PV Based High Efficiency Battery Charger

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Abstract— The research on the renewable and green energy sources, especially the solar arrays and the fuel cells, becomes more and more important with the shortage of energy with ever increasing of the oil price. Interleaved Boost converter (IBC) has better performance characteristics when compared to a conventional boost converter due to its increased efficiency, reduction in size and greater reliability. This paper focuses on the design and development of a battery charger with PV input and constant output voltage of 19.5V that utilizing two phase interleaved boost converter topology. The various parameters of the IBC are compared with a conventional boost converter. Simulation studies have been carried out using MATLAB/SIMULINK. The hardware is implemented with a battery, interleaved boost converter and ARDUINO Mega 2560 board. The ARDUINO board is used to generate the pulses for boost converter switches and the output voltage of interleaved boost converter is given to charge the battery. This topology increases the performance of the dc to dc converter and reduces the ripples. The result obtained through the simulation is verified with the hardware.

Key words: Photo-Voltaic Cells, Interleaved Boost Converter, Battery, Input Current Ripple, Output Voltage Ripple

I. Introduction

In the current state of affairs, the utilization of the renewable energy generating system has been increased dramatically due to the exhaustion of fossil fuel and the influence of the surroundings. The major renewable-energy sources are photovoltaic energy, wind power, solar energy and fuel cell. And, these are systematically accepted for distributed power generation. The unregulated output power of renewable energy sources ought to be regulated through the power converters, and the power system reliability will be bonded depending on the performance of the converters. DC-DC converters play a crucial role in interfacing the non-conventional energy sources like photovoltaic current to helpful DC or AC form. It is therefore necessary that the interfacing converter should be highly efficient in transferring the power to ensure proper load management. The battery charger/discharger is generally required as the interface between the equipment and the battery.

Among the renewable energy resources, solar energy is one of the most demanding energy sources over the globe. The PV modules comprise of several solar cells, which convert the energy of the daylight directly into electricity, and are connected as required to provide desired levels of DC current and voltage [1]. These power sources have quite low-voltage output and need series connection of voltage booster to supply enough output voltage [2]. Several converter topologies have been proposed for maintaining a relentless output voltage. DC-DC boost converter is generally used to boost the voltage to the required level [3]. But the output voltage of boost converter fluctuates with variation in load. Also the maximum voltage gain can be achieved with a duty ratio close to one. Since, the turn-off period of the switch becomes short with increase in duty cycle, current ripples will be large which increases the power devices conduction losses [4]. In addition, the converter shown in fig.1 requires a large electrolytic capacitor in order to compensate the power pulsation when the inverters are connected to the single-phase grid because the power is fluctuating at twice of the grid frequency.

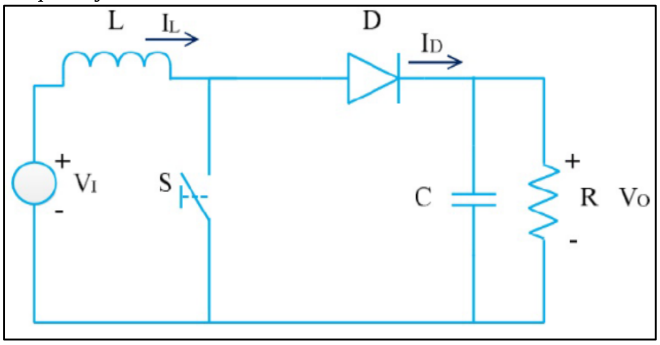

Fig. 1: Conventional boost converter [3]

The voltage gain can be extended and the current ripple can be reduced by using cascade structure. Since the cascaded structure needs two sets of power devices, magnetic cores and control circuits, it increases the complexity of the circuit and makes the circuit expensive. Also the system stability of cascade structure is less, so that more care is required while designing the control structure of a cascaded boost converter [4].

Three-level boost converters will double the voltage gain and components voltage stress is halved compared with the traditional boost converter. Lower voltage rated MOSFETs with lower on state resistance can be often used to reduce associated loss. However, the converter operates under a hard switching condition, and the output diode reverse-recovery problem is severe. So soft switching techniques are needed, which will further increase the circuit complex and cost [5].

