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Analysis of High Step-up DC-DC Converter for PV Applications

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***Abstract*—With the increasing demand of electric power and depleting fossil fuels it is required to use the renewable sources as the medium of power supply. Among the renewable resources PV is becoming the fastest growing technology for the power supply. As the input voltage provided by PV cell is low and being associated with high costs, there becomes a need for interfacing the PV with Step Up DC-DC converter and designing a controller for the same to obtain high efficiency and cost effectiveness. This paper aims the designing of open and closed loop models of improved boost converter and SEPIC converter and hence finding the output of both converters. Simulations are carried out using MATLAB.**

***Index Terms*—SEPIC converter, Solar Cell, Solar Array.**

I. INTRODUCTION

The field of power electronics has been recently playing an active role in the advancement of semi-conductor devices which in-turn pushes renewable sources to be used along with converters for obtaining high efficiency at a considerable cost thereby providing high efficiency. Among the various available renewable resources like wind power, hydro power, municipal solid wastes, biomass, geothermal,solar thermal, solar photovoltaic and tidal wavethe most commonly used one becomes solar taken as input source.

The concept of PV when taken into account, the solar energy is available at all places at a considerable amount. The conventional PV array is a serial connection of large number of panels to provide high dc-link voltage via dc–ac inverter. It happens that due to insufficient solar power that is because of the shadows caused unexpectedlythe total power which gets generated from the PV arraydecreases. To overcome these problems aninverter is usually placed on top of the PV module, which produces maximum power from its corresponding PV module[1].

The concept behind PV module is that each PV panel operates at its maximum power point and projects that more number of variant PV panels needs to be connected at the same DC link voltage.This in-turn enables the use of isolated DC-DC converters allowing each panel to be grounded independently. Moreover, it is also possible to disconnect the PV panel in case of fire. Mostly, low voltage photovoltaic systems require highly efficient converters to deliver as much as possible energy to the load with high gain DC voltage conversion.

However, the use of a high step-up dc–dc convertergives better power-conversion efficiency thereby providing stable dc link to the inverter. There is a requirement of large step-up conversionfrom the panel's low voltage to the desired voltage level in the dc-dc converter. Some of the characteristics belonging to the high step-up dc–dc converters for these applications include high step-up voltage gain, high efficiency and no requirement of isolation[2].

The proposed paper aims to design improved step- up converter with PV input using MATLAB simulation. In addition a single ended primary inductor converter (SEPIC) converter with PV source voltage is also designed to operate at a wide range compounded with high efficiency to obtain up-and-down voltage conversion.This SEPIC converter uses the same boost converter concept but there is no inversion of the output voltage. Simulations are carried out using MATLAB and efficiency is determined.

II. OPERATING PRINCIPLES OF CONVERTER

The converter as the name suggests is a circuit which is used in industry as well as in research to convert one DC voltage to other. The inputs of the DC-DC converter areobviously unregulated dc input voltage and the desired output voltage must be a fixed voltage. The main limitation of these converters is unregulated supply of voltage and current, which causes incorrect function of DC –DC converters. To avoid these problems various control techniques are interfaced with these converters. The converter which converts AC to DC is inverter and the vice versa is rectifier. The converters had valves as switches in olden days. Nowadays the valves are replaced by power electronic switches. The main advantage of power electronic switches is faster switching and control.

The converter which converts DC to DC, to say where there occurs a change in the level of DC is known as DC-DC converter. There are some applications when the DC supply supplied by the source will not be same as the load rating and it becomes important to convert the DC source voltage level to the load level voltage in dc-dc converter.

The dc-dc boost converter is the front-endcomponent connected between the PV input source array and theoutput

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load. The limitations of implementing conventional boost converter may cause unexpected reverse recovery problem which might increase therating of all devices projecting an adverse effect on efficiency of the converter and also the problem of electromagneticinterference might become severe.To overcome such problem and boost up theefficiency of the converter, variousmodified step-up converter topologies have been implementedby several authors[3].[4] deals with the voltage clampedtechniquesused in the converter design to overcome the reverse-recovery problem of the output diodes. In [5] the concept of a novel step-up converter obtaining high efficiency was simulated. The design of atransformer-less boost converter for fuel cell applications to obtain high gain and reduce current ripple was discussed in [6].

In [7] a new controller scheme for photovoltaic (PV) powergeneration system using boost converter was discussed. The design of soft-switchingboost converter for PV applications with SARC was discussed in [8]. In contast to the above literatures this paper deals with the design of SEPIC convertersystem in comparison with improved boost converter for PV applications. The converter efficiency is noted for each converter and results are obtained to overcome the problem of conventional boost converters.

