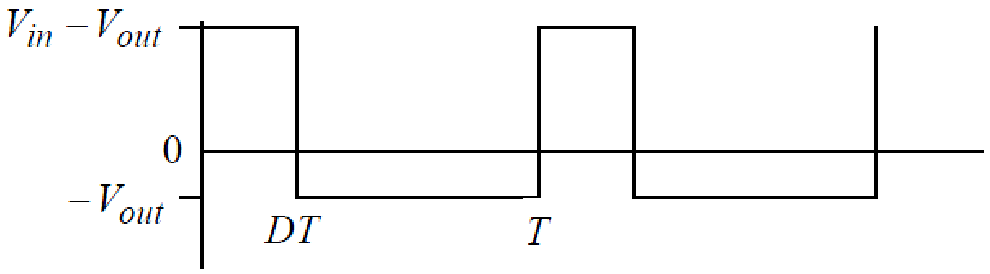

Figure 2.5 Inductor Voltage *Vs* Time in Continuous Conduction

From the steady-state principle of inductor, the value of average voltage v_L should be zero. Average v_L over one period

$$\frac{(V_{in} - V_{out})DT + (-V_{out})(1-D)T}{T} = 0 \quad (3a)$$

$$V_{out} = DV_{in} \quad (3b)$$

Equations (1) and (2) give the rate of rise and fall of i_L for buck mode. Applying KCL in the normal way, and perceiving that the normal current through a capacitor working in steady state is zero, it is

$$i_{Lavg} = I_{out} \quad (4)$$

From (1), (2), and (4) graph of i_L is

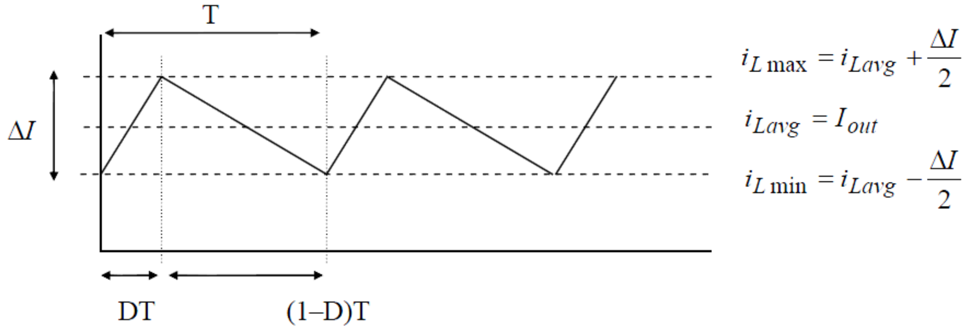

Figure 2.6 Inductor Current Waveform for Continuous Conduction

So, $$i_{Lavg} = \frac{i_{Lmax} + i_{Lmin}}{2}, \quad i_{Lmax} = i_{Lavg} + \frac{\Delta I}{2}, \quad i_{Lmin} = i_{Lavg} - \frac{\Delta I}{2} \quad (5)$$

From equation (1) and figure (1.6),

$$\frac{di_L}{dt} = \frac{V_{in} - V_{out}}{L} = \frac{\Delta I}{DT}$$

$$\Delta I = \frac{V_{in} - V_{out}}{L} DT = \frac{V_{in} - DV_{in}}{L} DT = \frac{V_{in} D(1-D)}{fL} \quad (6)$$

