Design and Implementation of Bidirectional DC-DC Converter fed DC Motor

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Design and Implementation of Bidirectional DC-DC Converter fed DC Motor

A Thesis submitted in partial fulfillment of the requirements for the degree of
Bachelor of Technology
in
Electrical Engineering

By

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Under the Supervision of

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Dedicated to

My Parents, and to each and every teacher, who taught us from alphabets to whatever till date. And to friends who have been there for us from genesis to apocalypse.

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CERTIFICATE

This is to certify that the thesis titled "**Design and implementation of Bidirectional DC-DC converter fed PMDC motor**", submitted to the National Institute of Technology, Rourkela by **Mr. Prashant Gedam (110EE0196)** for the award of Bachelor of Technology in Electrical Engineering, is a bonafide record of research work carried out by him under my supervision and guidance.

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ABSTRACT

The work aims at designing and implementation of a bidirectional DC-DC converter fed PMDC motor which can be used as the traction system for hybrid electric vehicle(HEV) system. As in designing the HEV the main problem is of battery storage system and by using the bidirectional converter we can improve the overall efficiency of the HEV. In bidirectional converter as energy flow can take place in either direction, it can work in both the motoring and regenerative mode.

In motoring mode, the converter acts as a boost converter and the voltage will be boosted and hence the current will be less so the I^2R loss will be less and system will be more efficient but when we talk about regenerative mode the system will act as a buck converter and the battery will be charged in the regenerative mode. So the overall efficiency of the system will increase. ZVRT technique is used to reduce the switching losses.

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List of Abbreviations

Brushless Direct Current	BLDC
Continuous Conduction Mode	CCM
Duty ratio	D
Direct Current	DC
Discontinuous Conduction Mode	DCM
Electromagnetic Interference	EMI
Hybrid Electric Vehicle	HEV
Hertz	Hz
Integrated Circuit	IC
Internal Combustion Engine	ICE
Insulated Gate Bipolar Transistor	IGBT
Metal Oxide Semiconductor Field Effect Transistor	MOSFET
Permanent Magnet Brushless Direct Current	PMBLDC
Permanent Magnet Direct Current	PMDC
State of Charge	SOC

Chapter 1

1.1 Introduction

From the previous two decades because of the expanding petroleum costs and the harmful outflows the auto commercial ventures has been distinctly searching out for the change. This has prompted the expanded rate of the advancement of the Electric Vehicle (EV) and Hybrid Electric Vehicle (HEV) advances. An EV dissimilar to ordinary vehicles which singularly relies on upon an ICE motor for the traction Moreover a HEV relies on upon an ICE and an ESS both. In this manner in an EV/HEV vitality transformation proficiency enhances and accordingly it expands the productivity and drivability and in the meantime decreases the harmful emissions furthermore the integration of ESS increases the efficiency by making provision for regeneration during braking. A large number of the business outlines in the present situation comprises of the ESS (basically battery packs) connected with the high voltage dc bus through a bidirectional dc-dc converter. Depending on the type of motor used. A large portion of the present analysis of the bidirectional dc-dc converters are carried out by acknowledging the voltage sources i.e. batteries on both the sides. Therefore the dynamics of the motors are left out while modeling the converters for an EV/HEV application. In this paper state space averaging technique has been applied to obtain the small signal model of the bidirectional dc-dc converter fed PMDC motor.

1.2 Literature Review

With the reason for enhancing the productivity of the drive train and to minimize the reliance on the petroleum powers, two or more wellsprings of propulsions(including ICE) are continuously utilized in the vehicle. the topological review of the different drive trains and the examination between them has been exhibited .With the reason for enhancing the productivity of the drive train and to minimize the reliance on the petroleum powers, two or more wellsprings of propulsions(including ICE) are continuously utilized in the vehicle. the topological review of the different drive trains and the examination between them has been exhibited. The power electronics and DC converter in the HVE Technology was reviewed and explained/ the examination between the different non segregated bidirectional DC converter on the basis of their performance has been done. .it also implemented the DCM operation for the power density maximization of the converter.

1.3 Motivation

One of the primary thought for the HEV drive train is to enhance the proficiency of the engine drive. This is possible by expanding the voltage level of the electrical storage system (ESS) and consequently reducing the high currents and accordingly the losses. The expansion in the voltage level of the ESS is possible by the expansion of the more number of the cells in the battery once again of the ESS of the HEV. Despite the fact that it expands the voltage level yet in the meantime it additionally builds the weight, size and expense of the framework which is clearly not an attractive choice for a vehicular provision which has stipulations on its size and weight. The other alternative is to utilize a bidirectional DC converter. Bidirectional DC converter support up the voltage level of the electrical storage system to the higher voltage level and subsequently lessening the current level henceforth the losses. Likewise Bidirectional DC converter brings about a significant improvement choice for high power conversion in the HEV drive prepare along these lines lessening general cost, size and weight of the framework alongside expanding effectiveness and accomplishing regenerative energy.

1.4 Objective

The basic objective of the work is to study the fundamental converter circuit and to design the bidirectional dc-dc converter circuit by using the state space modeling which can run the PMDC motor and hence can control it in an efficient way by improving the efficiency and reducing the losses. And use the above for the implementation and design of Electric bicycle.

