



Bidirectional Z-Source converter with hybrid system fed PMDC motor for electric vehicles

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ABSTRACT

The bidirectional DC-DC converters have been widely used in micro-grids, renewable energy systems, electric vehicles and other applications to ensure the power flows from and to, or between various energy storage devices. Energy storage systems have been a major research area in which battery is one of the most widely used. A new battery ultra-capacitor hybrid energy storage system is proposed for electric vehicles. The main objectives of using ultra-capacitors alongside battery are to improve the performance, increase the system efficiency and extend the battery life. In many applications, conventional bidirectional converters are inadequate since the specified range of input voltages and the specified range of output voltages call for an extremely large range of conversion ratios. A new bidirectional z- source converter with high voltage gain in both step-down and step-up operation modes is used here. In this work, an Ultra Capacitor is integrated with the battery in an Electric Vehicle using the new bidirectional converter to improve the dynamic performance of the vehicle system and enhancing the battery life. The simulation work is carried out using MATLAB/SIMULINK R2015 software. Hardware is made and the control strategy is implemented using TMS320F28027.

Keywords— Ultra-Capacitor (UC), Energy Storage Systems (ESS), Electric vehicles

1. INTRODUCTION

The role of energy storage devices in modern technology is increasing as renewable and sustainable energy sources is widely used. Such devices are considered as one of the key technologies for emerging markets as the use of more renewable energy sources, in order to minimize fossil fuel consumption and appropriate integration of clean energy sources in the grid and off-grid applications. Undesirably the coating nature of most renewable energy facilities, such as solar and wind, makes them unsuitable for standalone operation since they are strongly affected by weather conditions, causing energy variations and stability problems in the power network. Several measures can be adopted to deal with this problem, but are dependent on the existence of some type of energy storage devices.

Owing to the concerns about the environmental impact of transport, Battery Electric Vehicles (BEVs) have received a tremendous interest to reduce greenhouse emissions. The commercialization of BEVs has been possible due to advances in power electronics converters, battery technologies, battery charging systems, electric motors and power management control [6]. However, the BEV still faces major challenges that need to be solved. These major challenges are battery cost, battery lifetime, long charging time and limited range. In advance automotive applications, because the load profile varies rapidly according to the road conditions and the driver's behaviour, the energy storage system suffers from random charges and discharges, which have a negative effect on the life of the battery [8]. A common ground switched-quasi-Z-source bidirectional DC-DC converter [1] is a non-isolated topology which is based on the traditional two-level quasi-Z-source bidirectional DC-DC converter, changing the position of the main power switch. It has the advantage of high voltage-gain, lower voltage stress across the power switches, and an absolute common ground.

To solve the problems listed above, Hybrid Energy Storage Systems (HESS) have been proposed by many researchers. The basic idea of a HESS is to combine ultra-capacitors and batteries to achieve better overall performance. This is because, compared to batteries, ultra-capacitors have a high power density but low energy density. The hybrid energy storage system of electric vehicles has great potential to take full advantages of high power density with super-capacitor and high energy density with battery to improve the dynamic performance and energy efficiency of electric vehicles. In this project, a Super/ Ultra Capacitor is integrated with the battery in an Electric Vehicle using a New Bidirectional DC-DC Converter to improve the dynamic performance of the vehicle system and enhancing the battery life.

2. PROPOSED BATTERY-UC HYBRID SYSTEM FOR ELECTRIC VEHICLES

The proposed battery super capacitor hybrid system is shown in figure 1. There are two input sources, two bidirectional DC-DC converters, a dc bus and finally the PMDC motor. The project is focused on the Z-source bidirectional DC-DC converter [1]. The

main objectives of using ultra-capacitors alongside batteries are: improving performance (i.e., acceleration), increase the system efficiency (through the use of regenerative braking) and extend the battery life. The system uses a 24V battery and a 2.7V super-capacitor. The DC bus is rated to a voltage value of 24V. The batteries have a high energy density, but limited power density, is capable of supplying the main power to drive the motor. The super-capacitors have a low energy density and high power density. Therefore, by combining these two devices a high efficient, high performance vehicle can be obtained. The bidirectional z-source DC-DC converter is used to interface super-capacitor with DC bus. This converter is characterized by a simple control technique. In addition, the use of z-source bidirectional converter facilitates high voltage gain eliminating the need for costly super-capacitor.