For maximum ripple, D = ½. Thus,

$$\Delta I_{max} = \frac{V_{in}}{4fL} \tag{7}$$

RMS inductor current is

$$I_{rms}{}^2 = I_{rms}{}^2 + \frac{\Delta I^2}{12} \tag{8}$$

For the boundary of CCM, i_{Lmin} = 0 and $\Delta I = 2i_{Lavg} = 2I_{out}$ Using Figure 2.7 and the inductor discharging slope in (2),

$$\frac{-V_{out}}{L_{boundary}}(1-D)T = -\frac{V_{out}}{L_{boundary}\, f}(1-D) = -I_{out}, \tag{9}$$

$$L_{buondary} = \frac{V_{out}}{2I_{out}\, f}(1-D) \tag{10}$$

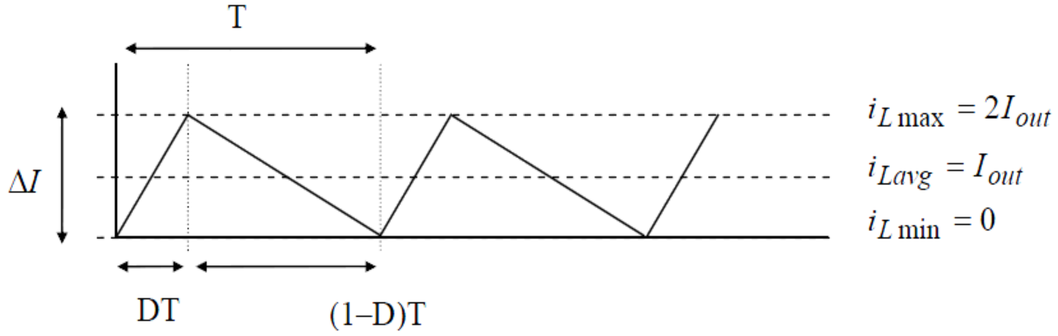

Figure 2.7 Inductor Current at the Boundary of Continuous Conduction

Boost Operation:

In the boost mode, power is transferred from low voltage (V_{out}) to high voltage (V_{in}).in this mode of operation *Q1* will be turned OFF whereas switch *Q2* can act as a controlled one. When *Q2* is closed, the diode D_1 get forward biased

$$\frac{di_L}{dt} = \frac{v_L}{L} = \frac{v_{out}}{L} \quad 0 \le t \le DT \tag{11}$$

And the inductor will be charging during this time. When the switch *Q2* and *Q1* are kept off, Since the diode D_1 gets forward biased the current flowing through it i_L will decreases at a rate of

$$\frac{di_L}{dt} = \frac{V_{out}-V_{in}}{L} \text{ , } DT \le t \le T \tag{12}$$

And the inductor is discharging. By steady-state inductor principle, the average voltage $v_L$across L is zero.

$$\frac{(V_{out})DT + (V_{out} - V_{in})(1-D)T}{T} = 0$$

$$V_{in} = \frac{V_{out}}{1-D} \tag{13}$$

The value of Inductor in low side results lower value of ripple current which improves the efficiency. For example we refer to charge and discharge of battery through these values and accomplish high efficiency and more life time.

The value of capacitor is found to be

$$C = \frac{I_{out}}{4\Delta Vf} \quad (14)$$

2.3b. BUCK-BOOST CONVERTER

In buck-boost converter, the switch will connect the inductor across power input and output alternatively. The output voltage polarity is reversed with respect to input voltage with a capacity of step-up or step-down from either of the directions. The conversion ratio is M (D) = - D/ (1 – D). At the point when one switch operates, other remain idle. Main limitation in this converter is that duty cycle should be kept less than unity for buck and more than unity for boost which requires continuous monitoring.

From both the modes of operation we can derive the following equations

$$Vout = -\frac{D}{1-D} V_{in} \quad (15)$$

Where $0<D<1 \Rightarrow D = \frac{\frac{V_{in}}{V_{out}}}{1+\frac{V_{out}}{V_{in}}}$

Circuit diagram:

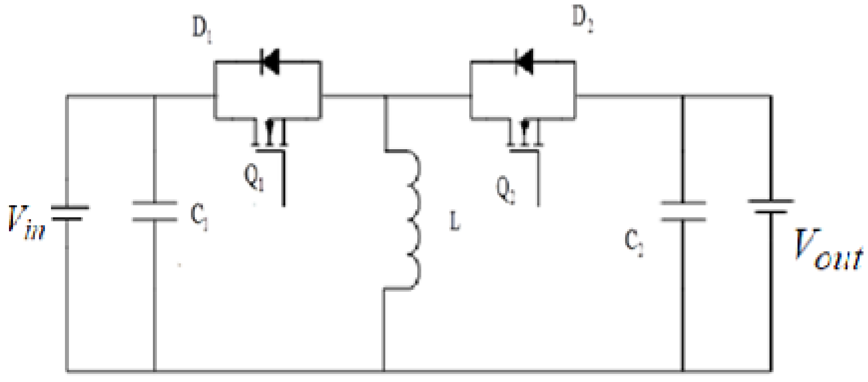

Figure 2.8 Buck-boost converter

2.3c. BUCK-BOOST CASCADE CONVERTER

It comprises of four switches, two capacitors and one inductor. During boost mode when battery level needs to work in discharge mode switch Q1 will be ON and Q2 will operate for boosting up the voltage level. The same operation of the switches Q3 and Q4 can be seen during buck mode of operation.

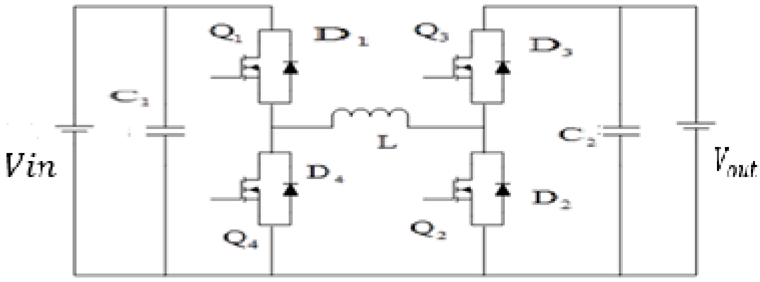

Figure 2.9 Buck-boost cascade converter

$$V_{out} = Vin \quad \text{during step} - \text{down operation} \ (0<D<1)$$

$$= \frac{V_{in}}{1-D} \quad during\ step - down\ operation \ (0<D<1)$$

Comparison between NBDC converters:

- In buck-boost cascade converter four switches and four diode are required, hence switching losses, number of control circuit needed more compared to half bridge and buck boost converter and cost is more.
- In buck-boost and buck-boost cascade converter, polarity of output voltage get reversed which may burden in many applications which is not the case with the half bridge converter.
- Half bridge converter can boost-up from only one direction and boost down from other direction, where as in buck-boost cascade and buck-boost converter buck or boost is possible from either direction.

2.3 SIMULATION.

Matlab simulation:

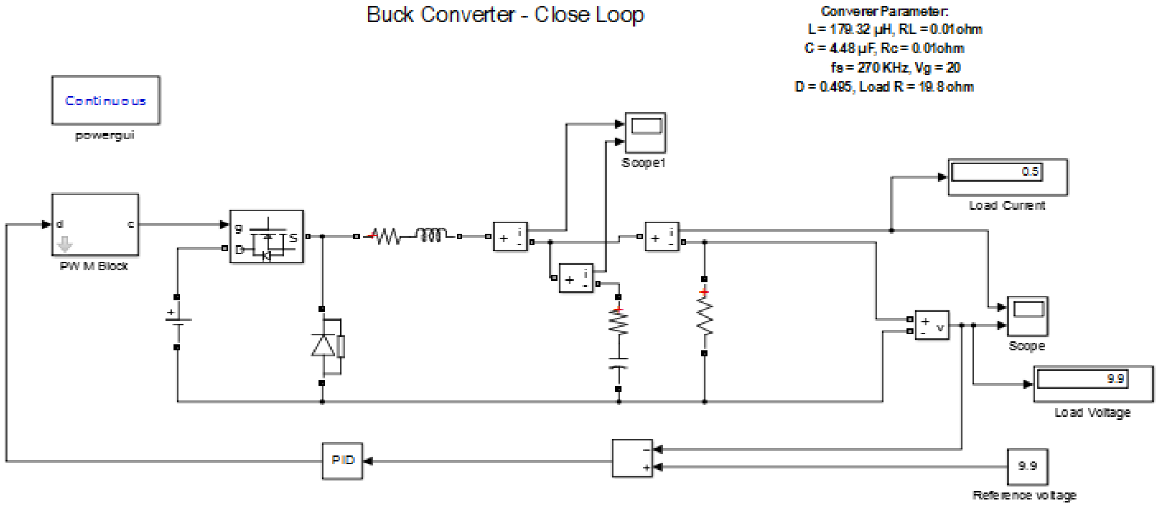

Figure 2.10 Close loop Buck converter.

Simulation output:

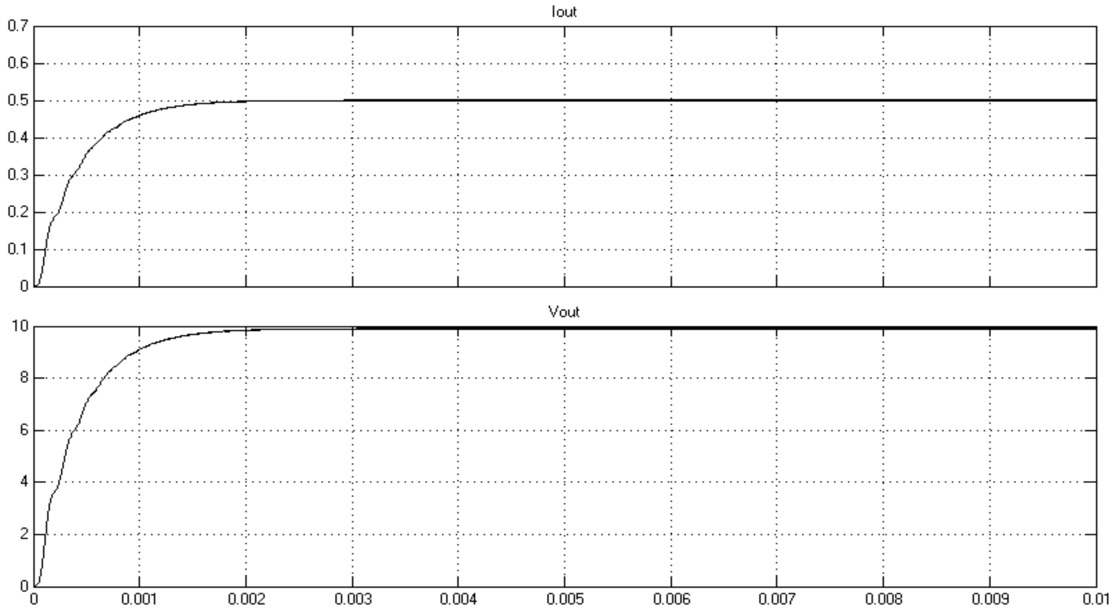

Figure 2.11 Output waveform of close loop buck converter

MOSFET Control using high and low side driver IR2110

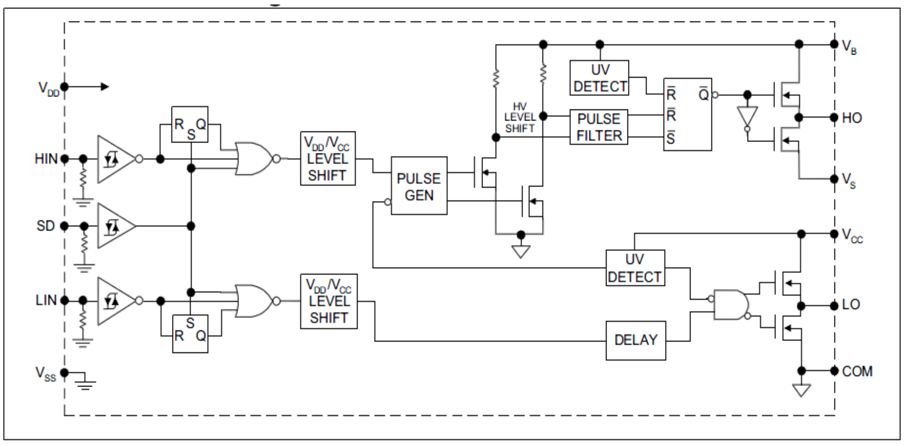

Figure 2.12 IR2110 internal diagram

International rectifiers like IR2110 MOSFET driver circuits which can be used as to drive both high and low side of a MOSFET.it consists of a floating circuit which can a bootstrap operation. This device can withstand up to 500V and a peak current of 2A.

High voltage on drain of MOSFET creates a problem of interaction with gate-drain capacitance which is known as Miller effect. To reduce it we implement totem pole output with low input impedance and high driver current by IR2110.

About PIN configuration:

PIN 1(LO): it is the output of low side MOSFET driver.

PIN 2(COM): it can considered as a return path for low side and its potential is equal to ground V_{ss} which is PIN 13.

PIN 3(VCC): it is low side supply.

PIN 5(VS): it is high side floating supply return.

PIN 6(VB): it is for high side floating supply to provide floating voltage to high side MOSFET.

PIN 7(HO): it is the output of high side MOSFET driver.

PIN 9(VDD): it is a logic supply pin whose value should be 5V.

PIN 10(HIN): it is the input signal for high side MOSFET driver output and its value should be between 4-5V.

PIN 11(SD): it is the shutdown pin used for protecting the circuit from damages. We can give 5V signal to shutdown IR2110 driver.

PIN 12(LIN): it is the input signal for low side MOSFET driver output.

PSPICE simulation:

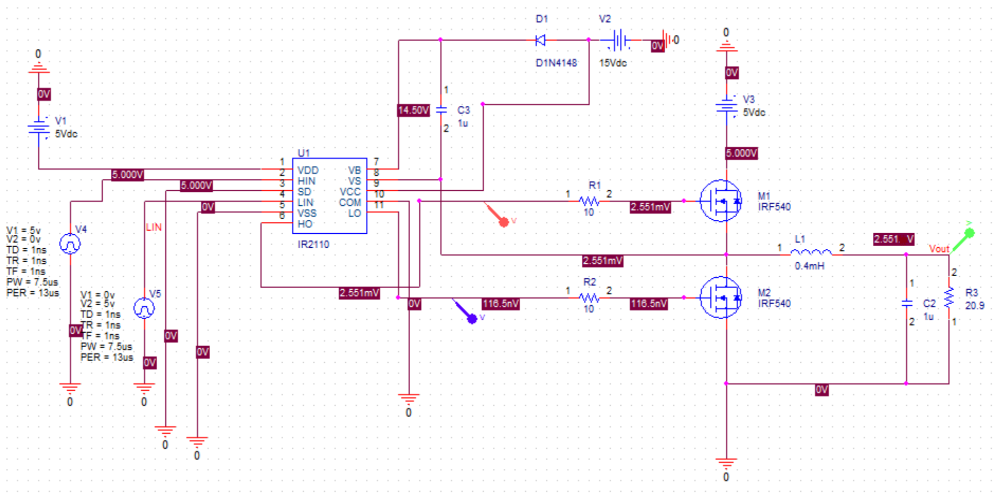

Figure 2.13 Spice simulation of buck converter

Output waveform

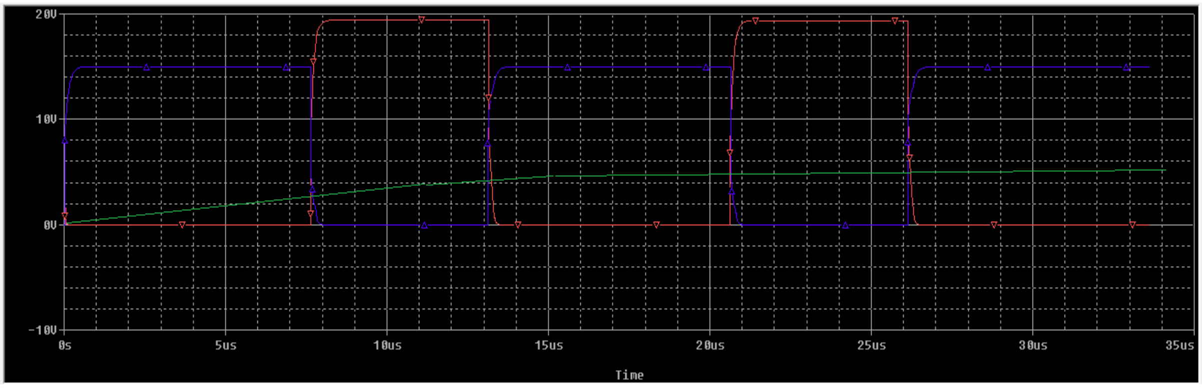

Figure 2.14 Out-put waveform

Parameter data value:

V_{in}	5 volt
V_{out}	2.55 volt
R	20.9 ohm
L	0.41 mH
D(duty cycle)	0.576

2.5 SPEED CONTROL OF PMDC MOTOR USING HALF BRIDGE CONVERTER

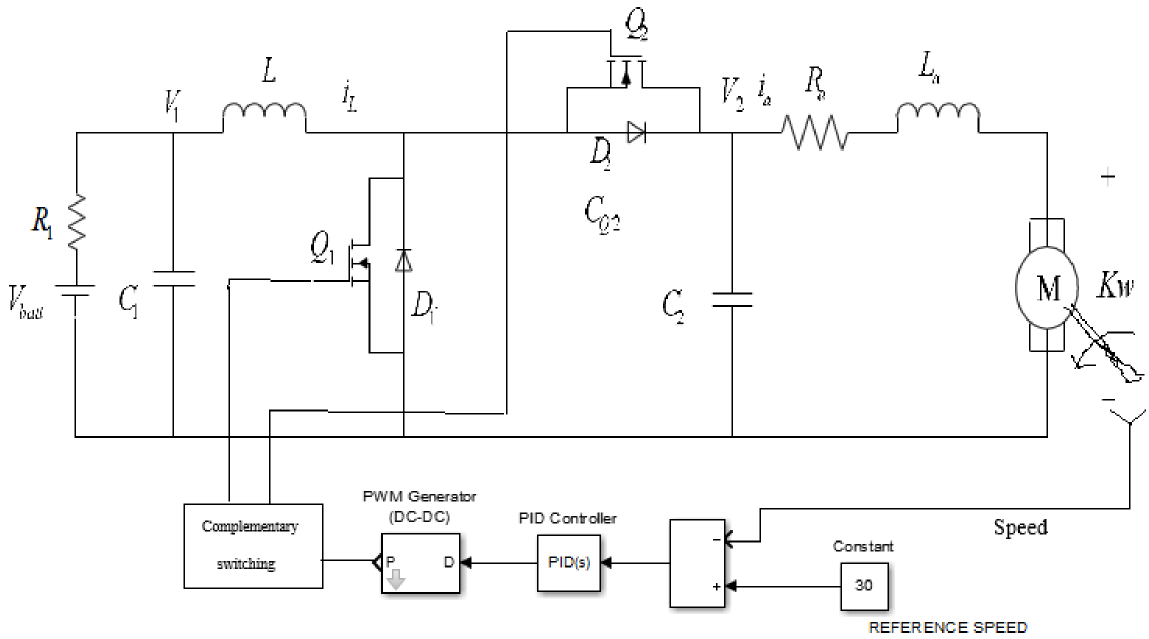

Figure 2.15 Half Bridge Non-Isolated Bidirectional DC-DC Converter fed PMDC Motor.

