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DC-DC Converter Implementing Soft Switching Technique for AC Power Applications

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Abstract

Global warming alerts the world to switch over to using Electric Vehicle (EV) and Hybrid Electric Vehicles (HEV). The Bidirectional DC-DC Converter (BDC) plays a significant role in controlling the energy flow for the Battery Ultra-capacitor Energy Storage System (BUESS) which is used for storing energy in EV or HEV. The bidirectional DC-DC converter (BDC) plays a vital role in controlling the energy flow for BUESS. The bidirectional DC-DC converter performs the step-up and step-down operation at zero voltage switching, as it operates in buck and boost modes. Due to the uncertain nature of renewable energy resources they pose to be not suitable for standalone applications as the only source of power. This problem can be overcome with the aid of batteries and supercapacitors for storing energy. Fast charging is done by a supercapacitor and slow discharging by a battery. A hysteresis control loop achieves the design of charging and discharging status. A BDC in addition to an inverter can be opted and is implemented in MATLAB/Simulink, and is used in AC power applications.

Keywords: Soft-switching, Bi-directional DC/DC converter, Super capacitor, Li-Ion Battery

1. Introduction

Growing demand of transferring of energy among two sources, bidirectional DC-DC (BDC)converter are widely used in uninterrupted power supply (UPS), electric vehicles, battery charges and fuel cells. Depending upon the requirements BDC are classified as two categories (i) isolated and (ii) non- isolated. A high frequency isolation transformer is used to

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isolate two bridges in Isolated bidirectional dc-dc converter (1-3). The main focus of this isolated BDC is to increase the power level (4,5), reducing voltage spike, reducing voltage and current stresses through the active switches.

Auxiliary circuits like snubber circuit, fly back, active clamp and passive clamp methods are used to achieve soft switching in isolated BDC and also used to improve the conversion ratio (6-8). Addition of auxiliary circuits and power transformer increases volume, weight, high number of semiconductor devices and losses in the snubber circuit.

In order to diminish these disadvantages, the interest is focused to the transformer less non-isolated bidirectional DC-DC converter (NBDC)10. It has the advantages of reduced number of switches to reduce losses, ripple current reduction. High power conduction mismatching problem in resonance converter can be overcome with the help of soft switching.

1.1 Bi Directional DC-DC Converter

Bi-directional dc-dc converters always find different applications like a battery charger and also in EV and UPS systems. In case of the HEV, electric energy is transferred between motor and battery. No emission is achieved by battery power or other electrical supply systems.. Batteries possess good energy density, optimal size, and agreeable reliability. Such a provision is suitable aptly for Hybrid Electric Vehicle (HEVs) with a battery as energy storing module to provide proper power flow. In HEV energy storage devices also perform the boosting activity. However the high initial cost of such vehicles and its range are still the limitations. BDC play the critical module role for the traction systems in HEV. The usage of BDC fed dc motor drive supports a suitable control for both motoring and required regenerative braking operation and also it contributes to significant increase in the performance of the drive system and its cumulative efficiency. Of late many BDC topologies have been emerged with zero loss switching resulting in transfer efficiency. BDC embracing coupled inductor was felt good for soft-switching technique with another good controller in the form of hysteresis current controller. To minimize switching losses and also to support reliability, Zero-Voltage-Switched (ZVS) technique and Zero-Current-Switched (ZCS) technique have yielded good results in BDC. A typical multiphase BDC is apt for any high power application. In order to get a high voltage rating or a good current rating it can be performed with many converters in a combination of series or parallel performed with the low frequency of switching. A specific current controller was later identified for the BDC which embraces the switching across the different switches of the circuit in a complementary manner.

A bi-directional DC/DC converter is learned to support an energy storing systems with the hysteresis control method [3]. Energy storage devices are electric double-layer supercharge capacitors and Li-ion batteries—the battery used for slow discharging and the ultra-capacitor used for fast charging. Hysteresis control loop to design the charging and discharging status of the battery and supercapacitor. Solar is the input source of both battery and supercapacitor. Solar power can be said to be with zero emission and causes no toxic gases to be emitted. Non-Conventional clean power accessible almost every day of the year, even on shady days, creates some power. Return on investment, unlike paying for utility bills. Solar power is transferred to the devices by DC buses. Power measured can exhibit variations. Interleaving adds additional compensation, such as reduced ripple currents in the input and output circuits.