III. Configuration of the Proposed Boost Converter

Fig 1 shows the main block diagram of the converter having solar source as input with a controller to provide desired output power.In Fig1, theinput source is a PV panel which consists of inter connected solar array to provide the input voltage to the proposed boost converter and SEPIC converter.

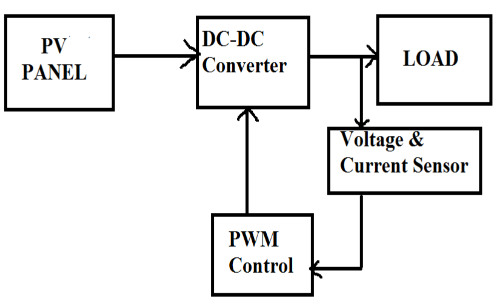

Fig.1 Main block diagram of Converter with its controller

There is an increment in the output voltage of the converter which supplies sufficient power for the load. The variation caused in the controller of the converter projects the efficiency of the proposed converter. The load voltage *V*0 is more than the source voltage *Vs*for both the proposed boost converter and SEPIC converter. The implemented boost converter consists of a series of switching-modepower supply incorporating at least two semiconductor switches (a diode and a transistor) and at least oneenergy storage element. In addition there is a combination of capacitor with inductor forming filters which are normally added tothe output of the converter thereby decreasing the ripples of output voltage. Stability in the output voltage is obtained by varying the duty cycle ratio of the input switching pulse implementing the pulse width modulation(PWM) control on the boost converter irrespective of the periodic variations of input voltage. In this paper, closed loop control of the proposed boost converter and SEPIC converter design with solar input is presented by implementing a new voltage gain for the converter varying the duty cycle. This voltage gain can be increased to provide a solution to the problem of reverse recovery by incorporating more clamping devices.

Fig. 2 shows the circuit diagram of the proposed boost converterconsisting of PV source with series inductor in the input side (L), the clamping diodes, D1, D2 and a regenerative circuit to sink the reverse recovery is formed by the capacitor C2. The high voltage is given to capacitor C1 and finally the diode D0 and capacitor C0 forms the output filter.

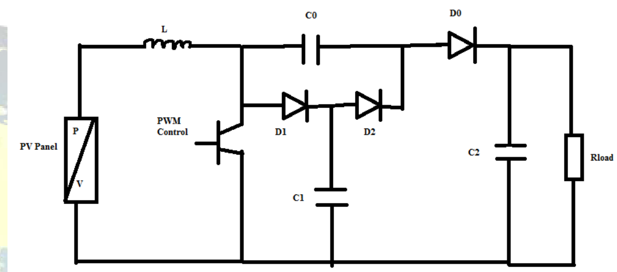

Fig.2 Proposed boost Converter with its controller

The average output voltage is given as

$$V_{0(avg)} = \frac{V_s}{2}\sqrt{D(1-D)^2}$$

where *Vs* is the input voltage, *D* is the duty cycle ratio.

IV. Configuration of the Proposed SEPIC Converter

The single ended primary inductor converter (SEPIC) is a type of DC-DC converter. The difference between DC-DC converter and SEPIC is that the output of SEPIC can be obtained as required either equal to, greater than or less than that of the input applied to SEPIC. It is a boost converter followed by buck-boost converter. It is similar to that of traditional buck-boost converter but the keeping the polarity unchangedas that of the input.

SEPIC converter also possesses the characteristics of having small input ripple current, step-down and step-up operation and can be easily extended to multiple-output. The paper in [9]introduces a quasi-resonant single-ended primary inductor converter (SEPIC) converter having input supplied by PV source. In [10] the concept of resonant switching and its control methods suitablefor designing the converters at high frequencies are projected. The proposed design provides higher efficiency over very wide input and outputvoltage ranges and power levels in contrast to the other designs. A good control over the input and output frequency is obtained by taking a new fixed-frequencyON/OFF control.

The operation of conventional PWM power converters occurs by switching pulses. As the switching frequency is

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proportional to switching loss, the switching frequency of the power converters is reduced. This problem is overcome by incorporating a resonant converter. The increase of switching frequency is done by the design of tank circuits (L&C) which are tuned to their respected values accordingly. This causes a reduction in switching loss thereby increasing theefficiency of the converter.

Bothquasi resonant and multi-resonant converter forms the proposed SEPICconverter. Bulk inductors are used in multi-resonant converters. In addition a parallel combination of capacitoris added with switch and diode in multi-resonant converter. Choke inductor L_{r1} along with couplingcapacitor C_s used in Quasi-resonant converter.

