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Design of Multi-Input Bidirectional DC to DC Converter for Electric Vehicles with Regeneration Capability

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Abstract*: *A multi-input bidirectional dc to dc converter which can be implemented for electric vehicles is discussed in this paper. The importance of the converter depends on the phenomenon of backing up of regenerated power during braking. Three energy storage systems feed a common DC bus that interfaces the bidirectional DC/DC converter. Lack of energy supply to the electric vehicles due to less charging stations can be overcome by proposed converter. Any one of the energy storage system will be active throughout the operation of the vehicle and that the DC bus is continuously fed by a constant DC power. Pulse width modulation scheme is used to convert the available supply in the battery toe appropriate supply of the DC bus. The converter is tested by connecting a brushless DC motor to the output and the performance is analyzed with three modes of power transfer. The converter is designed in MATLAB/SIMULINK tool and the performance characteristics are discussed.

Index Terms*: *Bidirectional dc/dc converter (BDC), multiple battery storage, hybrid electric vehicle.

I. INTRODUCTION

The decline in energy supply globally has stirred lots of changes in vehicular technology. At present superior technologies are under research to run electric vehicles in a large scale. Hybrid electric vehicles are comparatively much efficient due to their multiple energy sources. Electric vehicles and hybrid-electric vehicles (HEVs) are used to reduce vehicle emission and reduce contamination of the environment. Electric vehicles run on accelerating an electric motor for propulsion and rechargeable batteries as storage devices [1].

Vehicular industries have initially switched to smart hybrid vehicles which run on both electrical power and combustion engine. Owing to the lack of power supply to an electric vehicle, a complete electric vehicle is less significant [2]. The usage of Electric Vehicles (EV) is limited because of certain factors like restrictions in range, increase in charging time of battery, cost and efficiency [3]. These factors are ultimately related to the energy storage system. While selecting a battery for EV applications the following factors are to be considered; power density, energy density, weight, volume, cycle life, and cost, operating temperature, safety, material recycling, and maintenance [4].

Though battery energy storage systems have evolved to a larger extent, they cannot feed a large capacity motor due to its capacity and time of operation [5]. Therefore a drive which has a high reliability to operate multiple energy sources simultaneously would be the only solution. When we integrate multiple energy storage systems together to feed the motor, it runs continuously for a longer period of time [6]. Also when the motor does not suffer from low supply, it has an enhanced performance and the efficiency increases [7]. On the other hand braking is a common phenomenon in any vehicle by which large amount of energy is exhausted as heat. Similarly in an electric vehicle the motor a large amount of back emf is generated when the motor is suddenly stopped [8]. This EMF can be stored effectively and can be utilized for charging of the batteries [9].

A bidirectional dc to dc converter with multiple inputs and feasibility to utilize the regenerated power to charge the batteries is designed here and its performance is tested.

II. PROPOSED TOPOLOGY

A simplified block diagram of the proposed converter is depicted in Fig.1.

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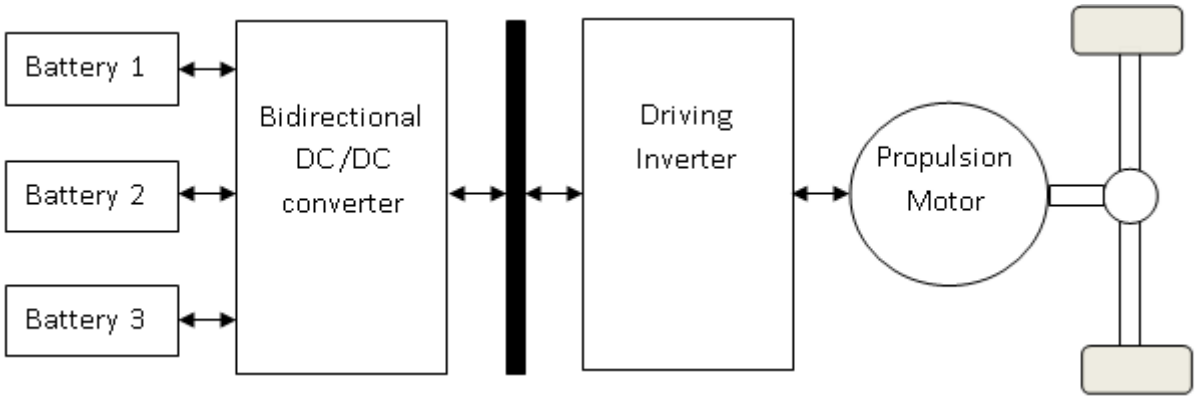

Fig. 1. Proposed bidirectional DC/DC converter

The converter interfaces three different sources of energy storage devices which has different voltage ranges. The converter can be made to operate in step down mode or step up mode with bidirectional power flow. Individual sources can be controlled and their output voltages can be varied independently when multiple sources are connected.