BDC finds various applications which includes renewable energy systems, fuel cells, Hybrid Electric Vehicles (HEV), and Uninterruptible Power Supplies (UPS). The inconsistent quality of most renewable energy resources holds them unsuitable for standalone operation. The known energy storage devices include mostly batteries and ultracapacitors where a dc-dc converter is always required. A prime expected property of a converter is bidirectional power flow control in all modes of operation.

BDCs are felt important in linking dc voltage buses for an optimal energy transfer. For example, a BDC plays an energy exchanger between primary healthy batteries (150-500V) and decent drive motor with 600V DC-link voltage. Maximum efficiency, ultra-light weight, perfect compact size, and good consistency are the needed requirements for the BDC. BDCs find their use in line-interactive UPS that avoids double renovation.

Interleaved means two or more power stages in parallel but driven in different phases. This makes filtering easier. Also, the current in the typical output capacitor can partly or wholly cancel depending on the operating cycle [10]. Cancellation of ripple in the input-output circuit voltage and current waveforms reduces current peak value.

1.2 Overview

The main aim of this paper is to be achieving minimum ripple rate using interleaving boost converter and they reduce the fluctuation. The addition of inverter to bidirectional DC-DC converter circuit is implemented in MATLAB/Simulink and it is used in AC power applications. The simulation result shows the measured battery soc, motor voltage Vs current, motor speed Vs torque, stator current.

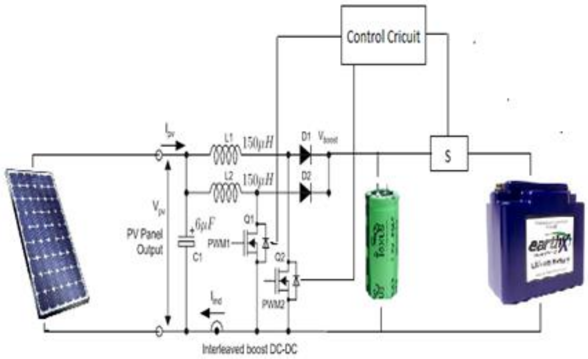

Figure 1. Circuit Diagram

Fig. 1 depicts the overall circuit for the electric vehicle's soft-switching BDC. A solar PV array is the input source of the circuit. Input needs to be given to the interleaved boost converter. It can support in reduction of ripple in input and output voltage, the switches being controlled by the hysteresis control technique.

A soft switching bidirectional converter with a simple auxiliary circuit has different modes of operation such as boost mode and the well known buck mode and this based on the operation of the current moving through each module in the circuit that is configured for the operation. In boost mode of operation the switch Q1 operated to control the intrinsic diodes of Q2 provides path for the current via the load. In buck mode switch Q2 controls the said parasitic diode of Q1 and paves way for the current to flow through the load.

It can be simplified that the steady-state analysis of the proposed converter is based on the following assumptions:

1. Snubber capacitor value Cs is opted to be extensive

2. Semiconductor devices must be with zero voltage drop

3. Ideal switches and passive components

2. Energy Storage Devices

Energy storage is a process for the control of energy produced at one time to be used at a later instant. A device can be designed to store energy and is called a battery. Energy transcends in many forms that includes solar radiation, chemical form and in certain cases from gravity and also as potential, electrical potential, electricity, elevated temperature, latent heat, kinetic energy and so on. Certain technologies provide short-term energy storage, while others can stand for much longer. Large energy storage is predominantly held pumped storage systems and hydroelectric dams.

Many examples can be cited for energy storage, regularly seen are the rechargeable battery, which stores chemical energy and instantly converts it to electricity to operate any device. There are hydroelectric dam, which stores energy in a tank as gravitational potential energy, and ice storage tanks, which store ice froze by cheaper energy at night to meet peak daytime demand for cooling.

