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Implementation of Interleaved Soft Switching Boost Converter With Photovoltaic Source

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***Abstract**:*
An enhanced soft switching technique for an interleaved boost converter with Zero Current Switching (ZCS) and Zero Voltage Switching (ZVS) during OFF and ON conditions of the main switches, that can drive large loads operated in duty cycle greater than 0.5 is proposed in this study. In this topology, auxiliary circuit is composed of resonant tank which is used to decrease the voltage stress on the main switches and a coupling capacitor is added additionally with minimum resonance which in-turn increases the life of operation of the converter. In this model, faster switching and suitable impedance matching is achieved with reduction in auxiliary circuit reactance that has contributed much increase in the overall performance. Coupled inductor in the boosting stage helps higher current sharing between the switches. A simulation module constructed using "MATLAB Simulink" illustrates the better results of the proposed converter. The experimental results for solar PV and boost converter obtained in both software and hardware are presented here.

Keywords: *Interleaved Boost Converter, Zero Voltage Switching, Zero Current Switching, Duty Cycle*

1. Introduction

A Photovoltaic energy source is capable of solving the problems of global warming and energy exhaustion, caused by increasing energy consumption. There is no air pollution or waste, and no mechanical vibration or noise. The output power of the solar cell can be changed easily by the surrounding conditions, such as irradiation and temperature. To transmit the power from the PV array to the load with higher efficiency, the interleaved soft switching boost converter is introduced. The presented converter can minimize switching losses, by adopting resonant soft switching [1] - [5].

The boost converter is a popular choice for most power electronic systems to serve as a pre-regulator, due to advantages of simplicity and high performance (Pan *et al*., 2009). However, as the power rating increase, it is often required to associate converters in series or in parallel. In high-power applications, interleaving of two boost converters is very often employed to improve performance and to reduce the size (Gallo *et al*., 2010). Because interleaving effectively doubles the switching frequency and also partially cancels the input and output ripples, the size of the energy-storage inductors and differential-mode EMI filter in interleaved implementations can be reduced (Jang and Jovanovic2007). Interleaving reduces the output capacitor ripple. current as a function of duty cycle [6]-[12].

The Simulink model for the SSSSBC and ISSBC is presented, and the performance evaluation of the SSSSBC and ISSBC, has been carried out.

2. Review of Literature

Literature collected from different journals, conference papers and books has been reviewed as follows.

A boost converter is designed to step up a fluctuating or variable input voltage to a constant output voltage of 48 volts with input range of 12 volts in [1]. A DC to DC converter is used to step up from 12V to 48V in [2] In designing process, the switching frequency, f is set at 50 kHz and the duty cycle, D is 50%. The tool that has been used for circuit simulation is MATLAB SIMULINK software.

Here we introduce an approach to design a boost converter for photovoltaic (PV) system using microcontroller in [3]. The converter is designed to step up solar panel voltage to a stable 48V output without storage elements such as battery.

This paper concerns with design and simulation of DC/DC boost converter to operate in PV system [4]. The system has a nonlinear dynamic behavior, as it work in switch-mode. Moreover, it is exposed to significant variations which may take this system away from nominal conditions, due to changes on the load or on the line voltage at the input. The input is obtained by PV array. In this paper the equations of a boost converter are analyzed and a design components and simulation of DC/DC boost converter is proposed. Here simple design equations are used to design the components value in different modes as CCM and DCM and simulation is done in simulink.

From the literature review it is found that mostly microcontrollers are used for generating PWM signal to perform switching control action. In this project a simple approach is used to generate the PWM signal with high accuracy and less cost. To improve the output power of solar PV panel a low cost DC/DC boost converter is designed.

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3. The Proposed System

The two phase boost converter is analysed in this paper. Since it is two phase boost converter each switch has switching gap of 180 degree. Each inductor current repeats linear increment and decrement with 180 degree based on switching pattern. At zero voltage across the resonant capacitor the switch is turned OFF, thus it operate with zero voltage switching (ZVS). At zero current through the resonant inductor the switch is turned ON, thus operate with zero current switching (ZCS) [5].The block diagram in Fig. 1 reveals that the system consists of PV source and two phase boost converter and load and each block is simulated using MatLab and the results are presented.