II. Proposed Circuit Topology

A. Circuit Configuration

Fig.2 presents the circuit structure of the proposed converter. The dual converter consisting of two boost switching cells connected in parallel. Such a system might be constructed in high power applications where the device rating is one of the limiting factors.

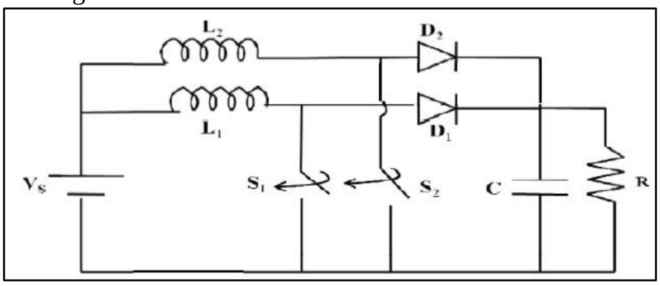

Fig. 2: Interleaving Two Boost Topology Switching Cells [6]

When the commutation instances of the two controlled switches are identical, the performance of the converter will be similar to a boost converter. If the converter switching cells are interleaved such that there is a phase shift of 180 degree between the two switches, the resultant will have less current ripple when compared with a conventional boost converter.

When both the switches S_1 and S_2 are in operating condition, both the inductors L_1 and L_2 will be in the charging mode and the output capacitor C supplies the load. When any one of the switch is operating (let the switch S_1 is operating alone), the inductor corresponding to the switch (L_1) will be in charging mode and the other inductor (L_2) will be discharged to the load.

B. *Control Strategy*

The control strategy adopted in this paper is voltage mode control. Since the output voltage of PV is continuously varying, we need to control it to a constant value. The main requirement of a battery charger is constant output voltage. Figure 3 shows the schematic circuit of simplified closed loop voltage mode control strategy.

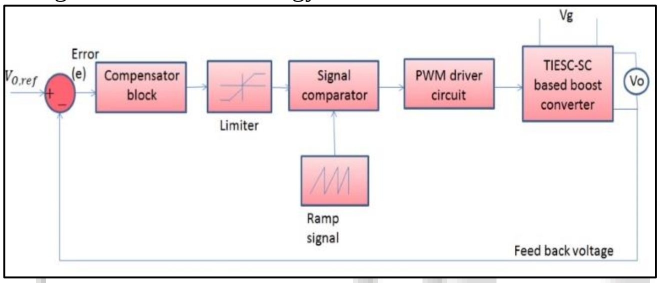

Fig. 3: Schematic Circuit of Simplified Closed Loop Voltage Mode Control Strategy [4]

In voltage mode control, the output voltage is measured and is compared with the reference value. The error generated will be processed by a compensation block in order to generate the duty cycle for the corresponding switches of interleaved boost converter.

C. *Design Aspects of IBC*

The design of IBC involves selection of inductor, output capacitor, number of phases, device selection and the freewheeling diodes. The inductors and diodes have to be same in all the parallel paths of an IBC.

1) *Boost Ratio*

The boosting ratio of the converter is a function of the duty ratio. It is same as that of a conventional boost converter. It is defined as

$$\frac{V_0}{V_{in}} = \frac{1}{1-D}$$

2) *Input Current*

The input current can be calculated using the input power and the input voltage.

$$I_{in} = \frac{P_{in}}{V_{in}}$$

3) *Inductor Current Ripple*

The inductor current ripple peak-peak amplitude is given by

$$\Delta I_{L1,L2} = \frac{V_{in}D}{f_S L}$$

where f_S is the switching frequency, D is the duty cycle, V_{in} is the input voltage and L is the inductance.

4) *Selection of Inductor and Capacitor*

In the operation of IBC the inductor is used to transform the energy from the input voltage to the inductor current and to convert it back from the inductor current to the output voltage. As per the principle the two inductors are identical in order to balance the current in the two boost converters. The value of inductance can be found out by the formulae

$$L = \frac{V_{in}D}{f_s \Delta I_L}$$

The value of capacitance can be found out by the formulae

$$C = \frac{V_0}{f_s \Delta V_0 R}$$

5) *Choosing the Number of Phases*

The factor which decides in choosing the number of phases is that the ripple content reduces with the increases in the number of phases. In a two phase IBC ripple reduces to 9% of that of a conventional boost converter.