Known energy storage include Li-ion battery and Supercapacitor. Li-ion batteries makes use of the intercalated lithium compound instead of the metallic lithium used in a non-rechargeable lithium battery. They find applications in many places including military, battery electric vehicle and aerospace applications. Lithium-ion batteries can pose safety hazards as they possess a flammable electrolyte which is kept under pressure. Acid-electrolyte batteries needs a variety of test conditions and also battery-specific tests.

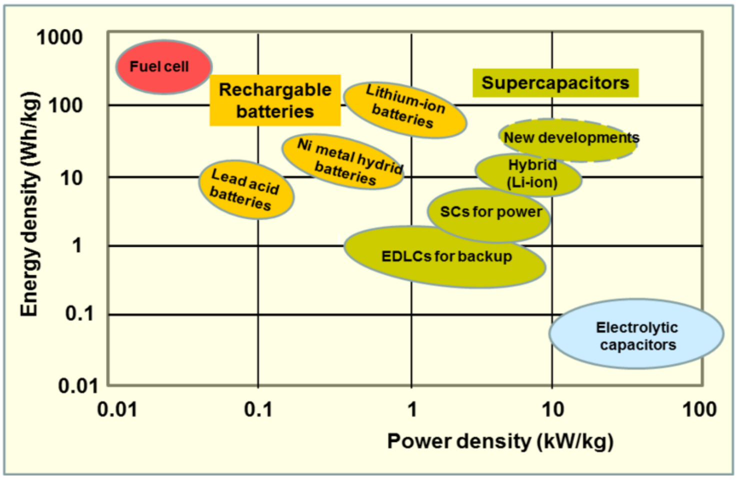

Figure 2. Power vs Specific energy of various capacitors and batteries

Supercapacitors on the other hand stores energy via two principles: static doubled-layer capacitance and electro-chemical pseudo-capacitance, and truly the allocation of the two types of capacitances depend on the type of material and designed structure the electrodes. Doubled-layer capacitors (EDLCs) – with activated carbonized electrodes or derivatives with more advanced electrostatically doubled-layer capacitance than electrochemical pseudo-capacitance. Pseudo capacitors with transitioned metal oxide or conductible polymer electrodes with a lofty electrochemical pseudo-capacitance. Hybrid capacitors – with multiple asymmetric electrodes, one of which exhibits electrostatically primary and the other primary electrochemical capacitance. Super capacitors occupy the gap between high power/low energy electrolytic capacitors and low power/high energy rechargeable batteries.

3. Simulation Studies and Result

The BDC for batteries and supercapacitor is simulated through MATLAB/Simulink software which can be easily implemented in real-time. The addition of an inverter exemplifies the bidirectional DC-DC converter circuit to be implemented in MATLAB/Simulink, and it is used in AC power applications.

