Closed loop control of Half Bridge Bidirectional DC – DC Converter for EV Application

Ragasudha C P[1] A. Nageswara Rao[2] Sophie Salins[3] Sonam Pal A[4]

[1, 3, 4] Presidency University, Bengaluru, India, [2] CMR Institute of Technology, Bengaluru

[1]ragasudha@presidencyuniversity.in

Abstract

This paper briefs about the performance of a Bidirectional DC – DC Converter in the domain of Electric Vehicles along with achieving the required speed of the motor while applying different loads. A Half Bridge Bidirectional Converter linked to a battery on Low Voltage(LV) side and a separately excited DC motor on the High Voltage(HV) side is employed in this paper along with the closed loop configuration of the motor drive by utilizing a PID Controller. The gains of the PID Controller are determined by the auto-tuning algorithm in MATLAB/SIMULINK. The converter's performance was analysed for the two modes.

Keywords: Electric Vehicle, Regenerative Braking Mode, Half Bridge Converter, Separately Excited DC Motor, PID Controller, Auto – Tuner.

List of Notations and Abbreviations

Electric Vehicle (EV), Hybrid Electric Vehicle (HEV), State Of Charge (SoC)

1. INTRODUCTION

Ever since the hike in gasoline prices and the harmful pollution caused by conventional vehicles, the demands for the Electric Vehicle (EV)/Hybrid Electric Vehicle (HEV) has increased. An EV depends on an Energy Storage System (ESS) for the traction power and, the HEV depends on both ICE and an ESS [1][2][7]. But the EV/HEV ESS have lot of limitations when it comes to pricing, storage capability and providing better mileage to the vehicle. These constraints in the ESS technology of the Electric Vehicle prevents them from advancing in the market. Since the primary concern, while EV/HEV drive design, is to boost the performance, many developments are made to achieve the same [3]. In our work we have demonstrated the performance of an EV drive comprising of a DC motor fed by a Bidirectional Converter. The utilization of the Bidirectional Converter in an EV drive increases the efficiency since it provides the provision of bidirectional power flow [8][9]. The closed loop control of speed of the DC motor by a PID Controller is also presented to achieve the required speed during varying loads.

1.1. Bidirectional DC – DC Converter

It was inferred that to improve the reliability of the ESS in the motor drive, the voltage level of the ESS must be greater. This can be accomplished by adding more cells to the battery pack of the ESS. But this method can increase the bulkiness of the drive which is not a desirable feature [1][2][7]. The solution for this problem is the utilization of a Bidirectional Converter which has the characteristic of flow of power in two directions. Bidirectional converters lower the current level to raise the level of voltage of an energy storage device to a greater level reducing the losses giving a rise to the performance of the motor drive. The Bidirectional DC – DC Converters are broadly divided into two general divisions i.e., Non – Isolated and Isolated Bidirectional Converter topologies. Since the Isolated Converters are to be provided with transformer and galvanic isolation, these converters are considered to be heavy for an EV drive train. Therefore, we have opted for the Non – Isolated Bidirectional Converters for the work.

The different Non – Isolated Bidirectional converters are basic Buck – Boost, Buck – Boost Cascaded, Cuk, Half Bridge, SEPIC/Zeta, Switched – Capacitor, and Interleaved Converters. In Buck – Boost Converters, the passive components and the power switches operates under high thermal and electrical stress resulting in high power loss. The Buck – Boost Cascaded converter requires a greater number of components [2][4][5]. The Half - Bridge converter has only one inductor and have greater performance due to the lower inductor current. The Switched – Capacitor converters suffer from high ripple current which causes Electro – Magnetic Interference (EMI) at the output due to the presence of a greater number of passive components. The Interleaved converters are extremely expensive and have a complex control strategy [2][6][7]. Out of all the converter topologies, the Half – Bridge topology was selected for our work since it was compact, efficient and easy to implement its control strategy [1].