Chapter 2

BIDIRECTIONAL DC-DC CONVERTER

2.1 Introduction

Bidirectional dc-dc converters help up the voltage level of the electrical storage system to the higher voltage level and along these lines lessening the current level and thus the losses .Also it encourages the noticeable improvement for the conversion of power by providing the path for regenerative mode These two attributes of the Bidirectional dc-dc converter achieve a recognizable change decision for energy transformation in the HEV drivetrain. Half bridge non-isolated bidirectional dc-dc converter has lower stress, less losses and less number of component contrasted with the bidirectional cascade, buck-boost and cuk converters. Subsequently half bridge non-isolated bidirectional dc-dc converter has been chosen for the present framework. As for motoring converter is operated at boost mode and in buck mode for regenerative mode

2.2 Converter Circuit and its Operation:

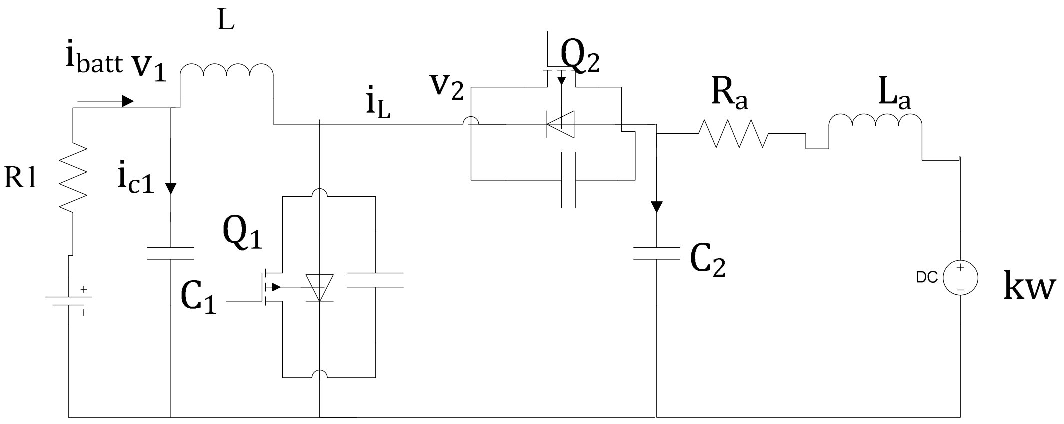

Figure 1: Bidirectional DC-DC converter circuit

2.2.1 Circuit Description

Half bridge non-isolated bidirectional dc-dc converter fed PMDC motor is as shown in the Fig 1. We are operating it in boost mode for motoring and in buck mode at the time of electrical regeneration. Towards the side having low-voltage a battery pack is installed and on the other side a PMDC motor whose speed has to be controlled is installed. It also contains a high-frequency capacitor as the energy buffer along the motor side as well as a smoothening capacitor along the battery side.

2.2.2 Converter Operation

Continuous conduction mode:

Bidirectional dc-dc converter operating in the continuous conduction mode (CCM) requires a larger valued filter inductor. Results in the larger size of the inductor and it also slows down the mode transitioning and transient response and

Discontinuous conduction mode:

With the circuit operating in the discontinuous conduction mode(DCM), the inductor value can be considerably reduced and the response becomes faster, therefore power density increases. DCM operation also facilitates zero-turn on loss and thus low reverse recovery loss in diode.

Switching:

At double the value of the average load current as the main switch is switched off, that results in the increasing of losses during the off mode. A snubber capacitor can be used to reduce it across the switches. Not only this , the inductor current also exhibits parasitic ringing during turning off of the switch. This is on account of the switch's yield capacitance in affiliation with the inductor has a tendency to sway and subsequently causes power dissemination and electrical stress on the systems [7]. This is the significant inconvenience connected with the DCM operation. The efficiency diminishes due to this negative impacts of the DCM operation. Therefore the soft switching techniques as well as the remedial measures for the parasitic ringing must be guaranteed in the converter design. This is possible by the complimentary gate switching technique. Accept that the converter is working in the boost for motoring mode with the fixed speed and load torque so that the armature voltage and the inductor current is at consistent state .

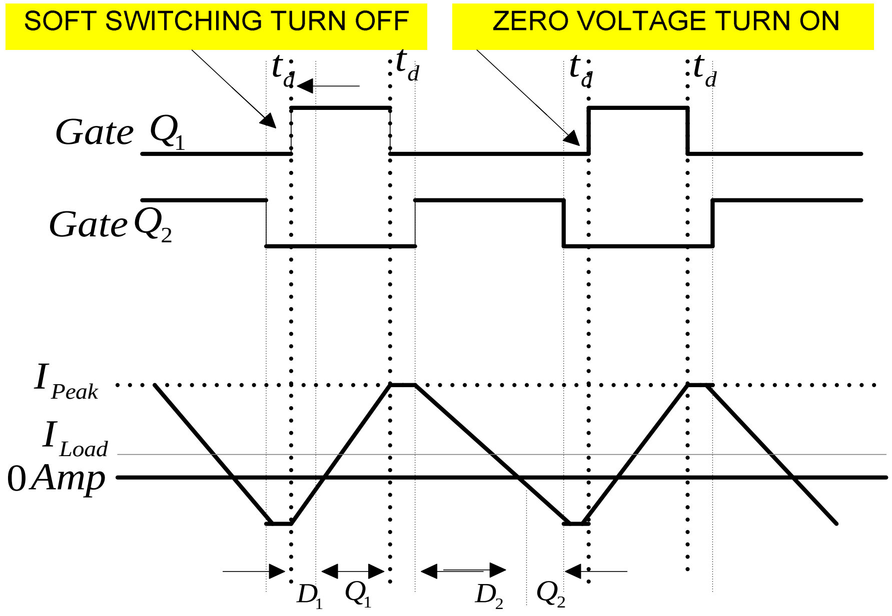

Figure 2: ZVRT soft switching technique [6].