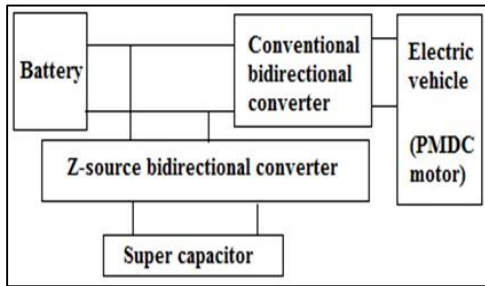


Fig. 1. Block diagram of the proposed system

2.1 Z-Source bidirectional converter

The bidirectional Z-source DC-DC converter is based on the traditional two-level quasi-z source bidirectional converter by simply changing the position of the main power switch [1]. As a result, the proposed converter can select the power switches with the low rated voltage, and the low on-state resistance, which in turn can improve the conversion efficiency. It consists of a switched-quasi-z-source network, 3 power switches and high or low voltage side filter capacitors are shown in figure 2. The converter can operate either in the step-up or in the step-down mode, enabling the bidirectional power flow between the high-voltage and low-voltage side. There are two operating modes that is, step-up operating modes and step-down operating modes.

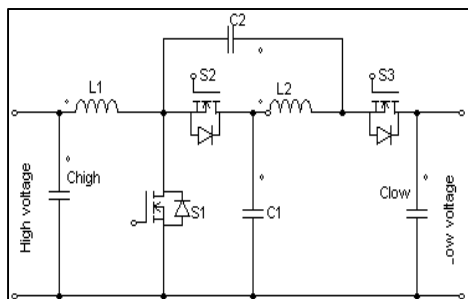


Fig. 2: Z-source bidirectional converter

In step-up operating mode, S₁ operates as the main power switch and S₂ and S₃ are the synchronous rectifiers.

Mode 1: S₁ is turned on, and S₂ and S₃ are turned off, the current flow paths are shown in figure 3(a). The inductor L₁ charged through S₁, while the capacitor C₁ is discharged, and the energy is transferred to the capacitor C₂ and L₂.

$$V_{l1} = V_{low} \tag{1}$$

$$V_{l2} = V_{c1} - V_{c2} \tag{2}$$

Mode 2: S₁ is turned off, and S₂ and S₃ are reversely turned on, the current flow paths are shown in figure 3(b). During this

interval, the input voltage V_{in} and the inductor L₁ charge the capacitor C₁ in series. The capacitor C₂ is connected in parallel with inductor L₂, then connected with V_{in} and L₁ in series to charge the capacitor C_{high} and provide the energy for the load.

$$V_{l1} = V_{low} - V_{c1}$$

$$V_{l2} = V_{c1} - V_{high}$$

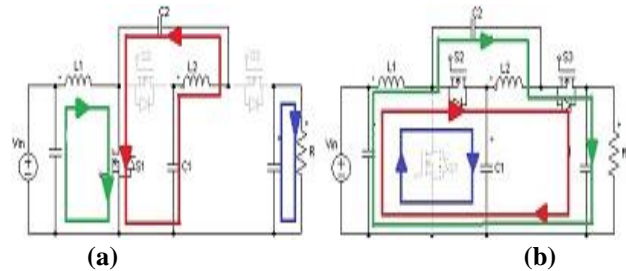


Fig. 3: Step-up mode (a) Mode-1 (b) Mode-2

The relationship between the voltage gain and the duty ratio can be obtained as:

$$M_{boost} = 1 + D_{boost} / (1 - D_{boost})$$

Inductance value can be given as:

$$L = V_{low} * D_{boost} / (F_s * \Delta i_L)$$

The capacitance value is given as:

$$C_{min} = I_{high} * D / (F_s * \Delta v_c)$$

In step-down operating mode, S₂ and S₃ operate as the main power switches, and S₁ is the synchronous rectifier. The duty ratio of the gate signals D_{buck} is taken as 1 - D_{boost}.

