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Optimal Bidirectional Battery Charger

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ABSTRACT

This paper presents a optimal bidirectional battery charger. The proposed charger acts as a current source, i.e., acts in constant current (CC) mode with a controlled output current in case of deep discharge of a battery, and as a voltage source, i.e., acts in constant-voltage (CV) mode with a controlled output voltage for near-100% battery state of charge. The proposed circuit is universal from the battery voltage point of view, i.e., can charge a battery with any given voltage rating, and adaptive from the optimum charging current requirement viewpoint, i.e., can adapt to the optimum battery charging current. The presented solution uses a magnetically coupled bidirectional converter topology. In order to make the system feedback controlled during the whole cycle of charging, the regulation loop is clamped, and hence, automatic and smooth transition from the CC to CV mode is achieved without the need of any extra switching circuit or control loop. Experimental and simulation results for a 250-W prototype are presented to verify the proposed system. The prototype shows maximum efficiencies of 90.24% under boost mode and 92.7% under buck mode of operation. The performance of the charger is verified using two different 12-V–7-Ah and12-V–32-Ah lead–acid batteries

Keywords: *Battery Charger; Constant Current (CC); Constant Voltage (CV); Boost Converter; State of Charge (SOC).*

1.0 Introduction

Generally a battery charger is a device used to put energy into a secondary cell or rechargeable battery by forcing an electric current through it. The charging protocol depends on the size and type of the battery being charged. Some battery types have high tolerance for overcharging and can be recharged by connection to a constant voltage source or a constant current source.

Simple chargers of this type require manual disconnection at the end of the charge cycle, or may have a timer to cut off charging current at a fixed time. Other battery types cannot withstand long high-rate over-charging; the charger may have temperature or voltage sensing circuits and a microprocessor controller to adjust the charging current, and cut off at the end of charge.

Slow battery chargers may take several hours to complete a charge; high-rate chargers may restore most capacity within minutes or less than an hour, but generally require monitoring of the battery to protect it from overcharge. Several different combinations of chemicals are commonly used

including: lead–acid, nickel cadmium (NICd), nickel metal (NIMH), lithium ion (Li-ion), and lithium ion polymer (Li-ion polymer).

2.0 Lead Acid Battery

The Lead Acid battery is made up of separator plates, lead plates, and lead oxide plates (various other elements are used to change density, hardness, porosity, etc.) with a 35% sulphuric acid and 65% water solution.

This solution is called electrolyte which causes a chemical reaction that produce electrons. When a battery discharges the electrolyte dilutes and the sulphur deposits on the lead plates. When the battery is recharged the process reverses and the sulphur dissolves into the electrolyte.

Keeping lead-acid batteries properly charged is the key issue to maximize the performance and lifetime of the battery.

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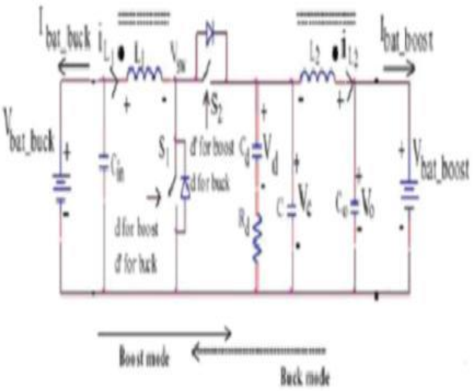
Fig 1: Circuit Diagram of Optimal Bidirectional Battery Charger



The proposed system uses a bidirectional magnetically coupled inductor topology with a damping network as shown in Fig. 1.5 . The converter operates in boost mode for power flow from Vbat_buck to Vbat_boost and in buck mode when power flow is from Vbat_boost to Vbat_buck. It uses two bidirectional switches with inbuilt body diodes to avoid the interruption of the inductor current. A dead time is inserted between the gate signals of these two switches to prevent shoot through. Low-pass filters are used on both input and output sides of the converter to smoothen the battery current. Magnetic coupling is used between the input and the output filter inductors. The converter uses a series damping network Rd&Cd. This damps out L1C resonance, and along with the help of magnetic coupling between the inductors, the RHP zero (in case of boost operation) can be completely eliminated. This makes the converter a minimum-phase system enabling a simple and linear control for boost operation. The coupled inductor with damping network also facilitates the use of smaller inductors, making the system with less weight and volume