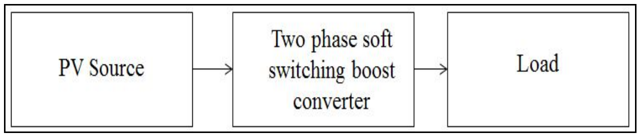


Figure 1: Block diagram of system

The PV panel is modeled using one diode model which consists of a current source in parallel with a diode, a shunt resistance and a series resistance as shown in Fig 2.

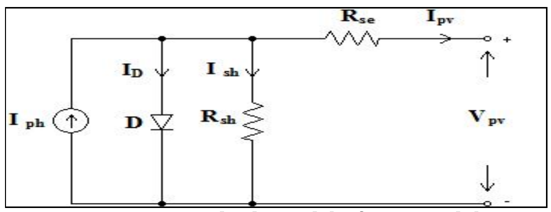


Figure 2: One diode model of SPV module

4. Single Soft Switching Boost Converter

Figure 3 shows the circuit diagram of the single switch soft switching boost converter. One resonant inductor L" two capacitors Ca and Cn and two diodes D1and D2 are added to a conventional boost converter, for soft switching, using resonance

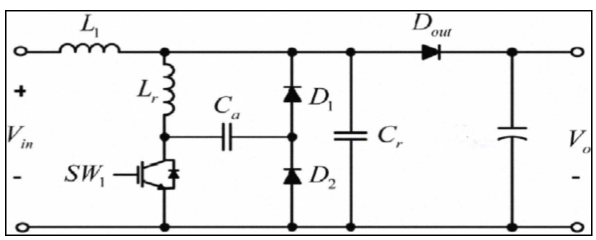


Figure 3 Circuit diagram of single switch soft switching boost converter

Figure 4 shows the key waveform for the SSSSBC. The working of the SSSSBC can be analyzed, with the eight modes according to the operating conditions, defined as:

- All switching devices and passive elements are ideal.
- The parasitic components of all switching devices and elements are ignored.
- It is assumed that the initial value of each operation mode is equal to zero.

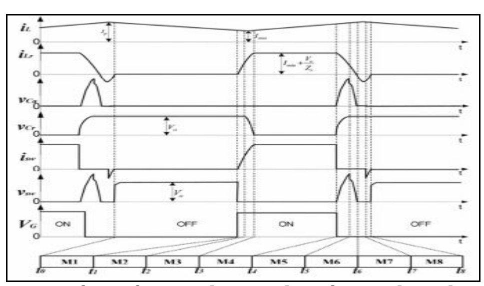
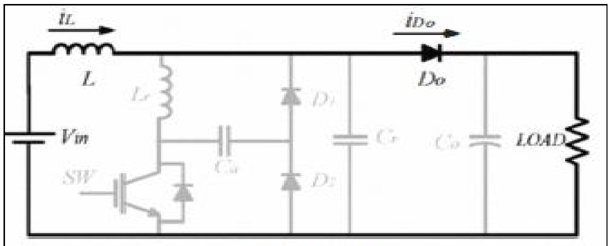


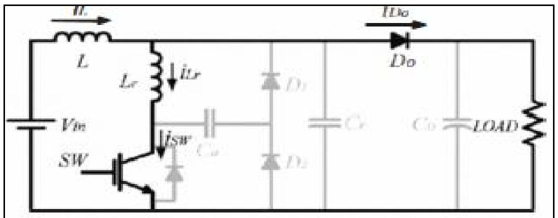
Figure 4: key waveform for single switch soft switching boost converter

- Mode 1: In this mode the switch is in the off state and the dc output of the solar cell array is transmitted directly to the load through Land Dout. During this mode, the main inductor voltage becomes **(-(V0 –Vin)).** Thus, the main inductor current decreases linearly.



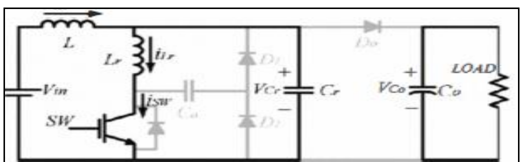
MODE 1

- Mode 2: In mode 2 the switch is turned on under zero-current switching (ZCS) because of the resonant inductor Lr. In this case, as the output voltage is supplied to the resonant inductor L" the current increases linearly. When the resonant current iLr becomes equal to the main inductor current h, the current of the output side diode D out becomes zero.