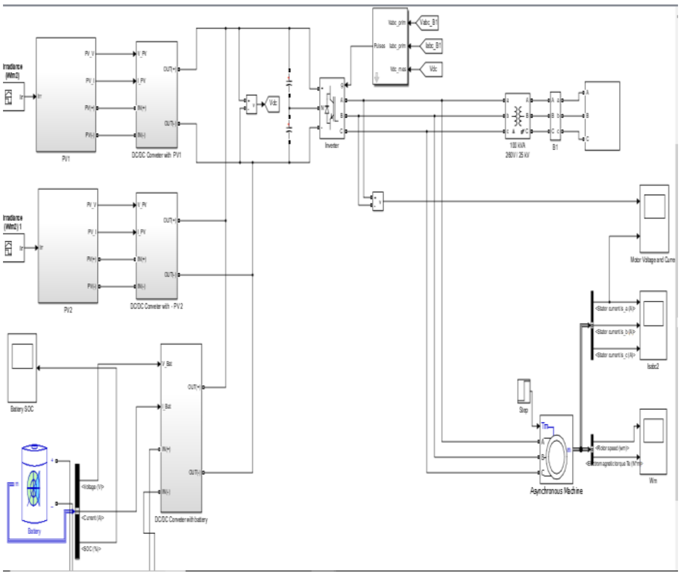

Figure 3. Overall circuit diagram of bidirectional DC-DC converter

Fig. 3. showcases the bidirectional DC-DC converter of battery and supercapacitor, which was designed in MATLAB/Simulink to create a PV panel for the input source of the system—using two converter blocks, the first converter block used as interleaving boost operation. Interleaving boost converters improves stability and reduces output voltage fluctuation. Second converter working as -chopper. It should be used to chop the input voltage from the first converter and then connected to the battery. Battery connected to the Demux will show battery charging and discharging state, and then battery output connected to the inverter block. The inverter should be used for the ac power application. So the inverter is connected to the asynchronous ac motor. Then they are connected to the scope, which will show the motor current and voltage, motor speed and torque, and stator current.

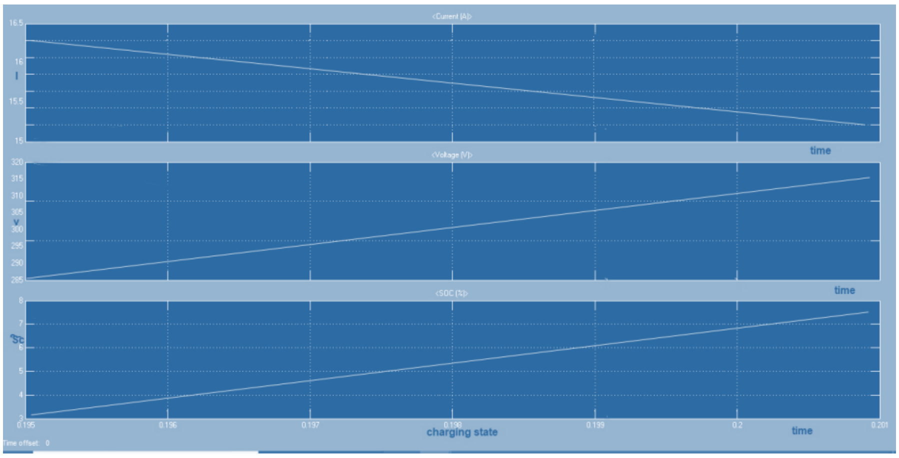

Figure 4. Battery charging state

Fig. 4 shows the battery charging state. When the battery charging voltage should be increasing, the current should be decreasing. Battery charging increased by 50 because of the input of the battery 50v from the chopper circuit.

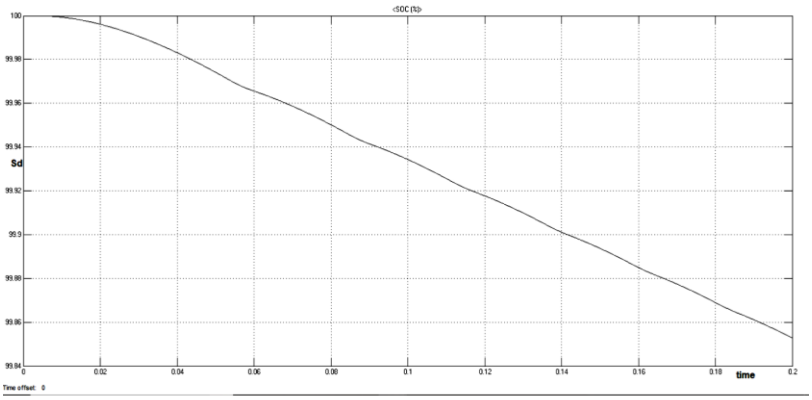

Figure 5. Battery discharging state

Fig. 5 shows the battery discharging state. Battery discharged by 100-99.97 because discharging state set by 100.

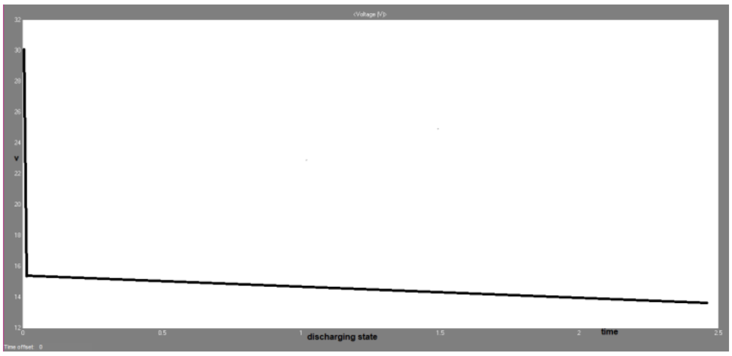

Figure 6. Battery discharging voltage

Fig. 6 shows the battery discharging state with respect to voltage. when battery discharging occurs battery voltage also gets decreased.