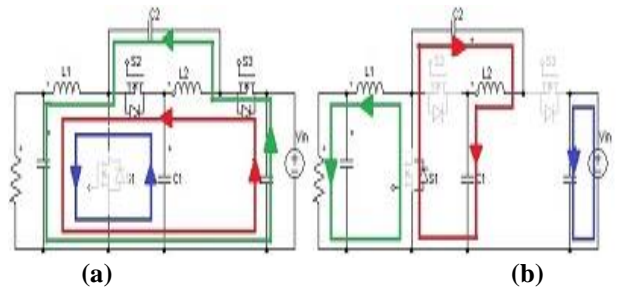


Fig. 4: Step-down mode (a) Mode-1 (b) Mode-2

Mode 1: S₁ is turned off, and S₂ and S₃ are turned on, the current flow paths are shown in Fig. 4(a). L₁, L₂, C₂, and the low voltage side load are charged by V_{in} through S₂ and S₃, while C₁ is discharged for L₁ and load through S₂.

$$V_{l2} = V_{high} - V_{c1}$$

$$V_{l1} = V_{c1} - V_{low}$$

Mode 2: S₁ is reversely turned on, S₂ and S₃ are turned off. The current flow paths are shown in figure 4(b). During this state, C₂ is connected in series with L₂ to charge C₁ through S₁. Inductor L₁ also supplies energy for the load through S₁.

$$V_{l2} = -V_{low} \tag{10}$$

$$V_{l1} = V_{c2} - V_{c1} \tag{11}$$

2.2 Conventional bidirectional converter

The conventional bidirectional DC-DC converter forms an important part in the proposed battery-ultra capacitor hybrid system. In addition to performing the bidirectional buck boost operation, this converter also facilitates speed control of the PMDC motor by varying the armature voltage. Basic 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 diodes in their structure which prevents reverse current flow. In general, a unidirectional DC-DC converter can be turned into a bidirectional converter by replacing the diodes with a controllable switch in its structure. Fig. 5 shows the structure of elementary buck and boost converters and how they can be transformed into bidirectional converters by replacing the diodes with

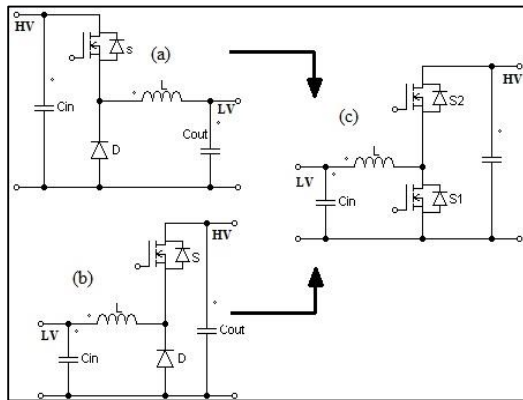


Fig. 5: Transformation to conventional bidirectional converter

3. SIMULATION AND RESULTS

The system model and the implemented control strategy has been simulated in the MATLAB/ Simulink as shown in figure 6. The main components in the system model are a new bidirectional quadratic DC-DC converter, a conventional bidirectional DC-DC converter, two sources (battery and UC) and finally the PMDC motor. Various parameters that are considered for the simulation has been given in table 1 and table 2.