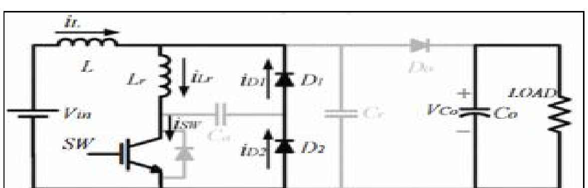
MODE 2

- Mode 3: When the output current iDou/ becomes zero, the mode starts. In this mode, the resonant inductor Lr and the resonant capacitor Cr resonate and the voltage of Cr decreases from the output voltage Va to zero. The main inductor current h. flows through Lr and the switch. The main inductor current becomes minimum.



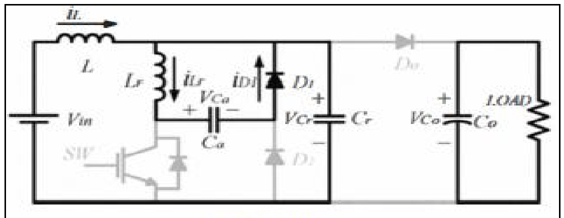
MODE 3

- Mode 4: When the resonant capacitor voltage VCr becomes zero, the two auxiliary diodes D 1 and D2 are turned on, and the mode starts. In this mode, the resonant inductor current is separated into two parts. One is the main inductor current h and the other is the current through the two auxiliary diodes. The main inductor current h increases linearly.



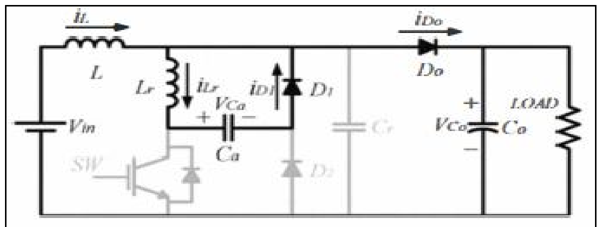
MODE 4

- Mode 5: In mode 5, the switch turns off under the zero-voltage condition because of the auxiliary resonant capacitor Ca. There are two current loops. One is the L-Cr -Vin loop for which the voltage of the resonant capacitor Cr increases linearly from zero to the output voltage Vo. The other loop is the Lr- Ca-D 1 for which the second resonance occurs. The energy stored in Lr is transferred to Ca. The resonant current hr decreases linearly and the voltage across Ca becomes maximal.



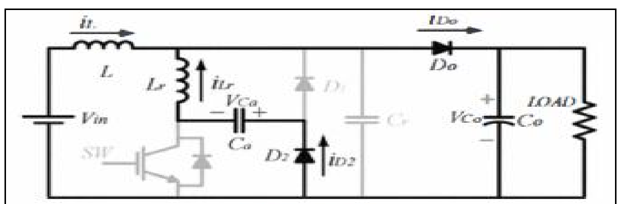
MODE 5

- Mode 6: When the resonant capacitor voltage VCr is equal to the output voltage V", the mode starts. In this mode, the energy flow from Lr to Ca is completed and the resonant current iLr becomes zero.



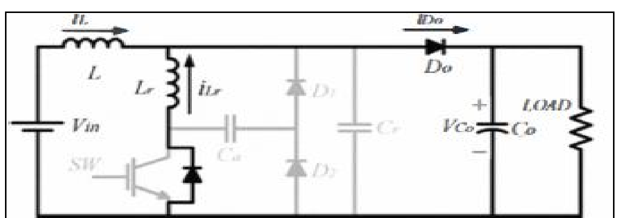
MODE 6

- Mode 7: In mode 7, the voltage of Ca decreases, continuously resonates on the Dr-Ca-Lr –Dout-Co loop, and the energy is transferred from Ca to Lr. When the Ca voltage becomes zero, the resonant current hr is the reverse of the current direction of mode 6 . When the voltage of Ca becomes zero, the antiparallel diode of the switch turns on, and it transitions to the next mode.



MODE 7

- Mode 8: There are two current loops. The main inductor current h transmits energy to the output through Dout and decreases linearly. The resonant inductor current if>r also transmits energy to the load through Dout, and flows through the antiparallel diode of the switch. The resonant inductor current iLr becomes zero.



MODE 8

5. Interleaveo Soft Switching Boost Converter

The interleaved boost converter consists of two single-phase boost converters connected in parallel. When each switch is controlled by the interleaving method the difference between the two PWM signals is 1800. Because each inductor current magnitude is decreased, the inductor size can be reduced. The input current ripple is decreased because the input current is the sum of each current through the inductor L1 and L2. Figure 5 shows the circuit diagram of the interleaved soft switching boost converter.