The Fig.3 indicates the proposed Resonant SEPIC converter. This proposed SEPIC converter eliminates the use of bulk inductor and the input is provided by Solar panel. It uses tworesonant inductors and capacitors $L_{r1}$and C_{r1}; $L_{r2}$and C_{r2}respectively.

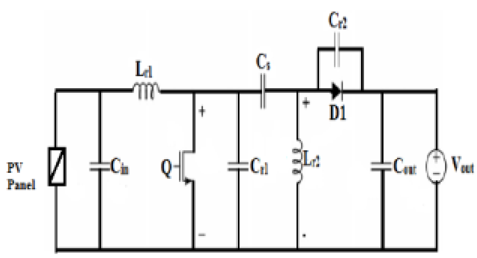

Fig.3 Proposed SEPIC Converter with its controller

The open loop SEPIC converter model is designed first and then the closed loop model is designed by achieving the resonant condition when the capacitors are connected in parallel with diode and switch.

V. Simulation and Results

The simulation for the test system is done and the results are obtained using MATLAB Simulink environment.

A. *Solar Cell*

Solar cell is the basic block for the solar photovoltaic generation which gives the value of voltage.

TABLE I. IRRADIANCE OF SOLAR CELL

Irradiance in W/m^2	
Minimum Value	600
Maximum Value	1000

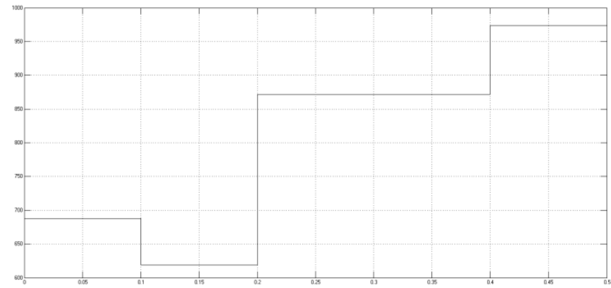

Fig.4 Irradiance of Solar Cell

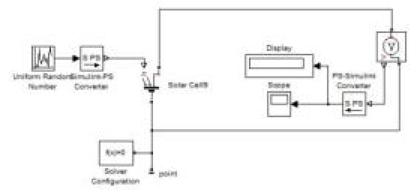

Fig.5 Solar Cell Simulink Diagram

TABLE II. SOLAR CELL RATING

Rated values for Irradiance of 1000 W/m^2	
Short Circuit Current, I_{SC}	7.34 A
Open Circuit Voltage, V_{OC}	0.6 V

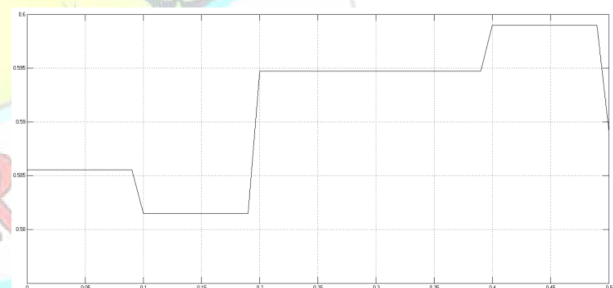

Fig.6 Simulink output for Solar Cell

B. *Solar Array*

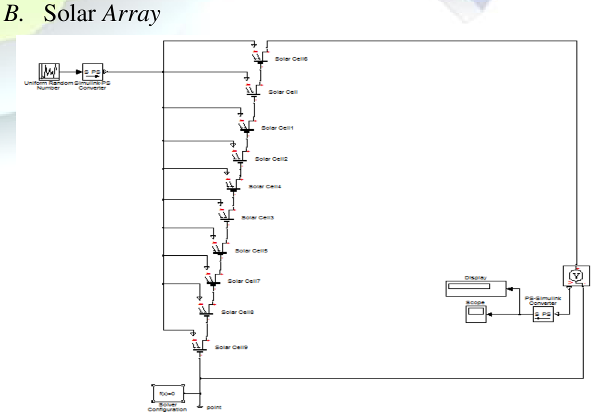

Fig.7 Solar Array Simulink Diagram

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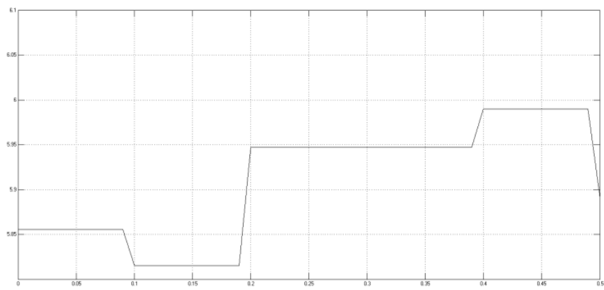