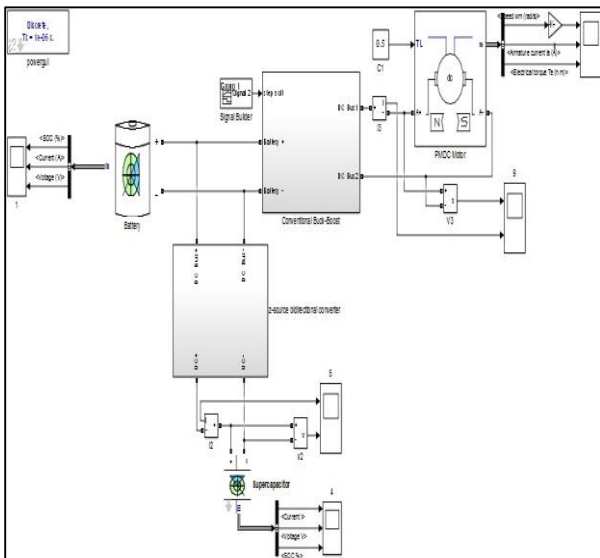


Fig. 6: Simulation of hybrid system fed PMDC motor

Table 1: Simulation parameters

E	Specifications
The input voltage, V1(boost) V2 (buck)	4V 24V
Switching frequency	20kHz
Inductor	30µH
Capacitor	150µF
Load	250W

Table 2: Simulation parameters

Parameters	Specifications
The input voltage, V1(boost) V2 (buck)	12V 24V
Switching frequency	20kHz
Inductor	40µH
Capacitor	5mF
Load	250W

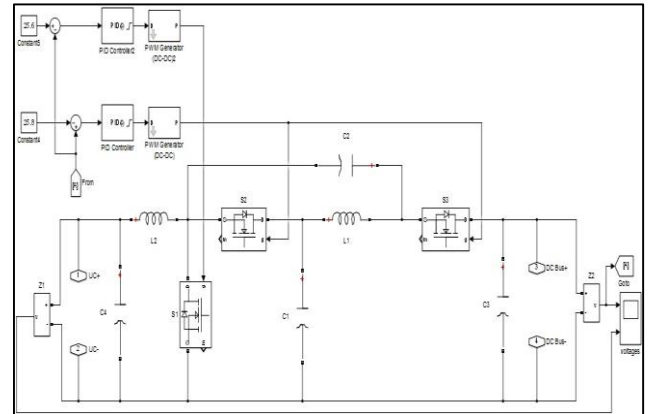


Fig. 7: Simulation of z-source bidirectional converter with control

The bidirectional DC-DC converter subsystem and its gate pulse generation are shown in figure 7. The high voltage side of this subsystem is connected to the DC bus and low voltage side to the Ultra-capacitor. The conventional converter subsystem and its gate pulse generation are shown in figure 8. One side of this subsystem is connected to the battery and another side to the PMDC Motor.

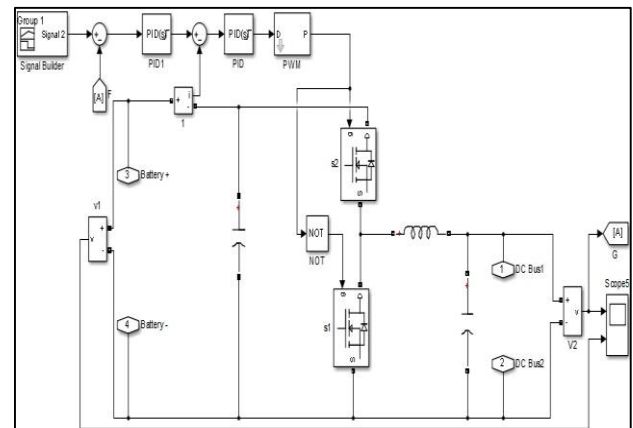


Fig. 8: Simulation of the conventional converter with control

To illustrate the working of the system, the speed of the motor is varied by changing the voltage applied to the motor using a signal builder. Initially, a terminal voltage of 24V is applied and is stepped down to 5V at 0.3 sec. This 5V is again stepped to 24V at 0.6 sec. Ultra-capacitor is initially taken to be uncharged and initial voltage is set as 0V. The battery supplies the PMDC motor during this time and the new bidirectional converter is idle. At 0.3 sec as the terminal voltage is stepped down to 5V, the regenerative action takes place and the new bidirectional converter becomes active and buck operation takes place and charges the Ultra-Capacitor. At 0.6 second, the terminal voltage is again stepped to 24V. The new bidirectional converter again becomes active and it boosts the Ultra-Capacitor voltage and supplies the bus. The initial demand will thus be met by the ultra-capacitor and the battery follows.