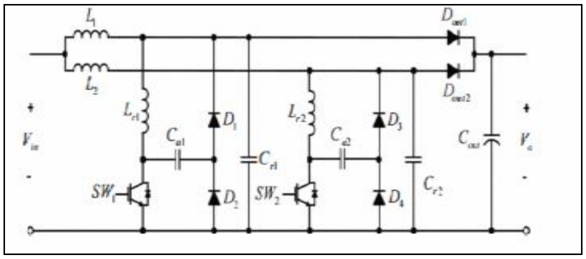


Figure 5: Circuit diagram for interleaved soft switching boost converter

6. Simulation Results and Inference

The soft switching two phase boost converter has been simulated with MATLAB. Table I shows the design parameters of the soft switching multi-phase boost converter [1].

Parameters	Values
Input Voltage, Vi	5 V
Output Voltage V0	10.7V
Inductor, L	33µH
Capacitor, C	0.1µF
Resonant inductor, Lr	2.2µH
Resonant capacitor, Cr	0.1µF
Switching frequency, fs	50 kHz

Table 1 : Simulation Parameters For Two Phase Soft Switching Boost Converter

The duty ratio is calculated using equation

$D=l-(Vin/Vout)$

Critical inductance is calculated by equation

$Lc=L=(1-D)DR/2f$

Critical capacitance is calculated by equation

$Co=C=D/2Rf$

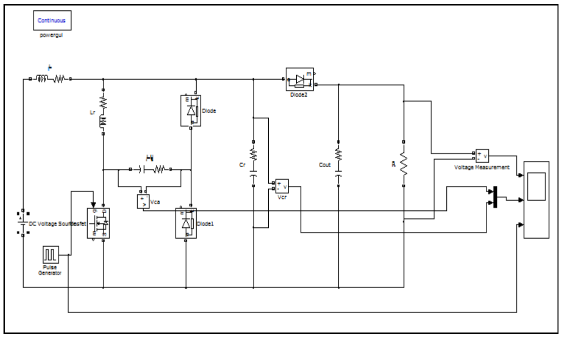


Figure 6: simulink diagram for SSSSBC

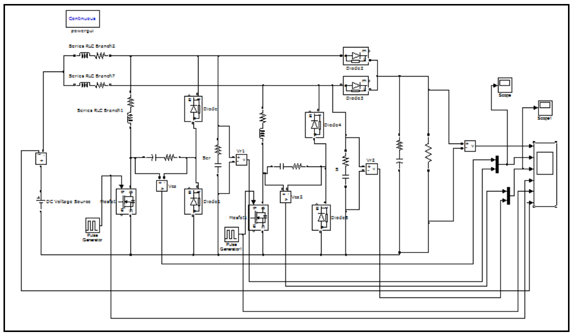


Figure 7: simulink diagram for ISSSBC

Figure 8 shows the main inductor current waveform of the single switch soft switching boost converter and the interleaved soft switching boost converter, it has been proved that the current through the main inductor in the ISSBC is less than that in the single switch soft switching boost converter.

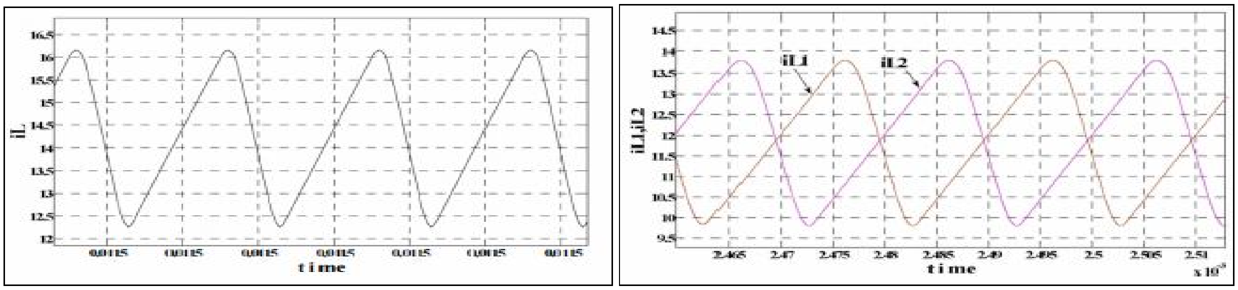


Figure 8 (a) main inductor current waveform of SSSBC (b) main inductor current waveform of ISSBC

The peak voltage of V_{Ca} is higher than that of the resonant capacitor voltage V_{Cr}. When the switch turns off, the auxiliary resonant capacitor voltage V_{Ca} increases and then decreases to the zero level, satisfying the ZVS condition.

