Single Ended Primary Inductor Converter for Delta Conversion of PV Systems

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Abstract: Electrical Energy can be generated by Photovoltaic (PV) systems. To achieve desired power range PV modules are connected both in series and parallel. There will be a difference between output power between PV cells, modules due to temporary shading, pollution or spread in cell behaviour. PV output power will be reduced due to this. In this paper in order to get the same output power during such condition delta conversion concept is introduced with the help of a DC/DC SEPIC converter. This is a converter capable of averaging out the difference existing in output power between PV cells, modules existing in PV system. The converter is simulated in MATLAB software and the results obtained are compared with the prototype hardware results.

Keywords: Photovoltaic, DC/DC converter, Delta Conversion, Single ended Primary Inductor Converter (SEPIC).

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1. Introduction

Conventional energy sources leads to decaying the environment, global warming, and fuel price hikes. Hence there is a demand for renewable energy sources. Solar energy is non-polluting source of renewable energy available in plenty [1]. India has long days of sunshine. Electricity can be generated using solar energy. Solar Photovoltaic cells converts solar radiations into electricity. SPV can be used for applications like water pumping, street lighting, domestic lighting, water heating, railway signals etc. Radiation of sun is converter into electricity by photovoltaic cell. Current is driven in the external load by means of the voltage output of PV cell due to electric field in it. Depending on the required output power and voltage 10-12 PV cells is placed in series in a string. PV modules are formed by connecting the strings in series and parallel. PV modules are available in different rating in the market. PV output depends on the light intensity. It is a current delivery device. The output power of the PV system decreases by 30%, when it is shaded 10% due to practical cases[2]-[10]. PV array are formed by connecting PV cells in series and parallel. When connected in series the voltage output of the module increases and during parallel connection current increases. In order to maximize the power output for a PV module maximum power point tracking of the system is necessary.MPP depends upon irradiance condition, temperature and load connected [11]-[12]. The decreased output voltage of a PV module can be improved by DC/DC delta converter. In this work SEPIC converter is used as a delta converter. In [13] S.Muthubalaji et.al proposed an enhanced model for PV System considering various weather conditions.

2. Working Of Sepic As A Delta

Conversion

SEPIC converter can operate from an input voltage which is more than or less than the regulated output voltage. In spite of minimal number of active components SEPIC converter can function in both buck and boost mode. A simple converter can regulate the output of the SEPIC converter which has low noise
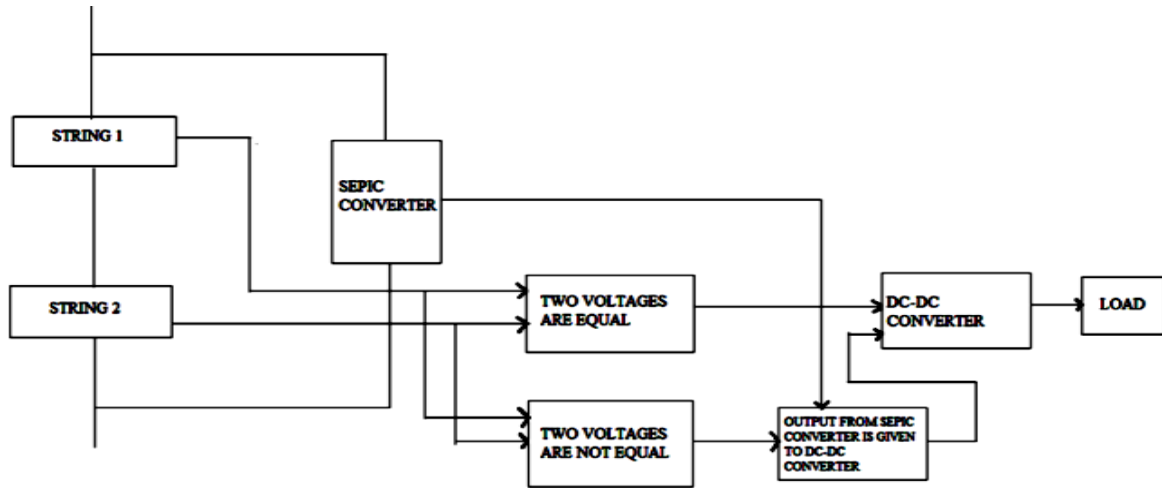
Fig. 1. Delta conversion concept