3.1 Simulation results

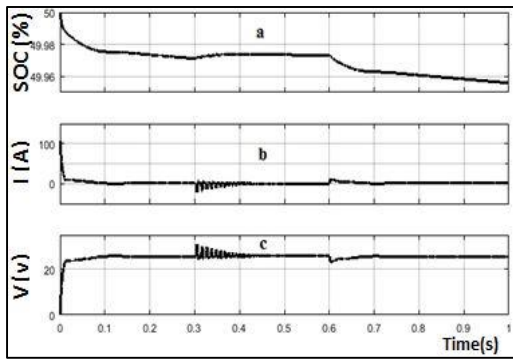


Fig. 9: Inductor currents (a) L1(b) L2

Figure 9 shows battery characteristics while using this UC-battery hybrid system for EV. Figure 10 shows the ultra-capacitor getting charged at 0.3 sec during regeneration and discharging during 0.6 sec.

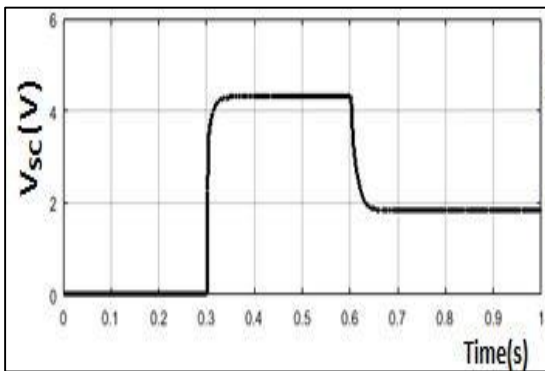


Fig. 10: Super-capacitor voltage

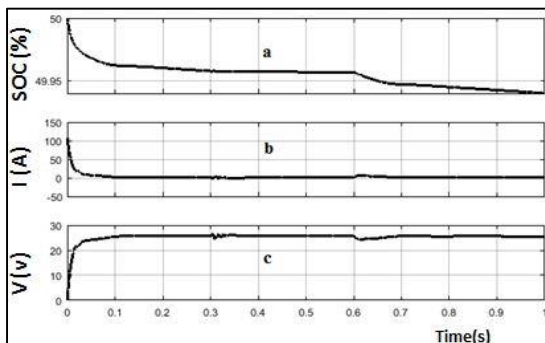


Fig. 11: Inductor current

Comparing the battery characteristics in figure 9 and 11, it is observed that the heavy oscillations in battery voltage and current during regeneration while using battery alone is reduced while using a UC-battery hybrid. Terminal voltage oscillations are also reduced while using a UC-battery hybrid.

3.2 Analysis

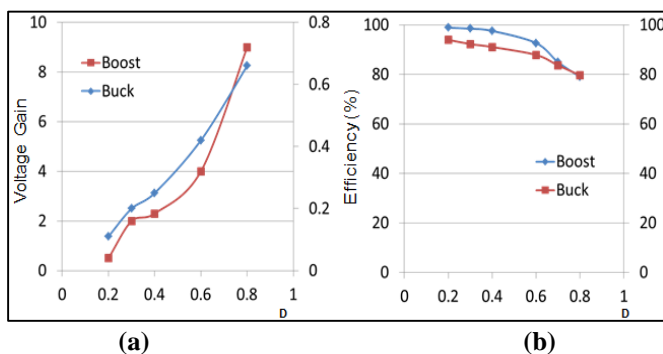


Fig. 12: (a) Duty ratio Vs Voltage gain (b) Duty ratio vs. Efficiency

4. EXPERIMENTAL SETUP AND RESULT

The experimental setup for a battery-ultra capacitor hybrid system for electric vehicles using new bidirectional quadratic converter is shown in figure 13. A 12V, 250W PMDC motor is used in experimental setup instead of 24V, 250W PMDC motor. The components used for the prototype are listed in table 3.