Fig.8 Simulink output for Solar Array

TABLE III. SOLAR ARRAY RATING

Rated values for Irradiance of 1000 W/m^2	
No of cells	10
Solar Cell rating	0.6 V
Solar Array rating	6 V

C. Solar Panel

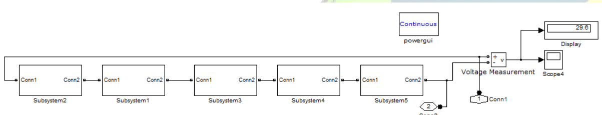

Fig.9 Solar Panel Simulink diagram

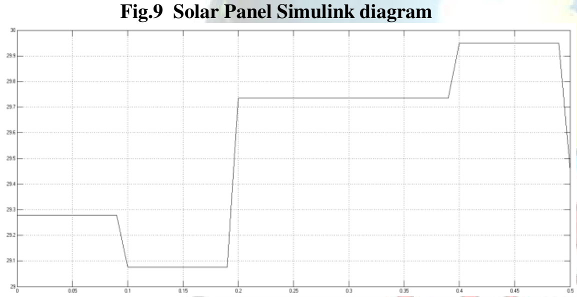

Fig.10 Simulink output for Solar Panel

TABLE IV. SOLAR PANEL RATING

Rated values for Irradiance of 1000 W/m^2	
No of arrays	5
Solar Array rating	6 V
Solar Panel rating	30

D. Proposed Boost Converter

For the improved boost converter the input voltage Vin from the solar panel was taken to be 10V. The values were taken as L= 5mH, C=2000µF and 30mF, and Rload= 10 Ω respectively.

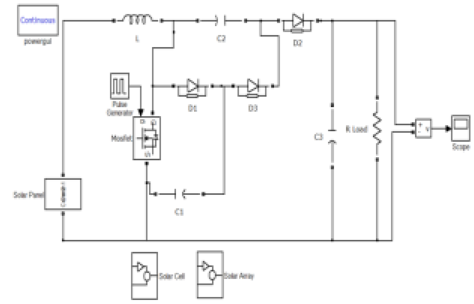

Fig.11 Simulation diagram of open loop boost converter

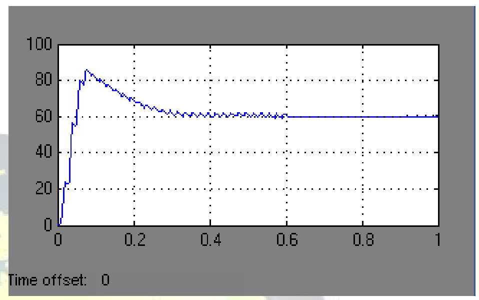

Fig.12 Output voltage waveform of open loop boost converter

The presence of clamping diodes D1, D2 and Capacitor C2 in figure 11 forms a regenerative circuit which matches the reverse recovery voltage and thus boosts the output voltage. In order to reduce the error voltage a PI controller is designed as shown in figure 13 by approximating the proportional and integral gain values to obtain the desired voltage.

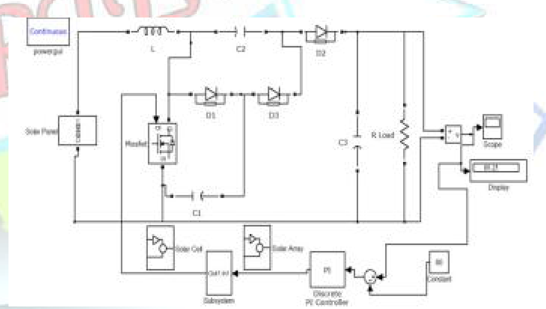

Fig.13 Simulation diagram of closed loop boost converter

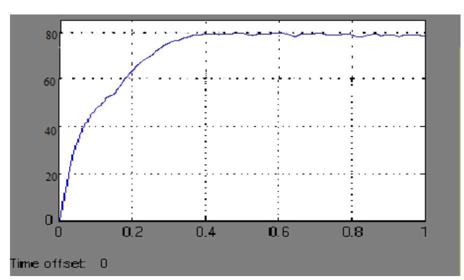

Fig.14 Output voltage waveform of closed loop boost converter

It is observed from the figure 12 and figure 14 that the output voltage has crossed 80 V when the input from solar panel is given as 10V. The filters are added at the output stage which reduces the output voltage ripple as indicated in figure12 and 14.