Let at first the primary switch Q1 is conducting as demonstrated in the Fig 2.2. also consequently the inductor current rises (c-d) till it achieves the dead (d-e) time when all the devices gets turned off, and hence the inductor current will charge the capacitor Cq1. Additionally Cq2 will release to Cq1. Because of the presence of the snubber capacitors CQ1 and CQ2 the charging and discharging rates are diminished. Since the voltage over the capacitor can't change suddenly, thus the switching on and switching off losses are decreased. After this the inductor current courses through the diode

D2 (e-f) and it diminishes since voltage over capacitor C2 oppose it lastly it gets zero at point f. After this it inverts its extremity through Q2 (f-g), consequently the switch Q2 gets on at zero voltage in view of the freewheeling current through D2. Additionally the diode gets switched off at the zero voltage (at f) and in this manner the reverse recovery losses are diminished. Again the negative inductor current goes however switch Q2 which helps in charging CQ2 and discharging CQ1 throughout the dead time and after that again the negative current is circulated through diode D1 till it gets zero and the switch Q1 turns on. Along these lines the switch Q1 turns on at Zero Voltage condition. Here despite the fact that the inductor current achieves zero value before the beginning of the following cycle as in the ordinary DCM operation, however then additionally it is continuous due to the complimentary gate switching and the bidirectional conducting switches.

2.3 Circuit Parameter Design :

Since it is desired that the converter should operate in the DCM, therefore the value of the inductor should be selected so as ensure DCM operation in both the modes. So as to ensure DCM operation of the converter for all the power range, we can optimize the inductor value. The inductor current ripple is given by

$$\frac{dI}{dt}=\frac{V_2}{L}-\frac{V_1}{L} \qquad (2.1)$$

The current ripple can be given If I_{load} is average inductor current by

$$\Delta I = 2.I_{Load} \qquad (2.2)$$

Hence we get

$$\Delta I = \frac{1}{2}\frac{V_2 - V_1}{L_c}\frac{V_1}{V_2} \qquad (2.3)$$

Also , $I_{min} = I_{Load} - \Delta I$

And , $I_{peak} = I_{Load} + \Delta I$

Therefore ;

$$I_{min} = I_{Load} - \frac{1}{2}\frac{V_2 - V_1}{L_c}\frac{V_1}{V_2} \qquad (2.4)$$

And

$$I_{peak} = I_{Load} + \frac{1}{2}\frac{V_2 - V_1}{L_c}\frac{V_1}{V_2} \qquad (2.5)$$

The value of L for which the converter works in the DCM mode for the current comparing to the most extreme energy rating of the device could be chosen. The quality of L at which *Min I* simply goes negative is the verge of CCM and DCM operation. The capacitor value can be figured out from the voltage ripple specification as given below:

$$C_1 = \frac{\Delta I}{8\Delta V_{IN}}T_s \text{ , and } C_2 = \frac{V_2 D}{R_A \Delta V_2}T_s \qquad (2.6)$$

Chapter 3

3.1 State Space Modeling

The state space equation for different mode has to be developed in this section.

3.1.1 CASE – I : when Q1 is on and Q2 is off

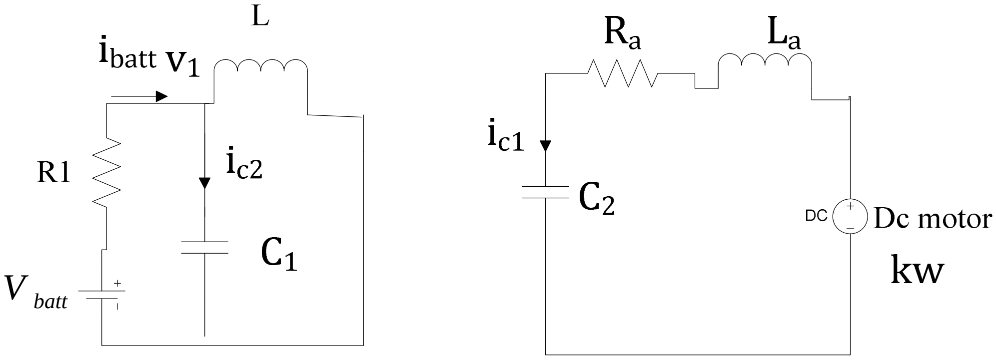

Figure 3: Equivalent circuit with Q1-on, Q2-off

voltage across the inductor L is given by

$$V_1 = L\frac{di_L}{dt} \tag{4.1}$$

Similarly the voltage across the armature inductance is given by :

$$\frac{di_L}{dt}=\frac{V_1}{L} \tag{4.2}$$

$$V_2 = i_A R_A + L_A \frac{di_A}{dt} + Kw$$

$$\frac{di_a}{dt} = -i_a \frac{R_a}{L_a} + \frac{V_2}{L_a} + \frac{Kw}{L_a} \qquad (4.3)$$