Table 3: Simulation parameters

Parameters	Specifications
The input voltage, V1(boost) V2 (buck)	2V 12V
Switching frequency	20kHz
Inductor	20μH
Capacitor	400μF
Load	250W

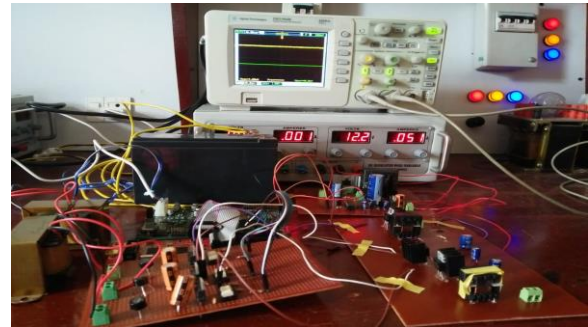


Fig. 13: Hardware implementation

Figure 14 and 15 shows the openloop output pulse for the converters in boost mode as well as in buck mode. The motor speed is controlled using the conventional bidirectional converter by changing the input to the motor. While the motor is running if the speed of the motor is suddenly reduced, regeneration occurs and there is a slight increase in bus voltage and if the motor is suddenly accelerated there occurs a sag in bus voltage. The openloop outputs of the converters having a fixed duty ratio's are shown in figure 16 and 17.

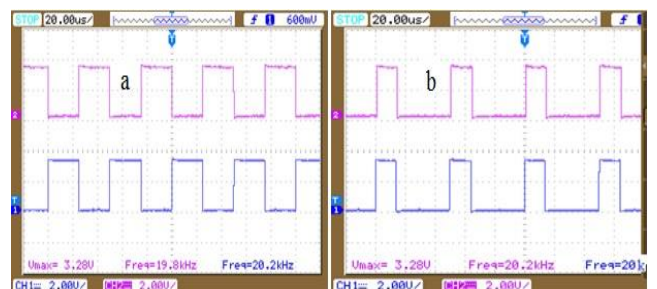


Fig. 14: Gate pulses (a) Conventional converter (b) Z-source converter in buck mode

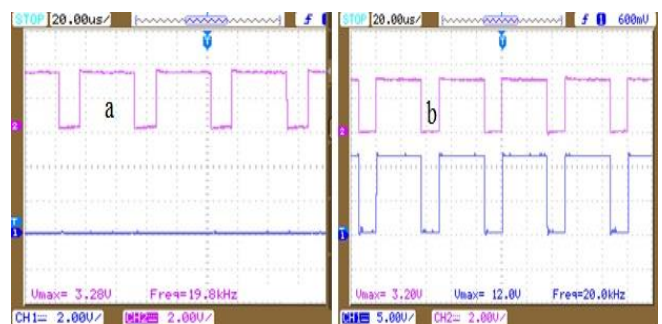


Fig. 15: Gate pulses (a) Conventional converter (b) Z-source converter in buck mode

The closed loop outputs for the z-source bidirectional bidirectional converter is shown in figure 18.