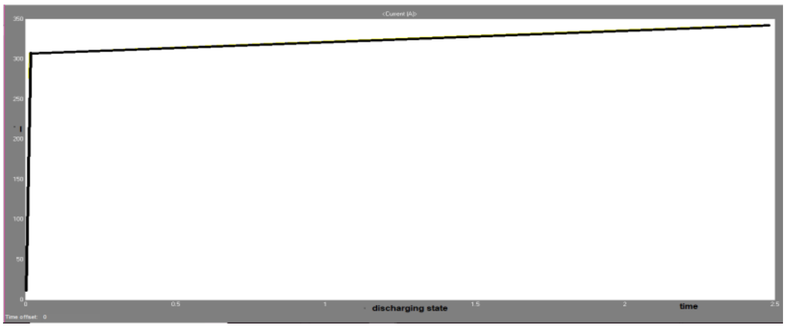

Figure 7. Battery discharging current

Fig. 7 shows the battery discharging current. when discharging state consider as current should be increasing voltage should be decreasing.

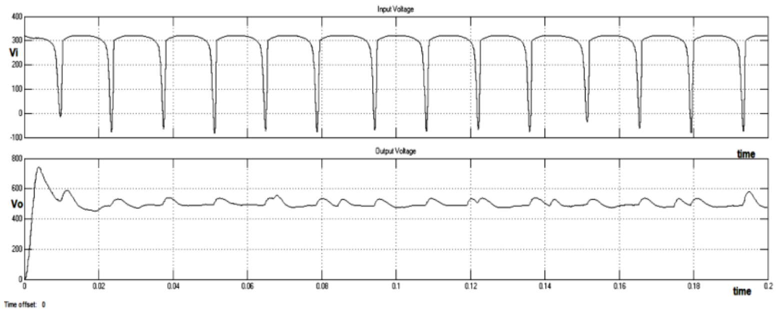

Figure 8. Boost converter input voltage and output voltage

Fig. 8 highlights the variations of a bidirectional DC-DC converter using boost converter which is finds its use for boost operation in boosting up the output circuit voltage of the converter

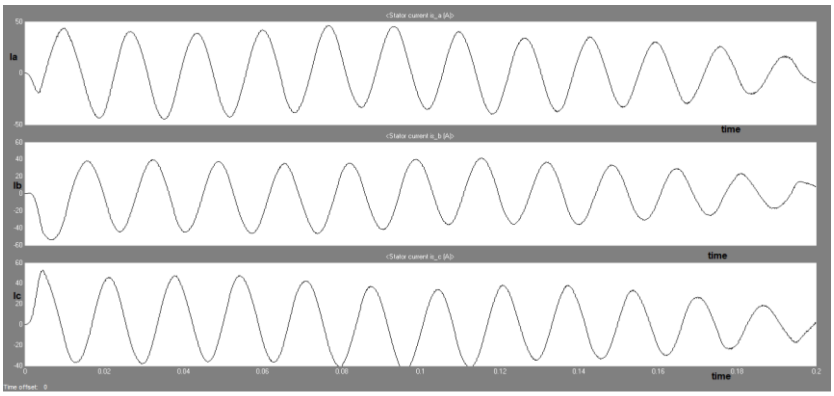

Figure 9. Stator circuit current

Fig. 9 has captured the stator current vs time. Stator current has three phases. This graph shows that the three phases are balanced. Stator rated current Ia, Ib, and Ic values should be considered as Ia varies from max 50 to min 50, Ib varies from max 50 to min 50, and Ic varies from max 50 to min 50. In case three phases are unbalanced means it will create a jogging effect in the motor. So the three phases are set in a balanced condition.