2. Bidirectional DC – DC Converter with battery and DC Motor

Figure 2.1 shows the Bidirectional Converter fed Separately Excited DC Motor drive. MOSFET switch Q2 with the diode D1 is modulated to accomplish the boost converter operation. MOSFET switch Q1 with the diode D2 is modulated for the converter to work in buck mode which reverses the flow of power. It should be remembered that the inductor current directions in the two modes are opposite. To achieve motoring and regenerative braking of the engine along with the motor’s speed control, a control model is provided using a PID controller. In this model, a Lead Acid battery model was used to validate the motor output in both the modes. This strategy produces the required results when various speed commands are applied

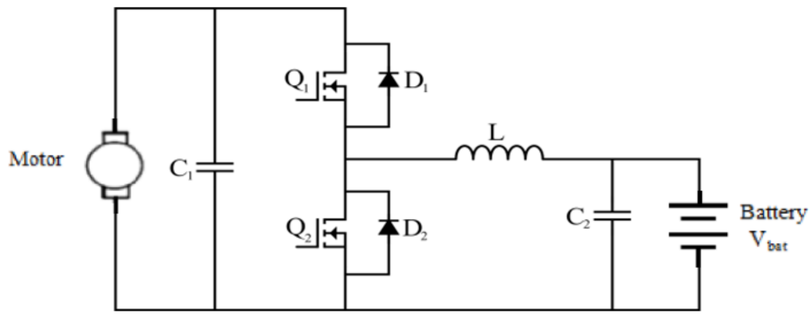


Figure 2.1. Bidirectional Converter fed DC motor

2.1 *Determining PID Controller's gain by PID Auto – Tuner in Simulink*

The PID Tuner uses the auto-tuning algorithm to identify a linear transfer function from the input and output data sets and tune the controller gains. The PID Controller's step response was tuned to have the following responses as shown in Table 2.1.1 and the Controller gains are determined as shown in Table 2.1.2.

Table 2.1.1: Step response parameters from auto – tuning of PID Controller

PID CONTROLLER STEP RESPONSE PARAMETERS		
Sl. No.	**Parameters**	**Values**
1	Rise Time (s)	0.5s
2	Settling time (s)	0.15s
3	Overshoot (%)	2.8%

Table 2.1.2: PID Controller gains from auto – tuning of PID Controller

PID CONTROLLER GAINS		
Sl. No.	**Parameters**	**Values**
1	K_P	0.015
2	K_I	0.1
3	K_D	0.0002

Table 2.2.1: Parameters and values used for modelling

Parameters	Values
Motor Ratings	5HP, 240V,1750rpm
Inductor (L)	50µH
Capacitor (C)	220µF
Capacitor (C)	220µF
Battery voltage	48V
Battery capacity	140AH

2.2 *Closed loop simulation of the drive*

The MATLAB Simulation of the drive is as shown in figure 2.2.1. The parameters used for the simulation is given in Table 2.2.1. The total simulation time was considered as 2 seconds out of which the converter works in boost mode for the initial 1 second and buck mode for the other 1 second. The required speed of 60 rad/s (3600 rpm) is to be achieved for both the modes.

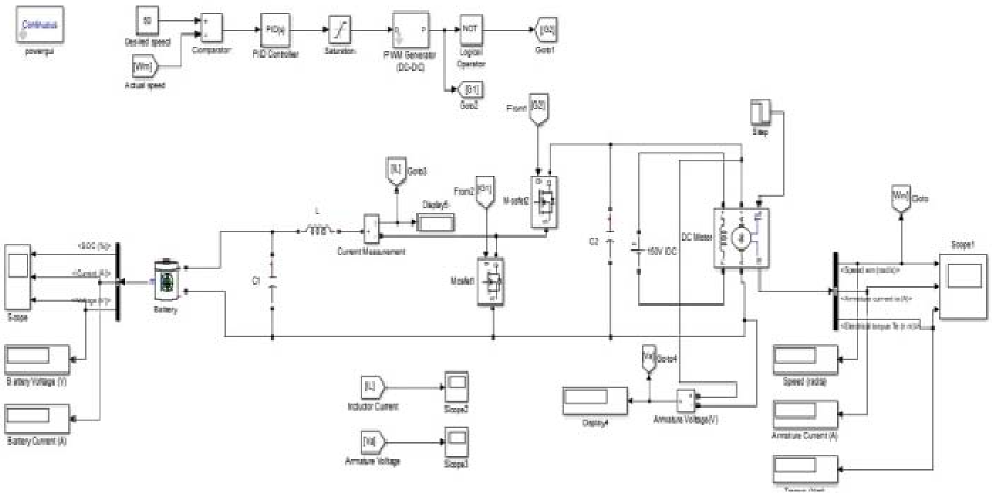
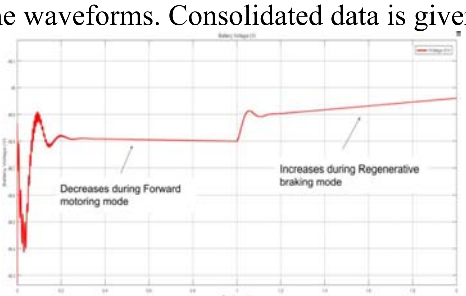