Also the capacitor currents iC1 and iC2 are given by

$$V_{batt} = R_1\, i_{batt} + V_1$$

$$I_{c1} = C_1 \frac{di_{v1}}{dt}$$

$$i_{batt} = i_l + i_{C1}$$

Therefore,

$$\frac{dV_1}{dt} = \frac{V_{batt}}{R_1\, C_1} - \frac{i_L}{C_1} - \frac{V_1}{R_1\, C_1} \qquad (4.4)$$

$$\frac{dV_2}{dt} = \frac{i_a}{C_2}$$

Finally the motor torque equation is given by

$$\frac{dw}{dt} = k\frac{i_a}{J} - \frac{B_m}{J}w - \frac{T_L}{J} \qquad (4.5)$$

Therefore the state space equations for the first interval tON are as follows:

$$\frac{dX}{dt} = A_{on}X + B_{on}U \qquad (4.6)$$

$$\mathrm{Y} = \mathrm{C_{on}}\,\mathrm{X} + \mathrm{E_{on}}\,\mathrm{U} \tag{4.7}$$

Where …

$$\mathrm{X} = \begin{bmatrix} i_L \\ i_a \\ V_1 \\ V_2 \\ w \end{bmatrix}, \mathrm{U} = \begin{bmatrix} V_{batt} \\ T_L \end{bmatrix}\ ,\ \mathrm{Y} = \begin{bmatrix} i_L \\ i_a \\ V_1 \\ V_2 \\ w \end{bmatrix} \tag{4.8}$$

$$\mathrm{A_{on}} = \begin{bmatrix} 0 & 0 & 1/L & 0 & 0 \\ 0 & -R_a/L_a & 0 & 1/L_a & -K/L_a \\ -1/C_1 & 0 & -1/R_1\,C_1 & 0 & 0 \\ 0 & -1/_{C2} & 0 & 0 & 0 \\ 0 & K/J & 0 & 0 & -\boldsymbol{B}_m/J \end{bmatrix} \mathrm{B_{on}} = \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ -1/R_1\,C_1 & 0 \\ 0 & 0 \\ 0 & -1/J \end{bmatrix}$$

$$\mathrm{C_{on}} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \mathrm{E_{on}} = \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \end{bmatrix}$$

3.1.2 Case II where Q1 is on and Q2 is off

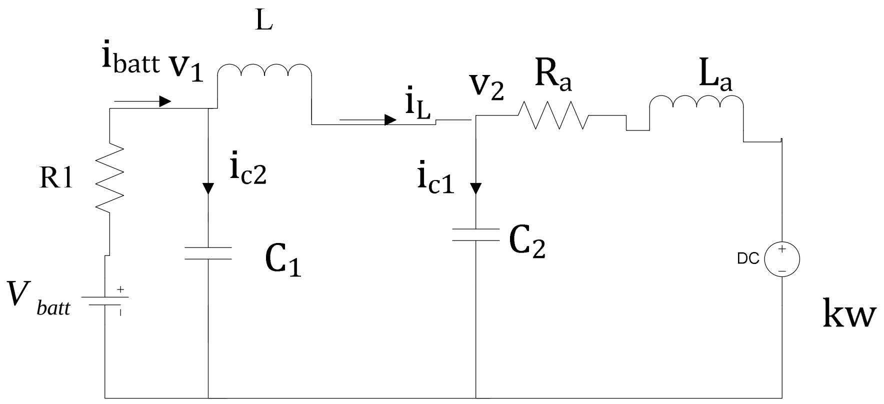

Figure 4: Equivalent circuit with Q1-off, Q2-on

Inductor voltage across the inductor L is given by

$$V_1 - V_2 = L\frac{di_L}{dt}$$

$$\frac{di_L}{dt} = (V_1 - V_2)/L$$

Similarly the voltage across the armature inductance is given by

$$V_2 = i_A R_A + L_A\frac{di_A}{dt} + Kw$$

$$\frac{di_a}{dt} = -i_a\frac{R_a}{L_a} + \frac{V_2}{L_a} - \frac{Kw}{L_a}$$

Also the capacitor currents i_{C1} and i_{C2} are given by

$$V_{batt} = R_1 i_{batt} + V_1 \tag{4.9}$$

$$I_{c1} = C_1\frac{di_{v1}}{dt} \tag{5.0}$$

$$i_{batt} = i_L + i_{C1}$$

Therefore,

$$\frac{dV_1}{dt} = \frac{V_{batt}}{R_1\, C_1} - \frac{i_L}{C_1} - \frac{V_1}{R_1\, C_1} \tag{5.1}$$

$$\frac{dV_2}{dt} = \frac{i_a}{C_2} - \frac{i_L}{C_2} \tag{5.2}$$

Finally the motor torque equation is given by

$$\frac{dw}{dt} = k\frac{i_a}{J} - \frac{B_m}{J}w - \frac{T_L}{J} \tag{5.3}$$

Therefore the state space equations for the second interval t_{off} are as follows

$$\frac{dX}{dt} = A_{off}X + B_{off}U \tag{5.4}$$

$$Y = C_{off}X + E_{off}U \tag{5.5}$$

Where…

$$\mathrm{A_{off}}=\begin{bmatrix} 0 & 0 & 1/L & -1/L & 0 \\ 0 & -R_a/L_a & 0 & 1/L_a & -K/L_a \\ -1/C_1 & 0 & -1/R_1\,C_1 & 0 & 0 \\ 1/_{C2} & -1/_{C2} & 0 & 0 & 0 \\ 0 & K/J & 0 & 0 & -\boldsymbol{B}_m/J \end{bmatrix} \qquad \mathrm{B_{off}}=\begin{bmatrix} 0 & 0 \\ 0 & 0 \\ -1/R_1\,C_1 & 0 \\ 0 & 0 \\ 0 & -1/J \end{bmatrix}$$

$$\mathrm{C_{off}} = [0\ 0\ 0\ 0\ 1] \qquad \mathrm{E_{off}} = [\ 0\ 0\ ]$$

Chapter 4

4.1 Simulation and results

The system model and the implemented control strategy has been simulated in the Simulink as shown in below Fig The various parameters that has been considered for the simulation has been given in Table I.