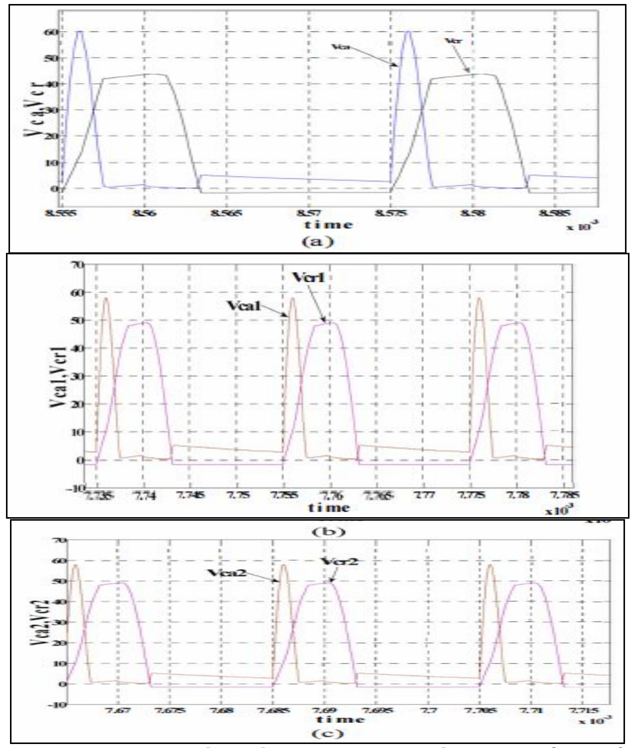


Figure 9: (a) resonant and auxiliary capacitor voltage waveform of SSSBC
(b) resonant and auxiliary capacitor 1 waveform of ISSBC
(c) resonant and auxiliary capacitor 2 voltage waveform of ISSBC

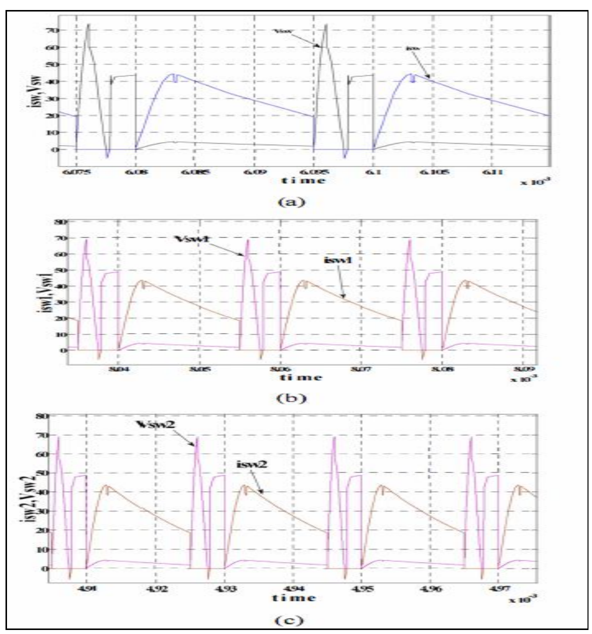


Figure 10: (a) switch current and voltage waveform of SSSBC
(b) switch 1 current and voltage waveform of ISSBC
(c) switch 2 current and voltage waveform of ISSBC

When the switch is turned on using the ZCS, the resonant inductor current increases. During the turning off of the switch using the ZVS, the resonant inductor current decreases.

With the single switch soft switching boost converter for the chosen parameters the output voltage obtained is lesser than the expected level, and the inductor current rating is also high. To obtain the expected output voltage, an interleaved soft switching boost converter is designed and developed. The ISSBC minimizes the output voltage ripple, input current ripple and the size of the passive components.

Selection of components for Hardware implementation*:*
We have used ATMEGA324P as a Microcontroller for the generation of pulses for the MOSFET SWITCH.

6.1. Selection of Electronic Switch
The electronic switch (Power MOSFET) is chosen based on its voltage and current rating which have to be higher than the maximum input voltage and current.

