Design & Simulation of Bi-Directional DC-DC Boost converter & Interleaved Converter for Hybrid Electric Vehicle

*Pankesh Bhargav[1],Shraddha Kaushik[2]

[1]*M.Tech Scholar, Department of Electrical Engg, Bhilai Institute of Technology, Durg*

[2]*Assistant Professor, Department of Electrical Engg, Bhilai Institute of Technology, Durg*

pankeshbhargav@gmail.com[1], shraddha.kaushik01@gmail.com[2]

Abstract

Electric Vehicle (EVs) adopting batteries, ultra capacitor are used for hybrid electric vehicle which provides a promising solution reduces power loss and increases efficiency for upcoming automotive industry. Batteries are integrated with DC-DC interleaved Boost converter and ultra capacitors with DC-DC Bidirectional converter to stabilize the voltage. Physical explanation about when to produce, consume & store electric power during regenerative braking is also implemented. The proposed converter is compared with other topologies, such as conventional boost converter (BC) and Bi-directional boost converter in order to examine its performance and simulated in this paper using MATLAB/Simulink. Further a DC motor is considered as a load to demonstrate the performance of this strategy.

Keywords: Hybrid Energy Sources; Battery Storage; Control Strategy; Electric Vehicle; Ultracapacitor; PMDC

1. Introduction

The objective of this paper integrating batteries and ultra capacitors is to create an energy storage system with the high energy density attributes of a battery and the high power density of an ultra capacitor [2]. Present challenges in electric vehicles having multiple energy storage systems lies in managing the net energy expenditure, determining the proportional power split and establishing methods to interface between the energy systems so as to meet the demands of the vehicle propulsion and auxiliary load requirements. However, to obtain high utilization efficiencies, these energy storage systems require an intervention of various power converters. As such, Bi-directional Boost Converter and a Bi-directional Converter is design, which is further connected to the load. This paper addresses the power and energy management problem in a systematic manner by adopting stable approach and a functional implementation model.

2. Proposed System for HEV Configuration

Hybrid electric vehicles have more than one source i.e. battery used as a primary source and ultra capacitors are used as its secondary source which provides it degree of freedom to supply power during peak power demands and transients [3]. The basic design of any HEV consists of two or more sources connected to converter that is fed to the permanent magnet DC (PMDC) motor which works on DC.

This paper shows a parallel structure in which two converters are connected in parallel and operated by two different sources. There are many advantages of parallel structure i.e. reliable in nature simple methodology. In this paper, the interleaved boost converter connected to the battery to maintain fixed voltage at load side and the bidirectional converter conned to the ultra capacitor which works in boost mode in the period of delivering power and in buck mode while observing power [4]. For a certain load power demand ($Power_{LOAD}$) partial power can be fed by battery ($Power_{BAT}$) and partially by ultra-capacitor (Power $_{UC}$) and the load power should satisfy the following condition ideally,

$$Power_{LOAD} = Power_{BAT} + Power_{UC}$$

Or more precisely, having η_{BAT} and η_{UC} as the efficiency of converters of battery and UC respectively and non-propulsion load Powernp

$$Power_{LOAD} = \eta_{BAT} \times Power_{BAT} + \eta_{UC} \times Power_{UC} + Power_{NP}$$

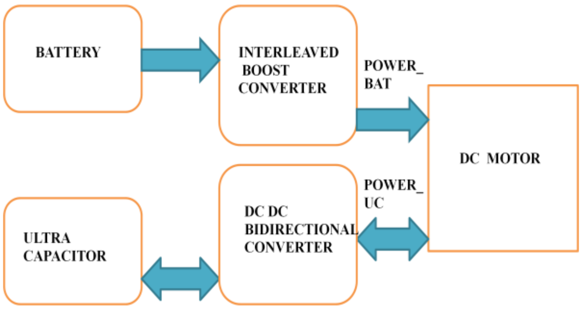

Figure 1. Parallel Structure of Hybrid Battery/UC Power System

2.1 EV System - Battery, Ultra-Capacitor and Pmdc Motor:

This section consists of different element models that have been used during simulation and shows its dynamics in practical implementation [10]:

2.1.1 Batteries

A serially connected lithium ion battery is required to feed the dc motor. It is relatively simple to model and can be modeled using an ideal source connected to an equivalent series resistance (ESR). In MATLAB, a predefined lithium ion battery model is used in which an ESR is connected in series with an ideal source whose voltage is related to discharge characteristics [8].