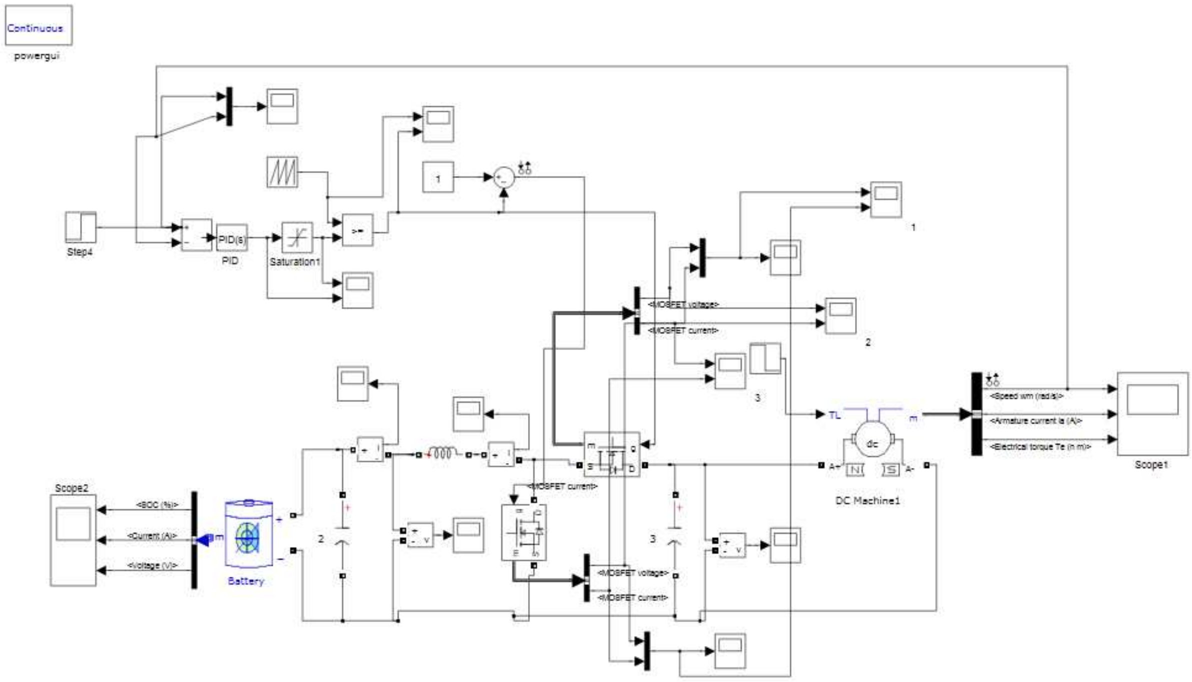

Figure 5: Simulink model for bidirectional DC- DC converter

TABLE I. PARAMETER VALUES USED IN THE SIMULATION

PARMETERS	VALUES
V_{batt}(battery voltage)	15 V
R_1, C_1, C_2	0.25 ohm , 5uF ,2.88 uF
L, L_a, R_a	100 mH, 28 mH, 1.4 ohm
K(motor torque constant)	0.5 NmA^{-1}
J (motor moment of inertia)	0.5215 kgm^2
B_m (viscous friction constant)	0.002953 Nms
K_p	0.1
K_d	0.0006
K_i	0.03