6.2. Selection of Inductor
The minimum inductance for boost converter to operate in continuous conduction mode is given in equation.
Therefore the selection of the inductor should be higher than the calculated value.

6.3. Selection of Diode
Diode reverse voltage rating is the main consideration for selecting the diode. Other important consideration is its ability to block the required off–state voltage stress and to have sufficient peak and average current handling capability, fast switching characteristics, low reverse–recovery, and low forward voltage drop.

6.4. Selection of Output Capacitor
The minimum capacitance for calculating ripple voltage is given above. The selection of capacitor is higher than the calculated value. Another important consideration is its equivalent series resistance, ESR. Since the capacitor's ESR affects efficiency, low-ESR capacitors could be used for best performance. ESR could be reduced by connecting few capacitors in parallel.

EXPERIMENTAL SET UP

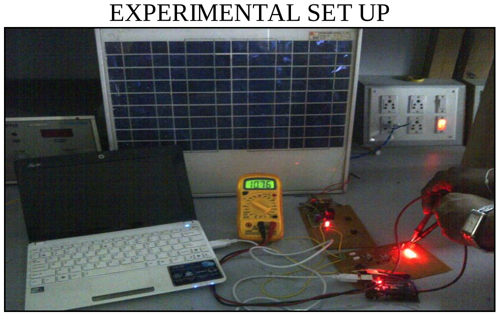


Figure 11: Complete hardware set up of ISSBC

Figure 11 shows the complete hardware setup of ISSBC which has been compared with the simulation results as given in table II

Parameter	**Simulation**	**Experimental**
Input voltage	5V	5V
Output voltage	10V	10.78V
Input current	0.35A	0.355A
Frequency	50kHz	41kHz
Input Inductor current ripple(p-p)	0.05	0.072
Output voltage ripple(p-p)	1.5	1.65
Duty cycle	0.7	0.45

Table 2: shows the comparison between hardware and simulation of interleaved boost Converter

From the table II it can be observed that in both simulation and hardware result the input current ripple and the output voltage ripple are almost zero.

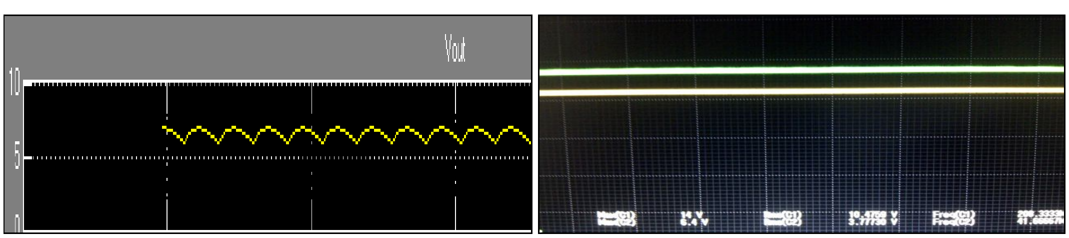


Figure 12: (a) output voltage waveform of ISSBC using MATLAB
(b) output voltage waveform of ISSBC with Hardware setup

Figure 12 shows the output voltage waveform of the ISSBC with the input of 5V output obtained is 9.8 V which is verified with the Hardware setup as shown in Fig11. Hence, it has been concluded that the output voltage is increased, and the output voltage ripple has been decreased with the interleaved soft switching boost converter

7. Conclusion

This project work presents a detailed design and analysis of a Interleaved boost converter for a switching frequency of 41 khz and different ripple reducing techniques. The high voltage gain converter is far suitable for applications where a high step up voltage is required, as in some renewable energy systems, which use, for example photovoltaic panels and/or fuel cells. Thus large step-up voltage, low switching stress and high efficiency are expected from this topology. As the power demand from these supply increases, a single boost converter may be insufficient . One of the disadvantages is that the input current ripple and output voltage ripple is more. In order to overcome this disadvantage of a single boost converter an interleaved boost converter can be implemented. In this project the simulation result of an interleaved boost converter is compared with single boost converter and the other ripple reducing techniques (ZVS & ZCS).MATLAB-SIMULINK simulation package is used to increase the efficiency by reducing the ripple in each topology as well as evaluating the benefits of increasing cost and complexity. Hardware implementation was also carried out, the results were compared with the simulation and were found to be satisfactory reducing ripple.

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