The Fig 2.15 depicts us a view of Half Bridge NBDC fed PMDC motor which can be put to operation in two different modes in which one is boost mode which is for forward motoring mode of operation and during buck mode we have electrical regeneration. The battery pack can be placed where we have a low voltage whereas a PMDC motor whose speed has to be controlled is introduced in the high voltage side. The circuit also consists of a high-frequency capacitor to guarantee the operation of a smoothening capacitor along the battery side. If the BDC is working in continuous conduction mode (CCM) then we may be in needing of a larger valued inductor. Consequently the size of the inductor increments and likewise eases off the transient response. If the circuit is working in the discontinuous conduction mode (DCM), the value of the inductor can be extremely lessened and the response gets to be quicker, subsequently there will be a considerable increase in power density. Zero-turn on loss will be encouraged by this mode of operation and in this manner less reverse recovery loss in diode. Anyhow, in the meantime the main switch will be turned off at twofold of estimated average load current which may in turn increases the losses during this state. By utilizing a snubber capacitor over the switches this can be diminished. Alongside this, the value of current flowing through inductor likewise displays parasitic ringing during turning OFF of the switch. This is on the grounds that the switch's output capacitance in connection with the inductor has a tendency to oscillate and subsequently causes power dissipation and electrical strain on the devices.

CONCLUSION

Different types of NBDCs topologies are analysed and compared. Among all of them half bridge BDC is the most suitable for light converter design with higher efficiency and low cost in HEV.

Based on topology analysis, parameter design is carried out to get appropriate values of parameter for desired output voltage. Using MATLAB and PSpice simulation output is obtained and thus verified with output waveforms and thus achieving desired targets.

Schematic diagram of bidirectional DC-DC converter fed PMDC motor is explained.

[1] Mahendra Chandra Joshi and Susovon Samanta, Electrical Engineering Department, National Institute of Technology, Rourkela, India, “Modelling and Control of Bidirectional DC-DC Converter Fed PMDC Motor for Electric Vehicles”, 2013 Annual IEEE India Conference (INDICON)

[2] F.Caricchi, F. Crescimbini, F. Giulii Capponi and L. Solero, University of Rome "La Sapienza", “Study of Bi-Directional Buck-Boost Converter Topologies for Application in Electrical Vehicle Motor Drives”, 1998 IEEE.

[3] Jan Leuchter, Pavol Bauer, Petr Bojda and Vladimir Rerucha, University of Defence, DELFT university of technology “Bi-directional DC-DC converter for super capacitor based energy buffer for electrical GEN-Sets” EPE 2007 – Aalborg.

[4] Hamid R. Karshenas, Hamid Daneshpajooh, Alireza Safaee, Praveen Jain Praveen Jain and Alireza Bakhshai, Department of Elec. & Computer Eng., Queen’s University, Kingston, Isfahan University of Tech., Isfahan, Canada Iran, “Bidirectional DC-DC Converters for Energy Storage Systems”.

[5] H. Matsuo, K. Iida, F. Kurokawa, H. Kimura, T. Koga and M. Asano “High power buck-boost type DC-DC converter applied to the auxiliary power source of the electric railway rolling stock”, Power Electronics Specialists Conference, 1993, 24th Annual IEEE 20-24 Jun 1993.

[6] Nandankar, P. ; Elect. Eng. Dept., Visvesvaraya Nat. Inst. of Technol., Nagpur, India ; Aware, M.V., “High efficiency discontinuous mode interleaved multiphase bidirectional dc-dc converter”, Power Electronics, Drives and Energy Systems (PEDES), 2012 IEEE International Conference , 16-19 Dec. 2012.

[7] Korkmaz, M. ; Dept. of Electr. & Electron. Eng., Selcuk Univ., Konya, Turkey ; Aydogdu, O. ; Dogan, H., “Design and performance comparison of variable parameter nonlinear PID controller and genetic algorithm based PID controller”, Innovations in Intelligent Systems and Applications (INISTA), 2012 International Symposium on , 2-4 July 2012.