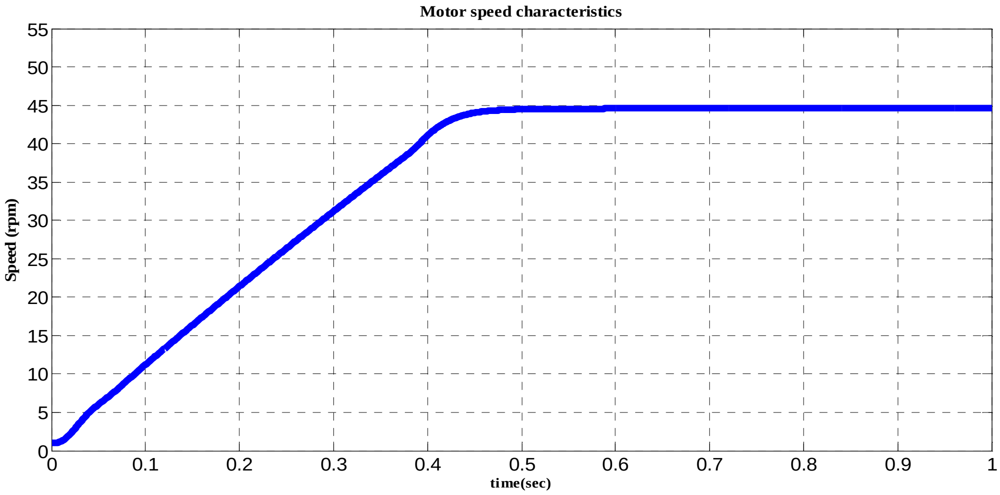

Figure 6: Motor speed characteristics

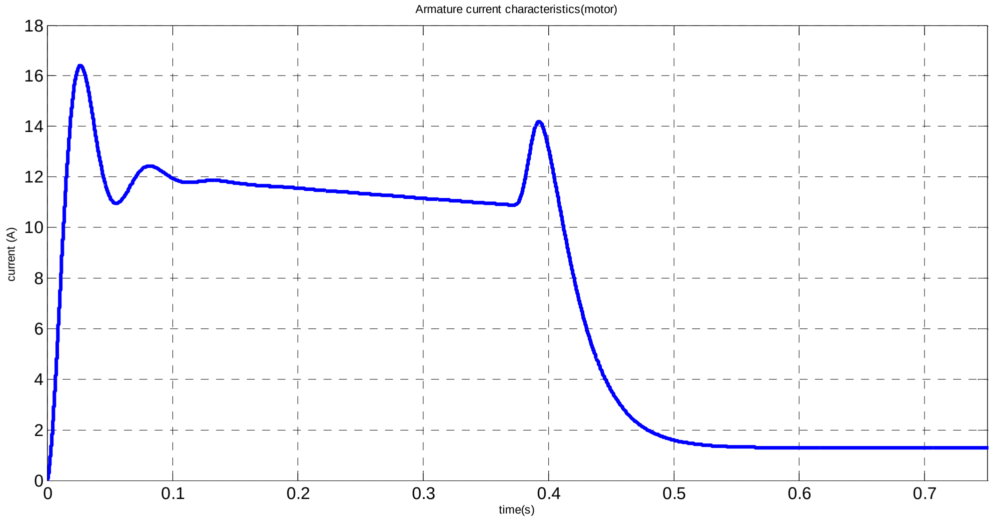

Figure 7: Armature current characteristics

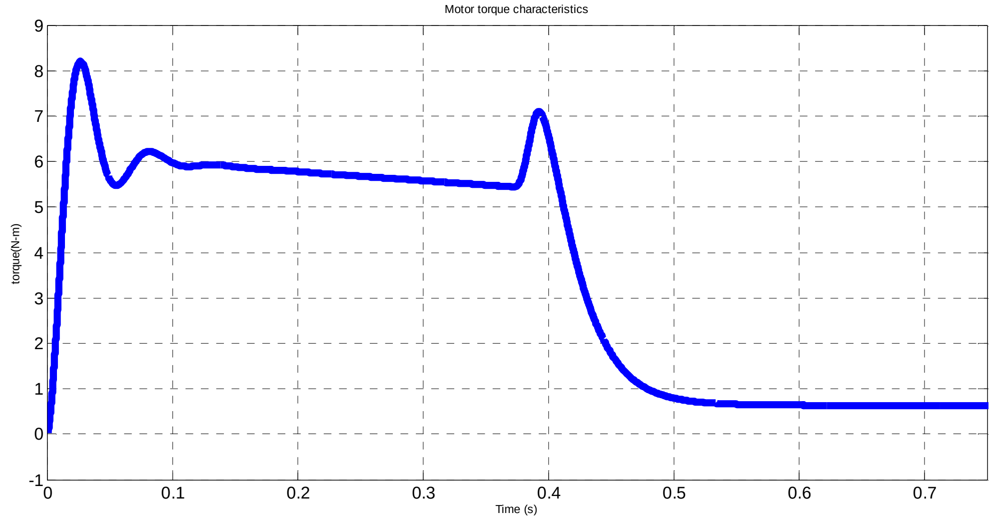

Figure 8: Motor torque characteristics

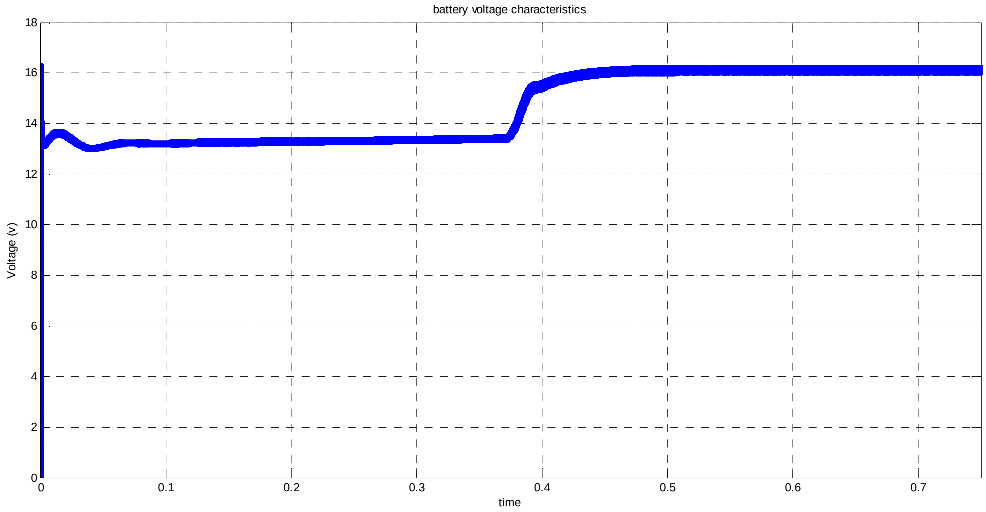

Figure 9: Battery voltage characteristics

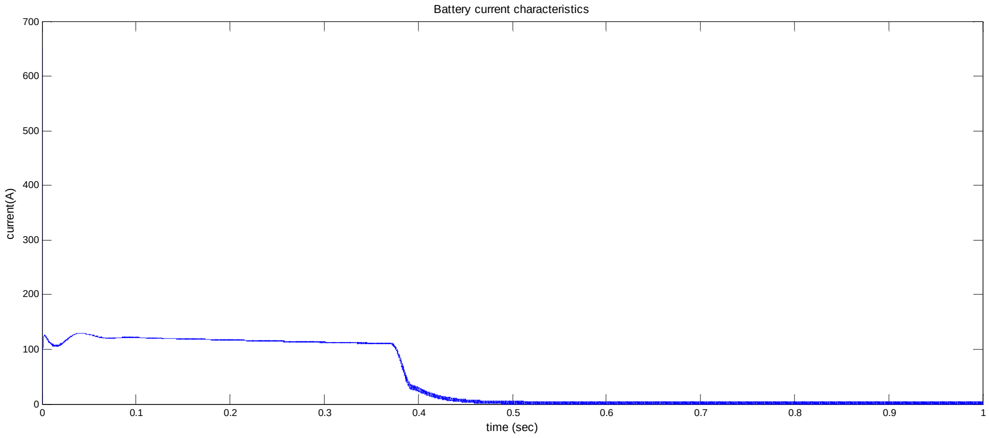

Figure 10: Battery current characteristics

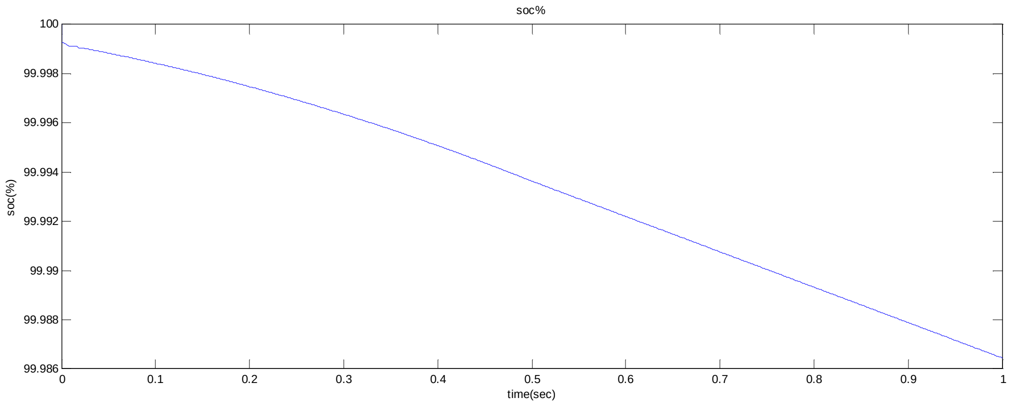

Figure 11: State of charge characteristics

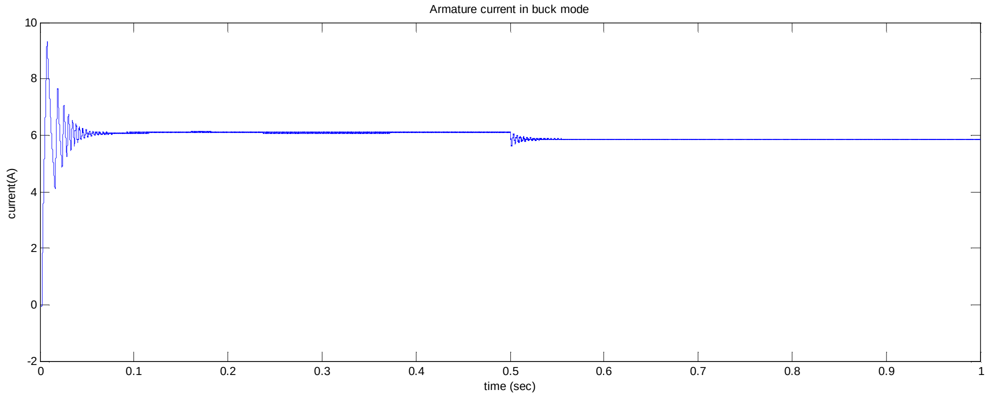

