FPGA based Interleaved Bidirectional Converter for Electric Vehicle

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***Abstract* — This paper explores about the implementation of a hybrid energy storage system (HESS) utilizing ultra capacitors (UCs) to secure the batteries of an electrical vehicle (EV) from high-peak currents , also elongate their lifetime. An interleaved bidirectional buck–boost converter working in a discontinuous conduction mode(DCM), which is designed to transfer the energy between the batteries and the UCs. The interleaved converter is designed and developed in MATLAB® Simulink platform and results are obtained. The frame work prototype is developed and implemented using FPGA Spartan – 3. The FPGA is responsible for engendering all the converter gate signals and implements the control needed to inhibit the battery current within a safe value. The control strategy is predicated on dividing the current demand of the motor into two parts (high-frequency current and low-frequency current), the batteries supply the low frequency part and the UCs supply the high-frequency part. This balancing of energy transfer reduces the high current demand and increases the life time of the battery.**

Keywords—Interleaved Converter, Field Programmable Gate Array, Buck Converter, Boost Converter, Hybrid Energy Storage System, Ultra Capacitor.

I. INTRODUCTION

Due to the increasing concern for environment protection and the uncertainty about oil reserves, now a day's electricity is playing a key role as an alternative energy source in the automotive sector. Using an Electric Vehicle (EV) reduces significantly the daily travelling costs because the maintenance and operation costs of these vehicles are lower than the conventional ones. Electric vehicles are propelled by one or more electric motor using electrical energy stored either in batteries or from other energy storage device. Electric motors give instant torque, developing strong and smooth acceleration. During Acceleration, Start-Stop driving cycles and some overheating or corrosion will leads to the Battery peak currents in Electric Vehicle. Reducing the high peak currents leads to the battery life extension. Ultra Capacitors are connected in parallel with the batteries act as a low pass filter, limits the battery current within a safe value in turn extending the battery life span. On Combining high energy density batteries and high power density UCs in hybrid electric vehicles (HEVs) results in an efficient performance with reduced volume [1]. Ultra capacitors that uses pseudo capacitive or battery-like materials in one of the electrodes with micro porous carbon in the other electrode to increase the energy density of the devices. The UCs are connected to the ZEBRA battery and to the traction inverter through a buck–boost type DC–DC converter, manages the energy flow allowing an excellent performance during acceleration and regenerative braking period in an Electric Vehicle [2]. HESS is designed with a combination of batteries and UCs; protect the batteries from high peak currents, combined with Vehicular technology is the recent trend in automotive field. In this paper, FPGA controller based interleaved bidirectional buck–boost converter working in discontinuous conduction mode for electric vehicles, is designed to transfer energy from batteries and UCs. The FPGA algorithm engenders control signal for the converter solid state switches and implements the control stage needed to smooth the battery current peaks. [5] discussed about an eye blinking sensor. Nowadays heart attack patients are increasing day by day."Though it is tough to save the heart attack patients, we can increase the statistics of saving the life of patients & the life of others whom they are responsible for.

II. PROPOSED SYSTEM

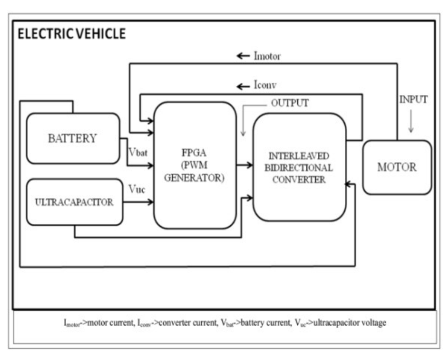
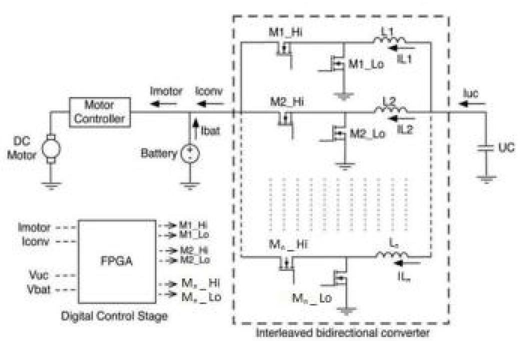


Fig.1 Block Diagram of the proposed system

An Interleaved DC-DC converter is adopted to transfer the energy between batteries and UCs, as a good solution for the application with high power and high current with low current ripple. Interleaving techniques have been widely used in power converters in recent days. Typical benefits of interleaving techniques include reduced device stress by separating power into each discrete phase, reduced filter size by increasing effective frequency, and alleviation of the effects of current ripple. Interleaved power converter operating in discontinuous conduction mode (DCM) improves the current balance without using current control loops, which can simplify control system with reduced cost. Fig.1 shows the block diagram of the proposed system.