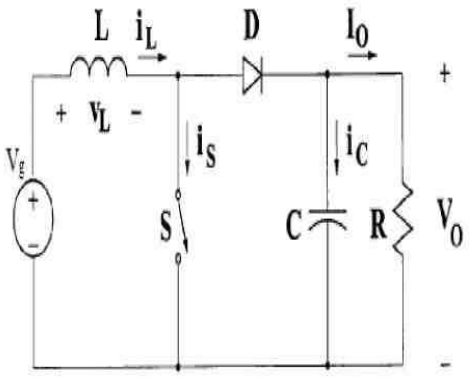
3.0 Boost Converter

DC-DC converters can be used as switching mode regulators to convert an unregulated dc voltage to a regulated dc output voltage. The regulation is normally achieved by PWM at a fixed frequency and the switching device is generally BJT, MOSFET or IGBT. The minimum oscillator frequency should be about 100 times longer than the transistor switching time to maximize efficiency. This limitation is due to the switching loss in the transistor. The transistor switching loss increases with the switching frequency and thereby, the efficiency decreases. The core loss of the inductors limits the high frequency operation. Control voltage Vc is obtained by comparing the output voltage with its desired value. Then the output voltage can be compared with its desired value to obtain the control voltage Vcr.

3.1 Operation of boost converter

The step up boost converter consists of a dc input voltage source Vg, boost inductor L, controlled switch S, diode D, filter capacitor C, and the load resistance R. When the switch S is in the on state, the current in the boost inductor increases linearly and the diode D is off at that time. When the switch S is turned off, the energy stored in the inductor is released through the diode to the output RC circuit.

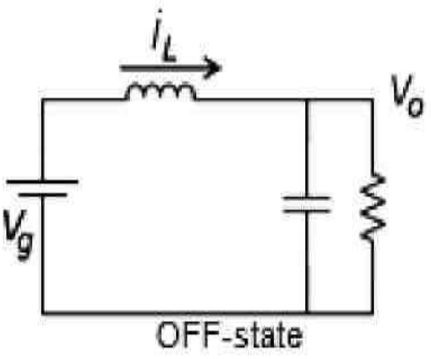
Fig 2: Circuit diagram of boost converter



3.1 Steady state analysis of boost converter

(a) Off State

In the OFF state, the circuit becomes as shown in the Figure.

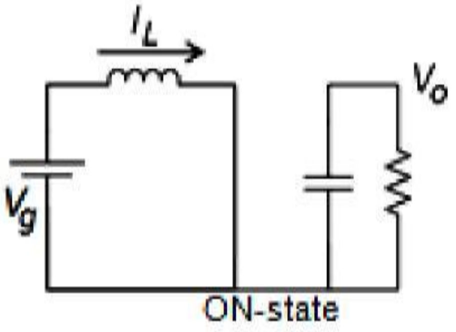


When the switch is off, the sum total of inductor voltage and input voltage appear as the load voltage.

(b) **On State**

In the ON state, the circuit diagram is as shown below in Figure,

Fig 3: The ON state diagram of the boost converter



When the switch is ON, the inductor is charged from the input voltage source Vg and the capacitor discharges across the load. The duty cycle, D=Ton/T where T=l/f

Fig 4: Inductor Current Waveform

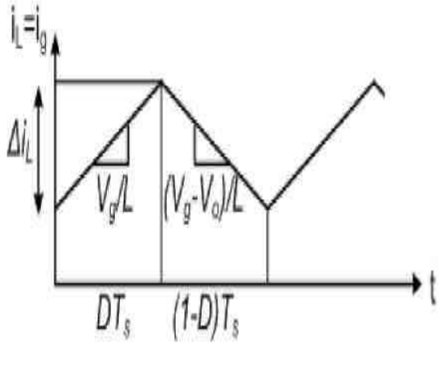
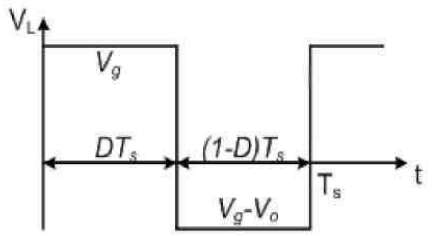


Fig 5: Inductor Voltage Waveform



From the inductor voltage balance equation, we have:-

Vg(DTs) +(Vs-Vo)(1-D)Ts=0

Vg(DTs)-Vg(DTs)-VgTs+VoDTs-VoTs=0

Vo=Vg/(1-D)

Conversion ratio, M=Vo/Vg=1/(1-D)

From inductor current ripple analysis, change in inductor current,

ΔIl=(Imax-Imin)

- Δ IL=(Vg/L)*(DTs)
- Δ IL = (VgD)/(fsL)
- L=VgD/fs(IL)