Multi-input DC to DC boost converter operated under battery charging and discharging mode. In battery charging mode either of the sources supplies power to the load and also delivers power to other sources. In battery discharging mode all sources deliver power to the load.

The circuit of the converter is shown in Fig.2 which has 3 sources and feeds a bidirectional dc to dc converter.

A. Modes of operation

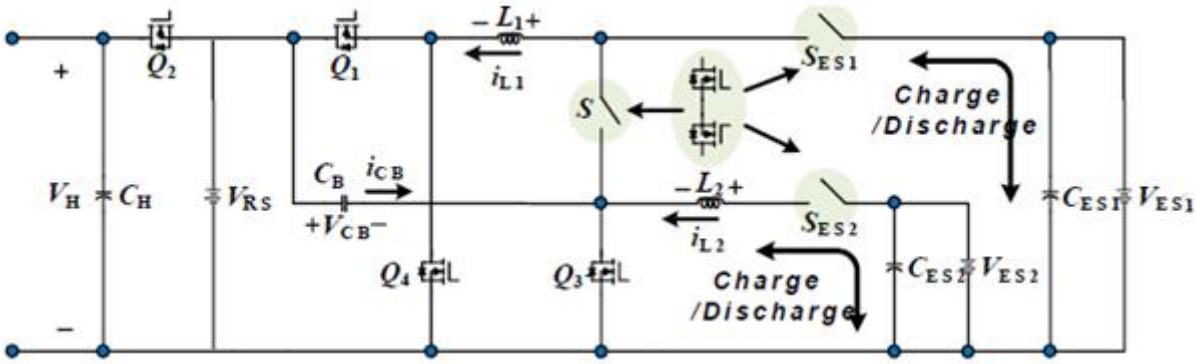

Fig.2. Modified bidirectional DC/DC converter with regeneration capability

The circuit of a modified bidirectional DC to DC converter consists of three operating sources VES1, VES2 and VRS. Here VES1 and VES2 are the main energy sources, whereas VRS is the battery which charges during the regeneration cycle. The converter can operate in step up mode, step down mode, charging mode, discharging mode and regeneration mode. The power flow is bidirectional in all modes of operation. The capacitors act as voltage divider blocks and the inductors increase the static voltage gain of the output. In addition the capacitors also reduce the voltage stress on the switches and feeds power whenever required. Therefore high duty cycle switching is reduced.

B. Low-Voltage Dual-Source-Powering Mode

In Low-Voltage Dual-Source-Powering Mode the switch S is turned off. The two bidirectional power switches are turned on and two low voltage dual sources feed the power to the dc-bus and loads. The switches in the bottom Q_3 and Q_4 are operated at a phase angle of 180 degrees and the switches Q_1 and Q_2 function as the synchronous rectifier (SR). In High Voltage DC-Bus Energy Regenerating Mode, the kinetic energy stored in the motor drive is fed back to the source during regenerative braking operation. The power obtained during regeneration can be much higher than the battery and that the battery is connected directly across the supply mains. This source is mainly used to charge itself during regenerative conditions.

C. Low-Voltage Dual-Source Buck/Boost Mode

Low-Voltage Dual-Source Buck/Boost Mode involves the transfer of energy transfer between main energy storage to the load and vice versa. The circuit is modified into a single-leg bidirectional buck-boost converter.

The duty ratio of the active bidirectional switch S is controlled and the step down converter directs the power flow from main energy storage to load. When the duty cycle, of Q3 is controlled, power flows from the load to main energy storage, such that the converter operates in step up mode.

D. Charging mode

During the battery charging mode the power flow is from one source to another or from the load to the source. The source VRS is charged only during the regenerative mode. The capacitors also act as charging pumps in case of excess power delivery from the load.

E. Converter control

Pulse width modulation technique is adopted to achieve all the above mentioned modes of operation.