The circuit diagram of 'n' Phase Interleaved Bidirectional Buck – Boost Converter is shown in Fig.2. Here only one phase is considered which consists of two power MOSFET switches, Main and Freewheeling. In order to achieve the discontinuous conduction operation in converter, a mathematical formula is developed to calculate the turn 'on' time of freewheeling MOSFET in buck and boost operation. The freewheeling MOSFET must be turned 'off' by zero current estimation of the inductor current. This time is estimated from the input voltage, output voltage and duty ratio of the main MOSFET. The converter is designed such that the current peaks extracted from the batteries could be reduced to half of its maximum value (300A) which means converter is designed to supply 150 A to the battery dc link and handling 7.8 kW.



Bidirectional Converter

The UCs is located on the low-voltage side of the converter, and the battery and the motor to be controlled are placed on the high voltage side. The converter operates in boost mode when the UCs delivers power to the dc link and in buck mode when the UCs absorbs power. In both modes, the converter is always working in the DCM; so the inductor current is reset to zero at every switching cycle. In bidirectional converter, the power can flow in either direction, which is useful in applications requires regenerative braking [3]. The amount of power flow between the input and the output can be controlled by adjusting the duty cycle. An ultra capacitor, is capable of holding hundreds of times more electrical charge quantity than a standard capacitor [4]. FPGA based PWM generator used to generate the control signals for converter in order to reduce the peak current. Peak current depends on the motor speed.

Fig.3 shows the inductor current response for buck and boost modes. The average phase inductor current (i_L), the average UCs current (i_{UC}), and the average converter output current (i_{CONV}) are directly related to the main switch duty ratio D_1, and can be easily calculated from the following equations.

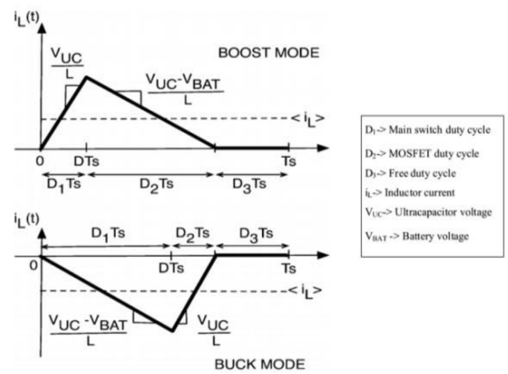


Fig.3 shows the wave form of Inductor current

III. SIMULATION RESULTS

The proposed system is simulated using MATLAB® Simulink. Fig.4 shows the Simulink realization of Xilinx block set design for the proposed system. Xilinx block sets are used for the purpose of arithmetic calculations and expressions. Xilinx block sets are used to generate the

VHDL or verilog codings for the respective simulink blocks which are compatible with FPGA. System generator is responsible for producing the required VHDL or verilog codings. Fig.5 shows the output waveform of DC-DC converter and Fig.6 shows the DC bus voltage and current waveforms.