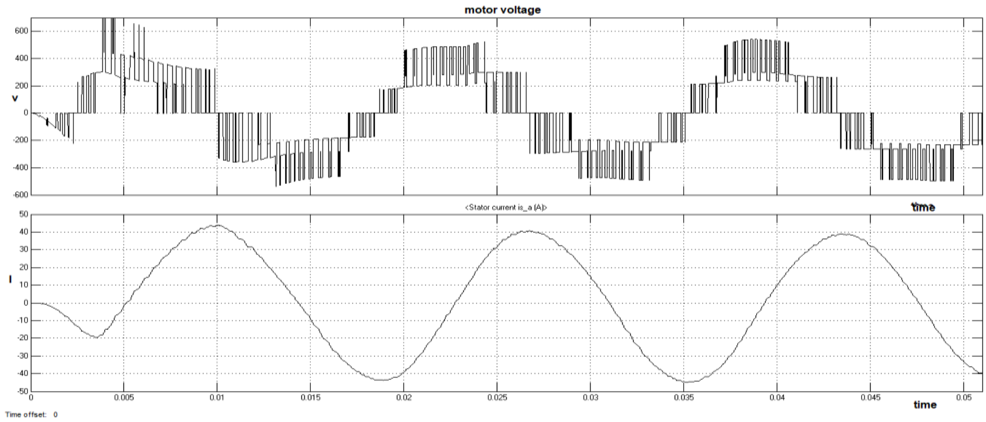

Figure 10. Motor voltage and its current

Fig. 10 exhibits the motor voltage and current. Motor voltage should be constant in motor voltage first peak increases to 600, which will show the high torque. The remaining will be maintained as 450. Current will depend on torque rating. If speed increases, then torque should decrease. In that manner, the current level should be increased to decrease.

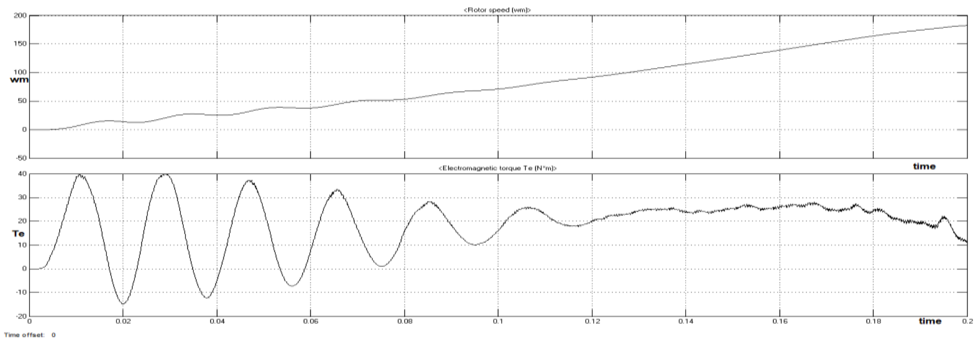

Figure11. Rotor Speed and Torque

Fig. 11 shows the rotor speed and torque. When starting the motor, it needs maximum torque. Once the motor start to run, then the speed should increase, the torque slightly decreasing. Torque needs both a positive side and a negative side because the motor rotates in 360 degrees. Motor torque should max 40 to min 10, and the rotor speed should be increasing in the order of 0 to 180. Speed should be increased by decreasing torque. Speed control of the motor should be smooth in ac motor compared to the DC motor.

4. Conclusion

In this article, soft switching bidirectional DC/DC converter with a simple auxiliary circuit for charging battery has been implemented. Slow discharging is done by a Li-ion battery, and fast charging is done by a supercapacitor. Hysteresis uses control loop to design the charging and discharging status of the battery and supercapacitor, and also to reduce the fluctuation. The minimum ripple rate can be achieved by interleaving the boost converter. It is able to achieve a minimum ripple rate and reduced fluctuation. Then the system shows the Vehicle speed and the torque, Vehicle motor voltage and the current, and Battery Soc. The addition of an inverter to a bidirectional DC-DC converter circuit is implemented in MATLAB/Simulink, and is used in AC power applications.

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