6) *Selection of Devices*

The device which is chosen is power MOSFET because of its high commutation speed and high efficiency at low voltages.

III. Simulation Studies of the Proposed Battery Charger

Complete circuit of the interleaved boost converter based battery charger is simulated using MATLAB/Simulink environment. At first, the efficiency, voltage gain and voltage stress across the switch of a simple interleaved boost converter is compared with that of a traditional boost converter. Since the output of PV is continuously varying, a closed loop voltage regulation is being done for the battery charging circuit so that the output of the converter is maintained a constant value. The designed values used for modeling the interleaved battery charger are shown in Table.

Parameters	Specifications
Input Voltage	5 – 15 V
Output Voltage	19.5V
Output Current	1.95A
Inductance	272µH
Capacitance	810µF
Output Power	40W

Table 1: Simulation Parameters of Ibc

The gating pulses for two phase interleaved boost converter is shown in figure 4. There is a phase shift of 180 degrees between the switching of the two MOSFETs. The output waveforms of the battery charging circuit is shown in figure 5. The output voltage, output current and output power of the proposed battery charger is shown separately.

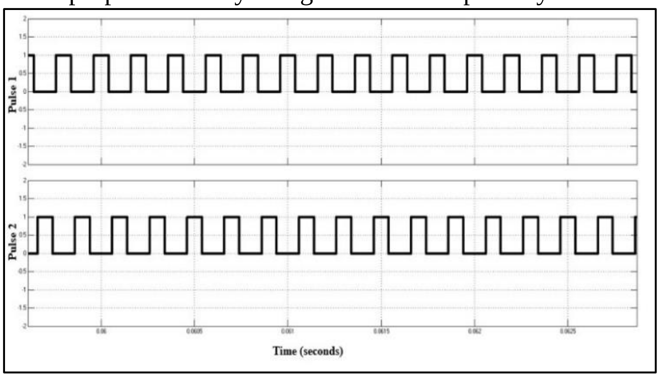

Fig. 4: Gating Pulses for Two Phase Interleaved Boost Converter

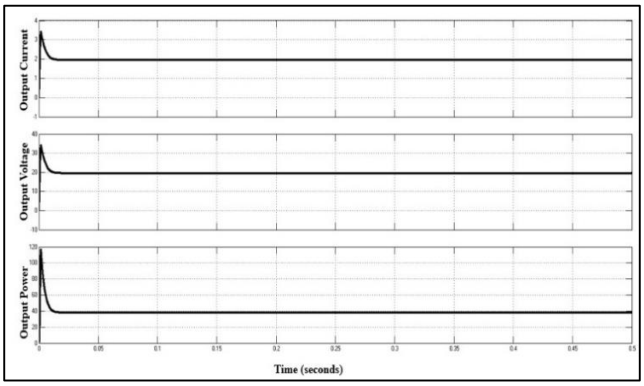

Fig. 5: Output Current, Voltage and Power Waveforms Two Phase Interleaved Boost Converter

For every change in load or input voltage there arise variations in the output voltage. For a battery charger, the main requirement is constant output for the load which is connected to it. Here the input is solar, which is continuously varying. As per the design considerations, the output should be maintained to a constant value of 19.5 V for a variation in input from 5 to 19 V. Thus a closed loop feedback control is being done in the MATLAB/Simulink platform. A negative feedback control is being done with proportional integral block.

Here the output voltage is taken and is compared with the desired value to produce an error in case of change in output voltage. This error is then processed in the PI controller, where, the voltage error produced is used for the generation of PWM signal by comparing it with the oscillator ramp signal. The value of P is taken as 1 and that of I is taken as 0.001. For the designed values, an output voltage of 19.5 V is obtained when the input is varying from 5V to 15V to produce a constant power of 40 W. Figure 6 gives the output voltage ripple waveform of the proposed charging circuit. The ripple content is very small and is found to be about 4%. The comparison of the interleaved topology with the boost converter topology is also shown in table II.