2.1.2 Ultra-Capacitors

Models of ultra-capacitor presented are a RC ladder network where V_{UC} depends on distributed capacitance. Apart from the ladder network, a series combination of capacitor with ESR and EPR can also be used to analyze the characteristics [7]. In MATLAB, a generic model of ultra-capacitor is considered having a stack of capacitors connected in parallel and series to meet the current and voltage demand [9].

2.1.3 PMDC Motor

PMDC motor is generally considered for application in electric vehicles and is same as separately excited dc motor excited by a permanent magnet in the field. The back emf and electromagnetic torque produced by the motor can be given as:

$$E_b = K_e \times \omega_m$$
$$T_e = K_t \times I_a$$

Where,

K_e is voltage constant and K_t is torque constant and $K_e = K_t$.

A generic model of dc machine is considered in MATLAB where two connections i.e. A+ and A- and one input T_L which feeds with the dc machine with load torque. In case of unknown load, the load torque changes which varies the armature current (Te α Ia) and hence the power requirement (Power_req) i.e. V * Ia, of the system.

3. Designing of Interleaved Boost Converter & Bi-Directional Converter

3.2 Interleaved Boost Converter

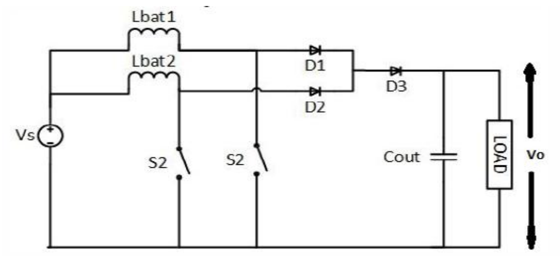

Figure 2. Interleaved Boost Converter

Classical interleaved boost converter can be simply obtained by operating two classical boost converters operating 180° out of phase. The input current is the sum of the two inductor currents, I_{L1} and I_{L2}. Because the inductor's ripple currents are out of phase, they cancel each other and reduce the input-ripple current produced by inductors of the boost converter. The best input-inductor-ripple current cancellation occurs at 50% duty cycle. The output-capacitor current is the sum of the two diode currents, I_1+I_2, minus the dc-output current, which reduces the output-capacitor ripple, I_O, as a function of duty cycle. As the duty cycle approaches 0, 50 and 100%, the sum of the two diode currents approaches dc. At this point, the output capacitor has to[1] filter only the inductor ripple current. The design parameters of IBC can be given as:

a) Boost ratio:

The boosting ratio of the converter is a function of the duty cycle. It is same as in conventional boost converter. It is given as,

$$V_o = \frac{Vs}{1-D}$$

Where, V_{dc} is the output voltage, V_{in} is the input voltage and D is the duty cycle

$$D = 1 - \frac{Vs}{Vo}$$

b) Inductor selection

Using the equation 3.6, ignoring diode voltage drop the inductor value can be given as

$$L = \frac{(Vo-Vs)\times(1-D)}{\Delta i\times f}$$

The value of inductor can be designed according to allowable current ripple

c) Capacitor design

As in the case of inductor, the capacitor value can be designed and can be given as

$$C = \frac{io\times d}{\Delta vo\times f}$$

3.3 Bidirectional Converters

There arises a need of a bidirectional converter which can flow current in both directions and can act as a buck and boost converter. The use of a Bi-directional DC-DC converter fed dc motor drive devoted to electric vehicles application allows a suitable control of both motoring and regenerative braking operations, and it can contribute to a significant increase the drive system overall efficiency.[6]