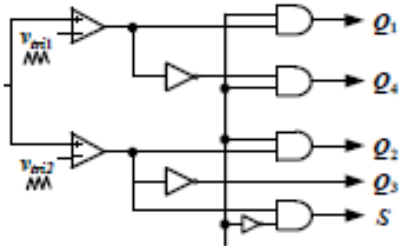

Fig.3. PWM technique for converter control

The input to the PWM controller is fed from a mode selector switch and the feed back from the propulsion motor. The PWM controller process the information and selects the appropriate duty cyle and controls the switches. The mode selection is based upon the operating characteristiscs of the motor so feedback is fed from the motor.

I. SIMULATION OF PROPOSED SYSTEM

The simulation of the multi input bidirectional converter is done in MATLAB/Simulink tool. The system includes three batteries that power a Brushless DC (BLDC). The output voltages of the battery in various modes are shown below.

Mode	Voltage range
Charging	48 V
Discharging	12 V
Boost Operation	16 V
Buck operation	40 V

Table.1 Voltages and modes of operation

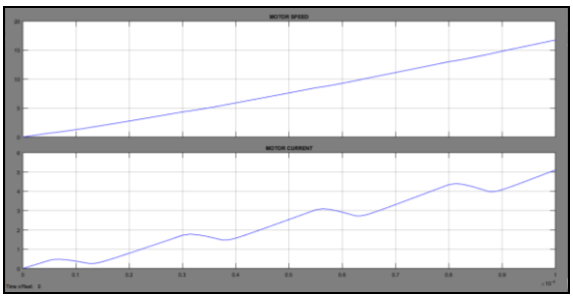

Fig. 4. Motor speed and Armature current

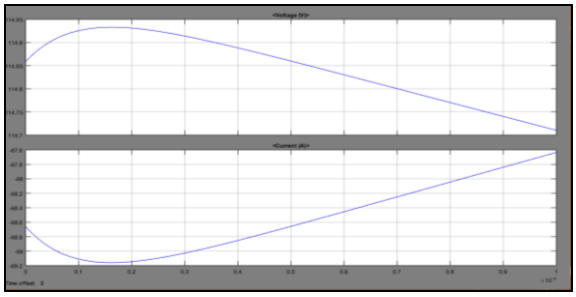

Fig.5. Regenerative braking mode

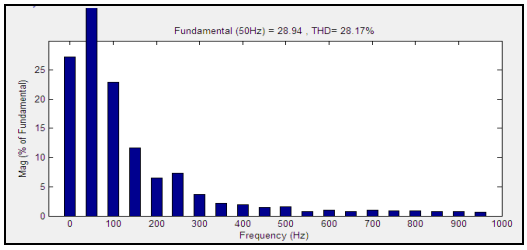

Fig.5. FFT analysis 1

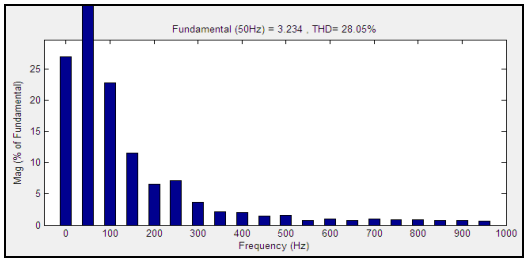

Fig.6. FFT Analysis 2

Inference from output waveforms

Table 1 shows the various modes and their corresponding voltages from the battery sources. It is to be noted that the voltages are high in boost mode and less in discharging mode. Fig.4 shows the raise in motor speed with respect to the increase in the armature current of the motor. The speed increases proportionately to the increase in armature current. Fig.5 shows the regenerative mode where the voltage drops to a negative value. The battery VRS is charged during this mode with the current. Fig.6 shows the FFT analysis to determine the Total Harmonic Distortion. The total harmonic distortion is found to be 28% in both the cases. Low THD values can be obtained by designing appropriate filters.

II. CONCLUSION

The proposed converter can interface multiple energy sources and high-voltage dc bus bars of different voltage ranges. The parameters involved in the circuit configuration, operation and analysis of Brushless DC motor were discussed on the basis of different modes of power transfer and charging and discharging mode. Simulation results are found to be satisfactory in all the modes of operation. The energy storage capacity is increased and it can be used more efficiently than the other converter. The results demonstrate that the bidirectional DC to DC converter can be successfully applied in hybrid electric vehicle system.

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