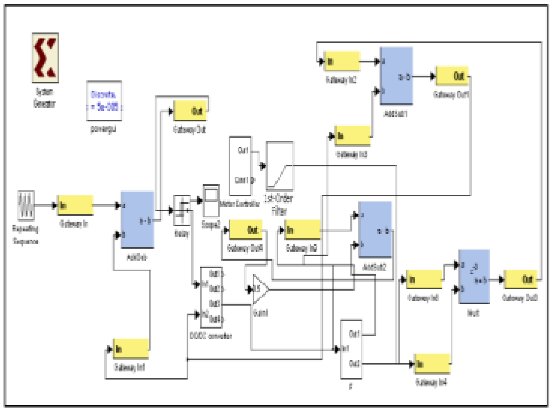


Fig.4 Simulink® realization of Xilinx block set design for the Proposed System

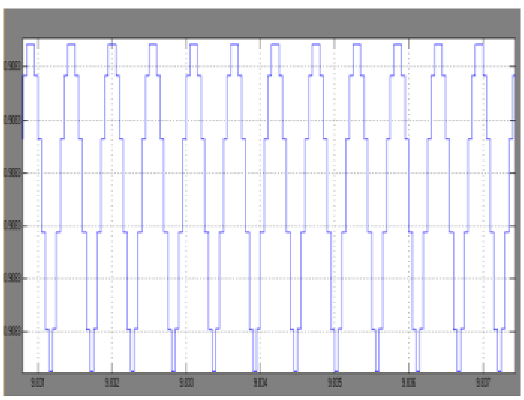


Fig. 5 Simulink® realization of Output of DC-DC Converter

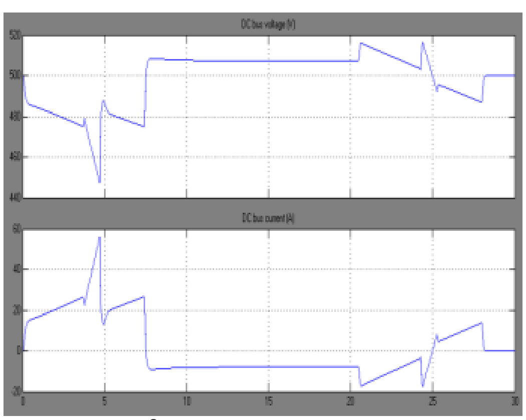


Fig. 6 Simulink® realization DC Bus Voltage and Current

IV. PRACTICAL IMPLEMENTATION

A Prototype hardware setup of Proposed system is developed. Fig.7 shows the consummate hardware setup with ultra capacitors. The DC-DC converter circuit consisting of two MOSFET (IRF540N) switches. Gate pulses to the circuit are generated by FPGA Spartan – 3. The battery and ultra capacitor are connected in parallel with FPGA. The battery supplies the low frequency current during running whereas the ultra capacitor supplies the high frequency current during starting.

Fig.7 Hardware implementation of Electric vehicle with Ultracapacitor

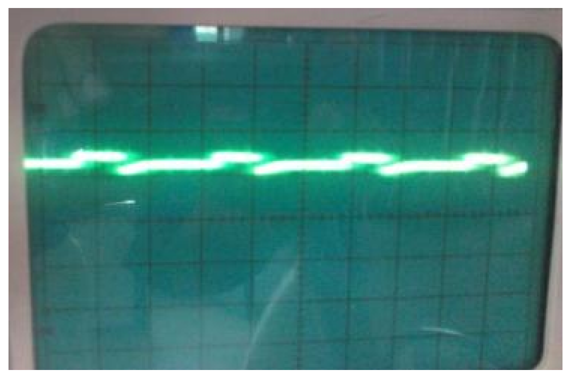


Fig.8 Battery Current of Electric vehicle without Ultracapacitor

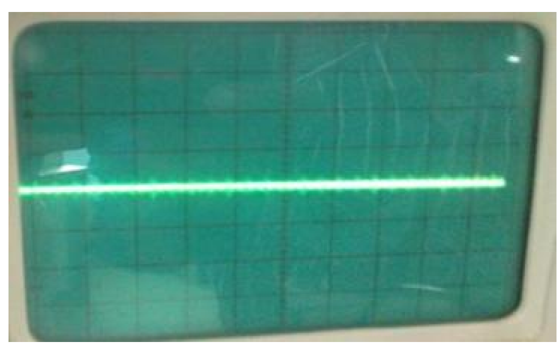


Fig.8 Battery Current of Electric vehicle without Ultracapacitors

V. CONCLUSION

Developing electric vehicles is important in reducing greenhouse gas emissions. This paper describes and implements an HESS with a combination of batteries and UCs to protect the batteries from high peak currents and, therefore, extended its lifetime. An FPGA controlled interleaved bidirectional buck–boost converter working in DCM is designed to connect the battery with the UCs. The FPGA is responsible of generating all the converter gate signals and implements the control stage needed to smooth the battery current peaks. Therefore high peak currents from battery are reduced. The lifetime of the battery is extended. The efficiency of the converter is 96.6% in buck mode and 95.1% in boost mode. At full load, the efficiency is reduced to 95.1% and 93.2%, respectively.

VI. REFERENCES

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