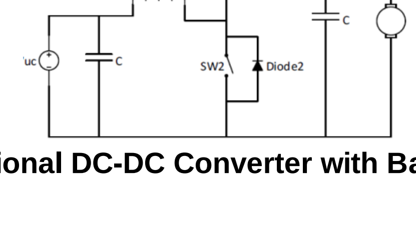

Figure 3. Bidirectional DC-DC Converter with Battery and DC Motor

Figure. 4. shows Bi-directional dc-dc converter fed DC motor drive. In this topology, boost converter operation is achieved by modulating SW_1 with the anti-parallel diode D_1 serving as the boost-mode diode. With the direction of power flow reversed, the topology functions as a buck converter through the modulation of SW_2, with the anti-parallel diode D_2 serving as the buck-mode diode. It should be noted that the two modes have opposite inductor current directions. A new control model is developed using PI controller to achieve both motoring and regenerative braking of the motor.

5. Hybridizations of Batteries and Ultracapacitors in EV Power Systems

5.1 Multiple Converter Configuration

The multiple converter method parallels the output of the two converters. Figure 7 shows the diagram of the multiple converter topologies [3]. The outputs of the two converters are the same as the DC link voltage. In order to obtain less balancing problem the voltage of both the battery and the UC is maintained lower than the DC link voltage[5]. The voltage of the UC can vary in a wide range so the capacitor is fully used. Multiple input multiple converter configuration has advantages over other structures like reliability, lesser stress and simple methodology [8]. The disadvantage of this method is that two full size converters are necessary which increases the cost.

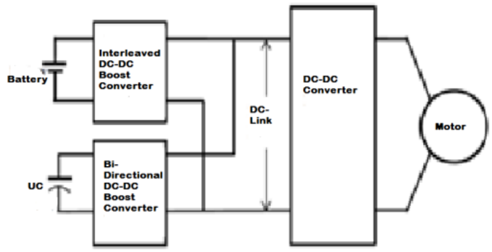

Figure 4. Multiple converter configuration

6. Control Strategy

The control circuit of the bidirectional converter is shown in Figure. 5. To control the inductor current of the bidirectional converter for controlling the output power deliverance and to provide fast response without oscillations to rapid speed changes a PI controller is used. In this control technique the inductor current I_L is sensed and compared with a reference speed I_{req}. The error signal is processed through the PI controller. The signal thus obtained is compared with a high frequency saw tooth signal equal to switching frequency to generate PWM control signals.

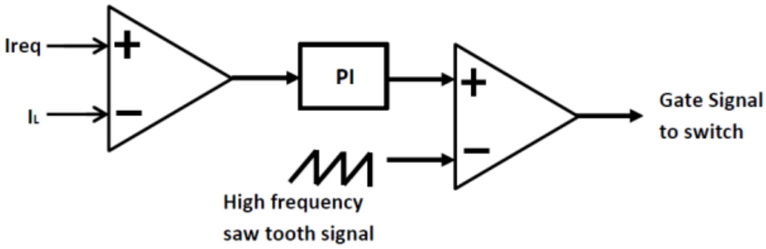

Figure 5. Control of Bidirectional Converter

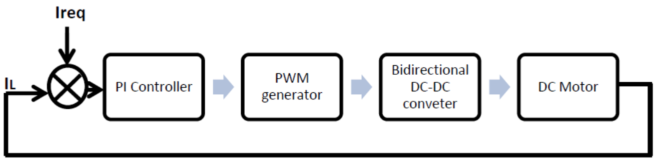

Figure 6. Closed loop Operation of Drive

Results:

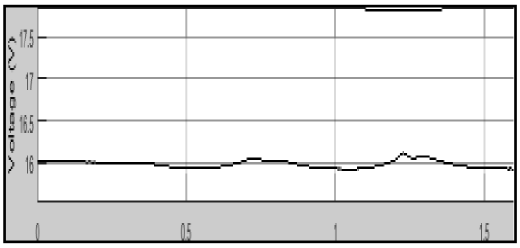

Figure 7. Ultra Capacitor Voltage

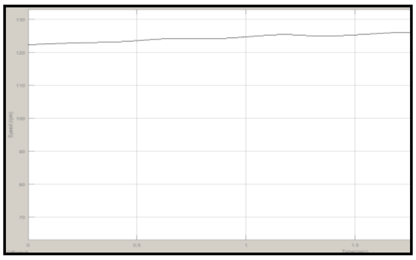

Figure 8. Battery Voltage

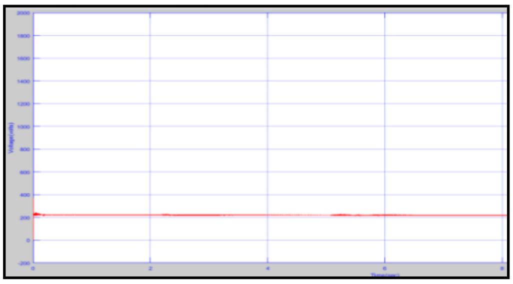

Figure 9. Boost Converter Voltage

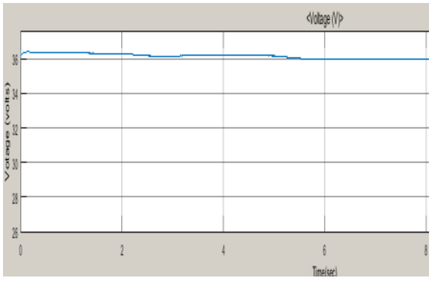

Figure 10.Speed PMDC Motor

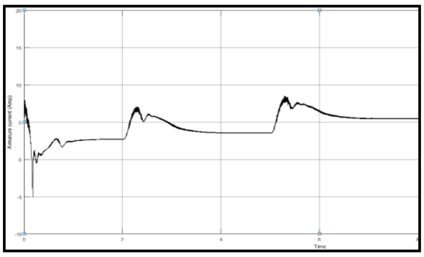

Figure 12. Armature Current

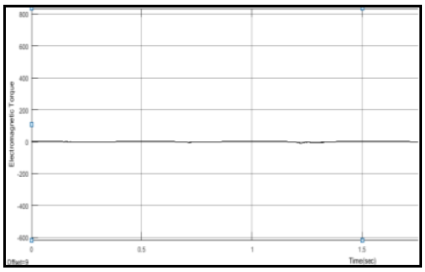

Fig 12.ElectromagneticTorque

Appendix

Parameters for the Ultracapacitor

Capacitance=500, Rated voltage=8, Equivalent series resistance =8.9e-3, Series Capacitors=18, Parallel capacitors=1, Initial Voltage=8

Parameters for Lithium ion Battery:

Open circuit voltage=7.2, Rated capacity=8, Equivalent series resistance =0.048, Initial State of charge=100

Parameters for DC Motor:

Field Type= Permanent Magnet, Mechanical Input= Load Torque, Armature resistance=0.6, Armature Inductance=0.012H, Torque constant=1.8N.m/A

7. Conclusion

In this paper, design and implementation of control strategy for a two source hybrid system is done considering dynamics of each source. Provided the constraint for battery which in turns increases the life span, a complete model have been developed and successfully tested on MATLAB/ Simulink software. The design of the system and control strategy used is validated to provide following points:

a) Model can be used directly in battery operated vehicles working in open loop control without changing the structure of the system.

b) Prevent rapid current change in the battery.

c) Can also be used during starting of the dc machine which will also reduce the power loss in the starter.

d) During regenerative braking, UC is fed with the excess power and while battery is cut off.

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8.1. Journal Article

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