The boost converter operates in CCM (continuous conducting mode) for L> Lb where

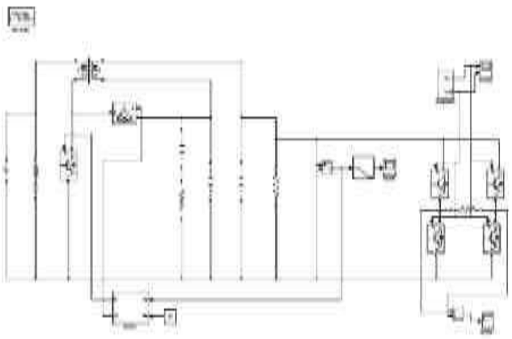
Lb=(1-D)2DR/2f

Cmin=DVo/VoRf

4.0 Simulation Output

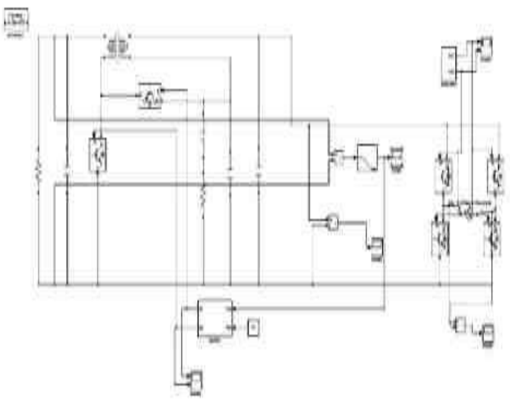
4.1 Simulation circuit for boost converter

Fig 6: Simulation Circuit of Boost Converter



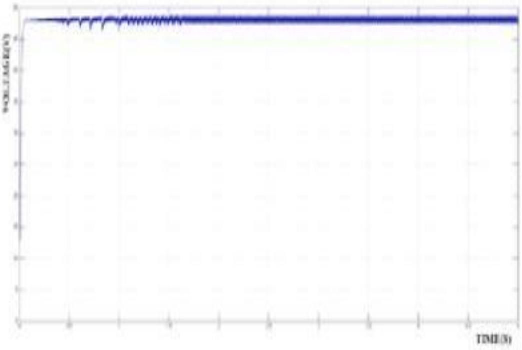
4.2 Simulation circuit for buck converter

Fig 7: Simlulation Circuit ot Buck Converter



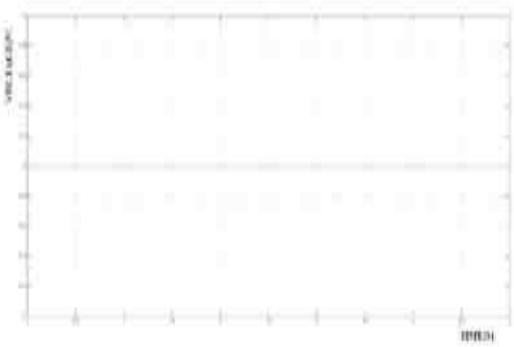
4.3 Boost converter output

Fig 7: Output Voltage Waveform



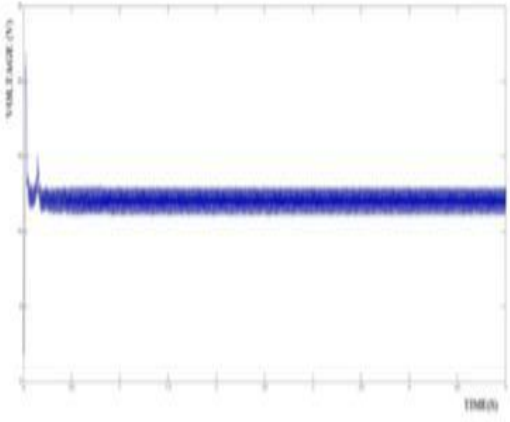
4.4 Boost converter input

Fig 8: Boost Converter i/p



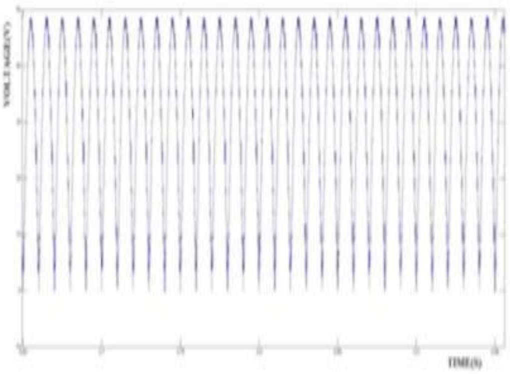
4.5 Buck Converter Output

Fig 9: Buck Converter o/p



4.6 Buck Converter Input

Fig 10: Buck Converter i/p



5.0 Conclusion

A optimal bidirectional battery charging system which exhibits universal (from the battery voltage viewpoint) and adaptive (from the optimum charging current requirement viewpoint) properties has been achieved.

The regulation loop is clamped and gives feedback control for CC and CV and even during the transition from CC to CV mode of operation. Smooth and stable transition from CC to CV is achieved without the need of any extra switch or control loop.

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