Figure. 2.2.1 Closed loop simulation of Bidirectional DC-DC Converter fed separately excited DC Motor.

2.3 Simulation results

Various system parameters obtained from the closed loop simulation of DC-DC converter fed separately excited DC motor are presented in this section along with the waveforms. Consolidated data is given in Table 2.3.1.



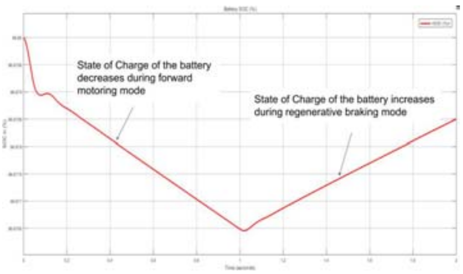


Figure 2.3.1 Battery Voltage in Volts

Figure 2.3.2 The SOC of battery in %

Battery Voltage and SoC of the Battery: The battery is discharged to run the motor during motoring mode and the battery gets charged during regenerative braking mode.Therefore the battery voltage decreases till 1s and increases till another 1s as shown in figure 2.3.1. As battery gets discharged during forward motoring mode, its SoC is seen to decrease and when the battery gets charged during regenerative mode the SoC of the battery rises as in figure 2.3.2

Battery Current: The battery current increases since the current is drawn to power the motor during motoring mode and decreases during regenerative braking mode which is shown in figure 2.3.3.

Inductor Current: During forward motoring mode the inductor gets charged by the battery and the current rises and is discharged to charge the HV side capacitor to run the motor. During regenerative braking mode the HV side charges the inductor and the output capacitor and then gets discharged to charge the battery. Waveforms are given in figure 2.3.4

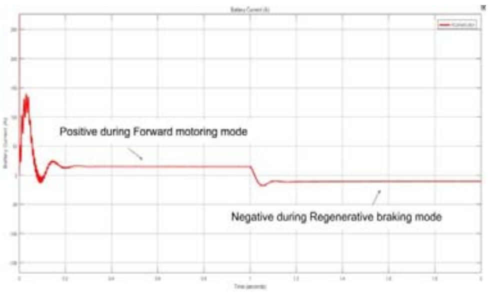


Figure 2.3.3 Battery Current in Amps

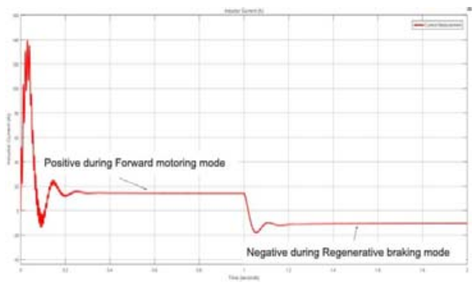


Figure 2.3.4 Inductor Current in Amps

Motor Torque: For the PID Controlled drive, during forward motoring mode a torque of 10Nm is applied to the motor up to 1 second and a torque of -10Nm is given for the next 1 second so that battery gets charged by the motor during regenerative braking mode since it acts as a generator as in figure 2.3.5.

Armature Current: Since the torque and armature current is directly proportional to each other it is positive during forward motoring mode and negative during regenerative braking mode and is around 9A.Waveforms are given in figure 2.3.6.