E. Proposed SEPIC Converter

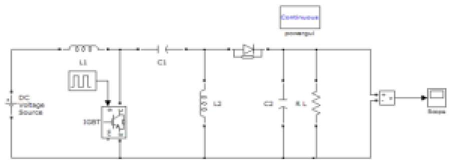

Fig.15 Simulation diagram of conventional SEPIC converter

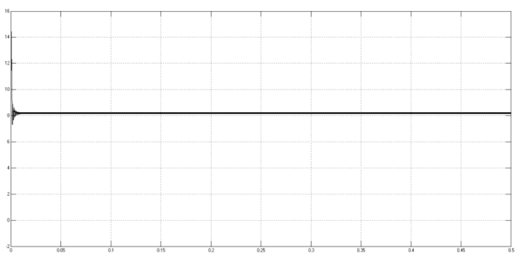

Fig.16 Output of conventional SEPIC converter with 50% duty cycle

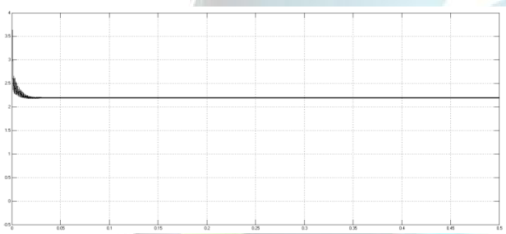

Fig.17 Output of conventional SEPIC converterwith 25% duty cycle (as buck converter)

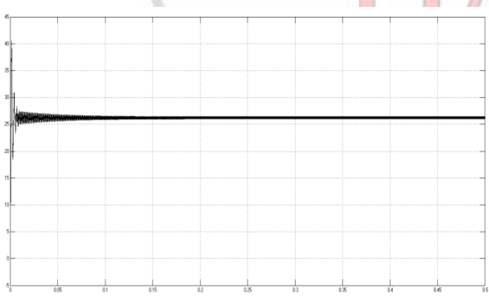

Fig.18Output of conventional SEPIC converter with 75% duty cycle (as boost converter)

TABLE V. SEPIC SIMULATION VALUES

Open loop operation	
Input, V_{in} = 10 V	
Duty Cycle	Output
25%	2 V
50%	8 V
75%	26 V

For resonant SEPIC:

$L_{r1}=L_{r2}$= 64.89µH, C_{r1}= 3.8pF; C_{r2}=20nF, C_S=10µF

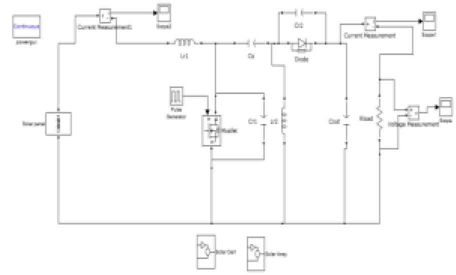

Fig.19 Simulation diagram of open loop SEPIC converter

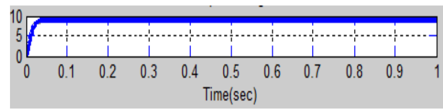

Fig.20 Output voltage of open loop SEPIC converter

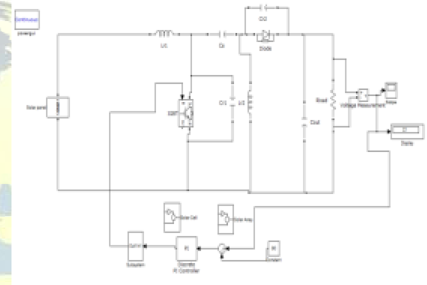

Fig.21 Simulation diagram of closed loop SEPIC converter

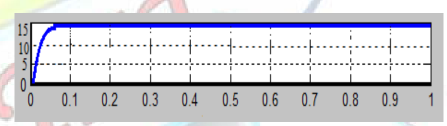

Fig.22 Output voltage of closed loop SEPIC converter

By calculating the output power the efficiency of both the proposed converters are found to be 92.6 %and 94% and both converters have obtained higher efficiency. SEPIC converter has the advantage of its operation at wide frequency ranges.

VI. CONCLUSION

In this paper an improved boost converter and SEPIC converter is designed for PV applications. The open loop and closed loop models are simulated using Matlab. It was observed that the proposed boost converter had higher output voltage than the conventional boost converter. In addition the design of proposed SEPIC converter gave better output voltage with low ripple without inverting the polarity over a wide frequency range. A faster transient response was also obtained with SEPIC converter thereby proving it to be much more efficient than the other converters.

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