Figure 12: Armature current in buck mode

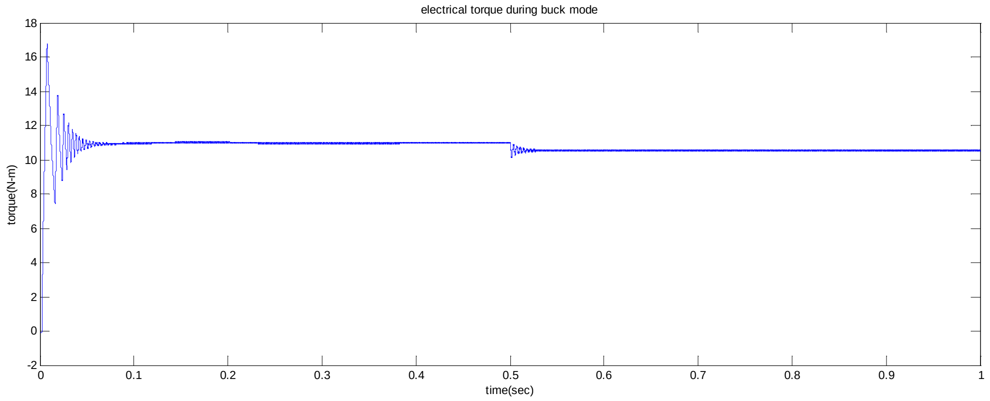

Figure 13: Torque in buck mode

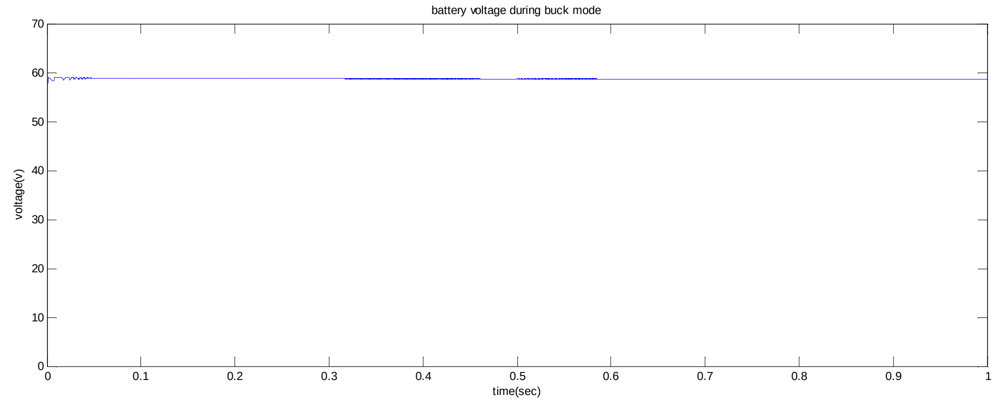

Figure 14: Battery voltage in buck mode

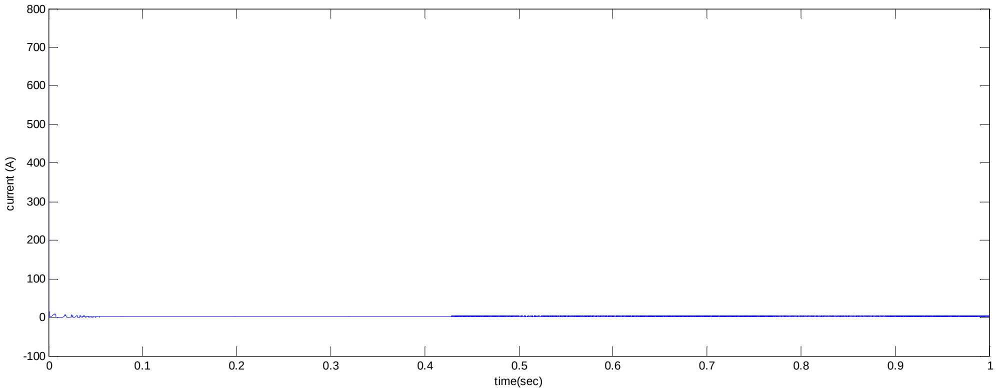

Figure 15: Battery current in buck mode

4.2 Hardware design

TABLE II. Apparatus USED IN THE HARDWARE DESIGN

PARMETERS	VALUES
V_{batt}(battery voltage)	9 V
R_1, C_1, C_2	11.2 ohm , 10uF ,5 uF
L, L_a, R_a	0.34 mH, 0.36 mH, 3 ohm
Pulse generator	-
CRO	digital

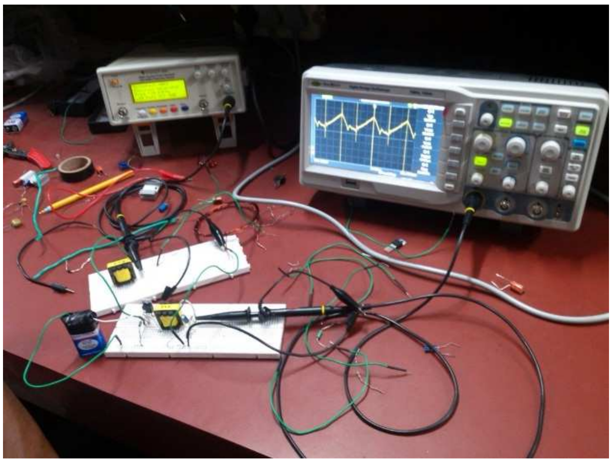

Figure 16: experimental setup