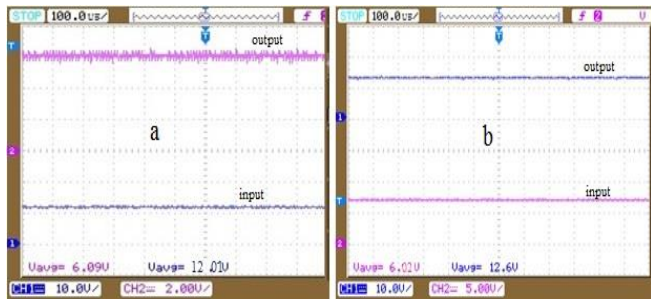


Fig. 16: Conventional converter (a) Buck mode (b) Boost mode

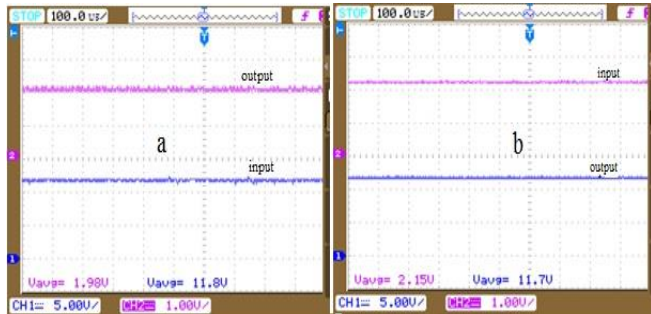


Fig. 17: Z-source bidirectional converter (a) Buck mode (b) Boost mode

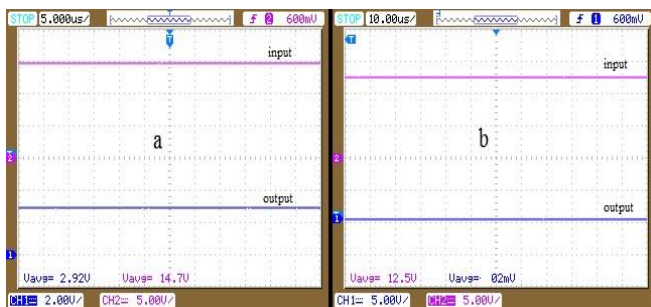


Fig. 18: (a) Bus voltage is greater than 12.5V (b) Bus voltage is less than 12.5V

5. CONCLUSION

The hybrid energy system is used with the objective of taking advantage of the best characteristics of the devices, creating a system that is superior to any of the devices used alone. In this project, bidirectional z-source DC-DC converter with battery super capacitor hybrid system fed PMDC motor for electric vehicles has been introduced. The bidirectional z-source converter offers high voltage conversion and simple control techniques. It can be used to store the super capacitor during

regeneration, and also to boost the capacitor voltage and supply the motor load during acceleration. The simulation work is carried out using Matlab/Simulink R2015 software. From the simulation results, it is observed that the large oscillations in the battery voltage and current during regeneration is reduced while using the battery super capacitor hybrid system. Super capacitor-battery combination is more suitable for the applications with fast transients. Such a system allows to store the energy during regeneration and use this energy when it's required. The experimental model of the proposed battery-ultra capacitor hybrid system for electric vehicles is made and the hardware open-loop results match the simulation results. It is suitable for battery charging of the electric vehicle.

6. REFERENCES

- [1] Yun Zhang, Jink Li, and Qiangqiang Liu, "A Common Ground Switched-Quasi-Z-Source Bidirectional DC-DC Converter With Wide-Voltage-Gain Range for EVs With Hybrid Energy Sources", IEEE Transaction on Industrial Electronics, June 2018.
- [2] Ke Jin, Mengxiong Yang, Xinbo Ruan and Min Xu, "Three-Level Bidirectional Converter for Fuel-Cell or Battery Hybrid Power System", IEEE Transaction on Industrial Electronics, vol. 57, no. 6, June 2010.
- [3] Susovan Samanta and Mahendra Chandra Joshi, "Modeling and Control of Bidirectional DC-DC Converter Fed PMDC Motor for Electric Vehicles", IEEE Conference, July 2013.
- [4] Ching-Ming Lai, Yu-Huei Cheng, Ming-Hua Hsieh and Yuan-Chih Lin, "Development of a Bidirectional DC-DC Converter with Dual-Battery Energy Storage for Hybrid Electric Vehicle System", IEEE Transaction on Vehicular Technology, Apr. 2017.
- [5] Yi-feng Wang, Li-kun Xue, Cheng-shan Wang, Ping Wang and Wei L, "Interleaved High Conversion Ratio Bidirectional DC-DC Converter for Distributed Energy Storage Systems Circuit Generation, Analysis and Design", IEEE Transaction on Power Electronics, 2015.
- [6] Jaya Aniruddha Mane and Prof. A.M Jain, "Design, Modelling and Control of Bidirectional DC-DC Converter for Electric Vehicles", IEEE Conference on Emerging Research in Electronics, 2015.
- [7] Hamid R. Karshenas, Hamid Daneshpajoo and Alireza Safaei, "Bidirectional DC-DC Converters for Energy Storage Systems", Energy Storage in the Emerging Era of Smart Grids, Publisher: In Tech, September 2011.