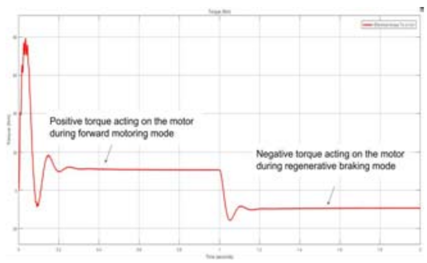


Figure 2.3.5 Motor Torque in Nm

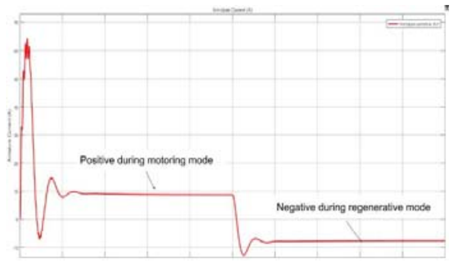


Figure 2.3.6 Motor Armature Current in Amps

Motor speed: The speed of the motor is to be maintained constant during both the modes. The required speed of 60 rad/s is reached and the desired speed is reached at a very fast rate during both the modes as shown in figure 2.3.7.

Armature Voltage: During motoring mode, the back emf is always less than the armature voltage as the duty ratio changes itself to run the motor at the required speed. Waveforms are given in figure 2.3.8. The back emf should be greater than the armature voltage to maintain the constant speed during regeneration.

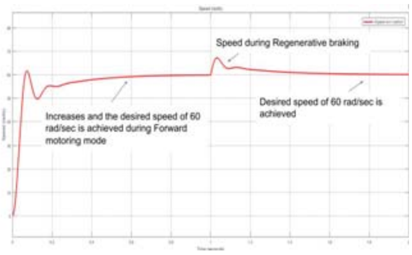


Figure 2.3.7 Motor speed in rad/s

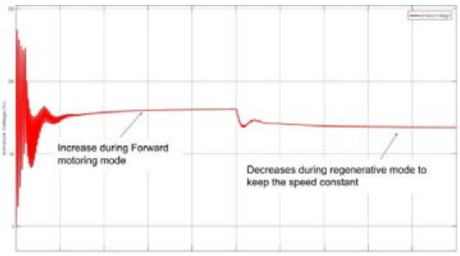


Figure 2.3.8 Motor Armature Voltage in Volts

Table 2.3.1: Observations from simulation results of PID controlled Drive

Sl. No.	Parameters	Motoring Mode	Regenerative Braking Mode
1	Battery Voltage (V)	Decreases from 48.84V to 48.81V	Increases from 48.81V to 48.96V
2	Battery SOC (%)	Decreases from 86.68% to 86.676%	Increases from 86.676% to 86.678%
3	Battery Current (A)	Range of 10A to 12A	Range of 10A to 12A
4	Inductor Current (A)	10A	-10A
5	Motor Torque (Nm)	10Nm	-10Nm
6	Armature Current (A)	9A	-9A
7	Motor speed (rad/s)	60 rad/s at 0.5s	60 rad/s at 1.5s
8	Armature Voltage (V)	Increases to 77V	Decreases to 68V

3. CONCLUSION

In this work, we have demonstrated the Motoring and Regenerative action along with the control of speed of the separately excited DC motor drive. The Half-Bridge Converter configuration was chosen for the work because it provides higher efficiency compared to other topologies of the Bidirectional Converter. The PID Controlled closed-loop system was efficient for the control of speed as the desired speed was reached at a faster rate at a time of 0.5s and hence the battery charge drawn to power the motor was less. The model was analysed in MATLAB/SIMULINK and the outcomes are supported by the waveforms.

4. FUTURE WORK

Despite its low cost, high reliability, and high dynamic efficiency, the PID Controlled drive is less efficient and fragile in the presence of disturbance and instability, as well as in avoiding large transients between directions. These issues can be addressed by using sophisticated control schemes like fuzzy logic which offers a fast solution as well as robustness due to adaptive characteristics relevant to non-linear and systems which are not accurate, instability, varying parameters, and load distortions.

5. REFERENCES

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