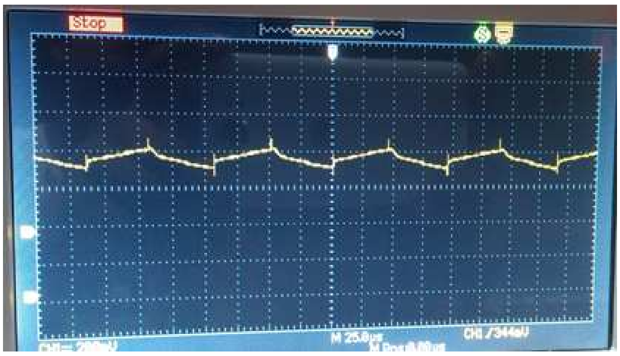

Figure 17: Armature voltage while motoring in boost mode

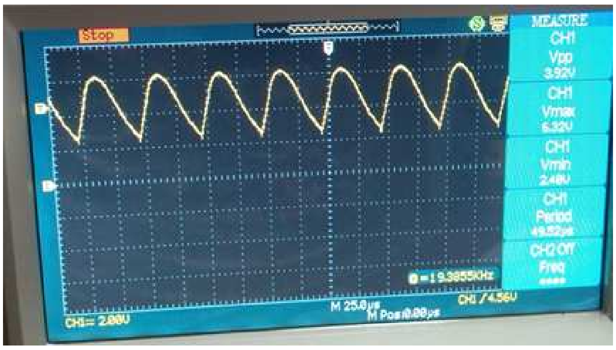

Figure 18: Motor’s back-emf in regenerative mode

Figure 19: Battery charging in buck mode while regeneration

Chapter 5

Conclusion

Bidirectional converter is being designed and speed control of the DC motor has been achieved with the designed bidirectional dc-dc converter. Different voltage and current waveform of the bidirectional dc-dc converter are obtained.

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