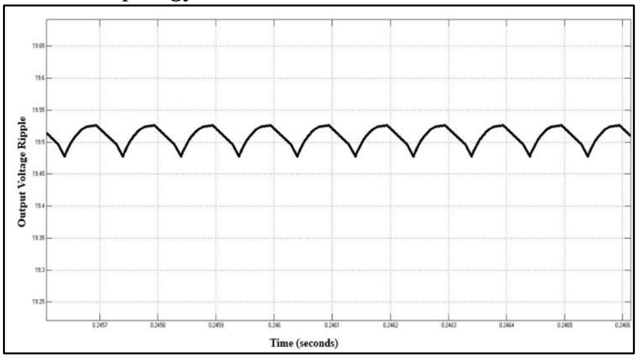

Fig. 6: Output Voltage Ripple Waveform for Two Phase Interleaved Boost Converter

Parameters	Boost	Interleaved Boost
Input Voltage	12V	12V
Output Voltage	18.2V	19.52V
Output Current	1.973A	1.95A
Duty Ratio	0.4	0.4
Inductance	139µH	272µH
Capacitance	810µF	810µF
Output Voltage Ripple	0.115	0.0425
Efficiency	89.86 %	93.66 %

Table 2: Comparison Between Conventional Boost Converter and IBC

IV. Experimental Setup

After performing the simulation studies, a prototype model of the battery charger is made to validate its use in real time applications. The prototype model is designed for feeding a 40W load from 5 – 15V varying input and to provide a 19.5V boosted output. In the laboratory, due to practical difficulties, a variable DC source is used as the input instead of photo-voltaic cell. Components used for the hardware implementation is shown in table III.

Components	Specifications	Type
Inductor L_1	1.3 mH	Air-cored
Inductor L_2	1.3 mH	Air-cored
Capacitor C_0	330 µF	Radial Electrolytic
Diode, D_1	IN4001	PN junction
Diode, D_2	IN4001	PN junction

Table 3: Components of The Proposed Power Circuit

The converter is implemented by ARDUINO mega2560 board. The power circuit of the interleaved battery charger circuit consists of 2 inductors, 1 capacitor, 2 diodes and a power semiconductor switch. The experimental setup of the proposed converter is shown in fig. 7.

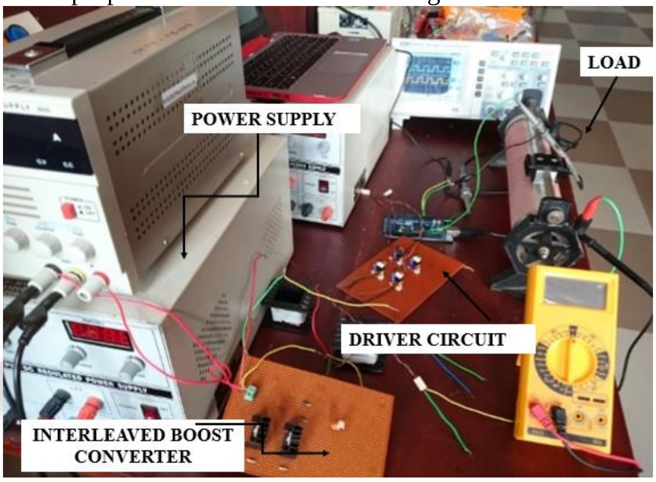

Fig. 7: Experimental setup of the proposed converter

V. Conclusion

This paper has presented the design and development of a high efficiency solar battery charging system. A DC-DC converter should be used as the source and load are both DC. An interleaved boost converter as designed and the various components values are calculated using standard IBC formulae. Though the IBC topology with inductors increases the complexity of the converter compared to the conventional boost converter, it is still preferred because of the low ripple content in the inductor current at the input and low ripple voltage at the output terminals. The stress across the switch is less for IBC when compared to conventional boost converters. The output is maintained a constant value with the variation in input using suitable proportional integral control techniques. Although a battery back-up system is not used in the demonstrated system, it also become obvious that there would be a need for a storage device such as a battery so that energy can be stored when the load is disconnected.

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