A. Delta conversion concept

SEPIC converter is used as a Delta Converter. Only when difference between two strings exists, the delta conversion takes place i.e., the SEPIC converter is active, otherwise it is in OFF state. Therefore, low cost and low efficiency converter can be used. Also, here one converter for two strings is used compared to conventional one, where each string consists of its own DC-DC Converter. When the voltage of two strings are equal the voltage is fed directly into the DC-DC boost converter which drives the load.
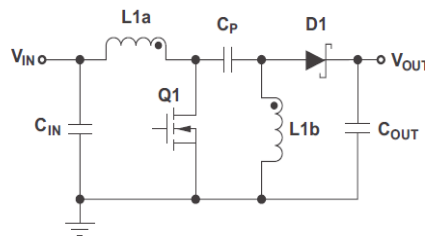

Fig. 2.   Schematic diagram of SEPIC Converter

During steady state operation of SEPIC converter the voltage across the capacitor C_{in} will be equal to $V_{in.}$. The average current across the capacitor C_{IN} is zero. Direct current (DC) is blocked by the capacitor. Load is supplied by the inductor $L_{1b.}$ Therefore, the average load current will be same as average current through inductor L_{1b} and it is independent of input voltage.

$$V_{L1a} = -V_{L1b}. \qquad (1)$$

Assuming the polarity of the winding as correct and the mutual inductance among the winding is zero, the voltage is of same magnitude both inductors is wound on the same core.

The average currents can be summed as follows:

$$I_{D1} = I_{L1a} - I_{L1b} \qquad (2)$$

SEPIC converter works in continuous conduction mode so the current in the inductor L_{1a} never falls to zero.

B Mode1: when q1 is on

When Q_1 is turned on (shown in fig 3), current in I_{L1a} increases and the current in the inductor I_{L1b} rises in the reverse direction. The input source supplies the energy. Capacitor voltage C_{in} will be equal to V_{in} when the switch Q1 is closed. Voltage across the inductor L_{1b} will be $–V_{in}$. Capacitor C_{in} supplies the energy to L_{1b} which increases the current I_{L1b} through the inductor.
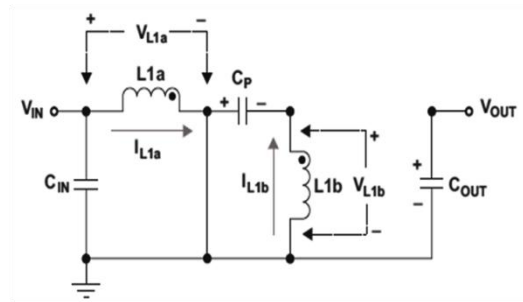
Fig. 3. SEPIC Converter mode 1 Q_1 on

C. Mode 2: when q1 is off

In mode2 Q_1 is off, (shown in fig 4) current through the capacitor C_p will be equal to the inductor current I_{L1a}. Current through the inductor I_{L1b} will flow in negative direction which gets added up with I_{L1a} and increases the load current. Applying KCL $I_{D1} = I_{Cp} - I_{L1b}$. So when switch Q_1 is in off condition load is supplied by both inductor L_{1a} and L_{1b}. L_{1a} charges C_p during Q_1 off mode which in turn charges L_{1b} during Q_1 on mode.
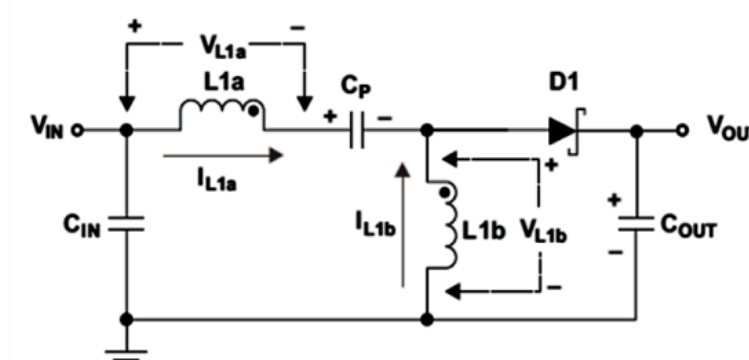

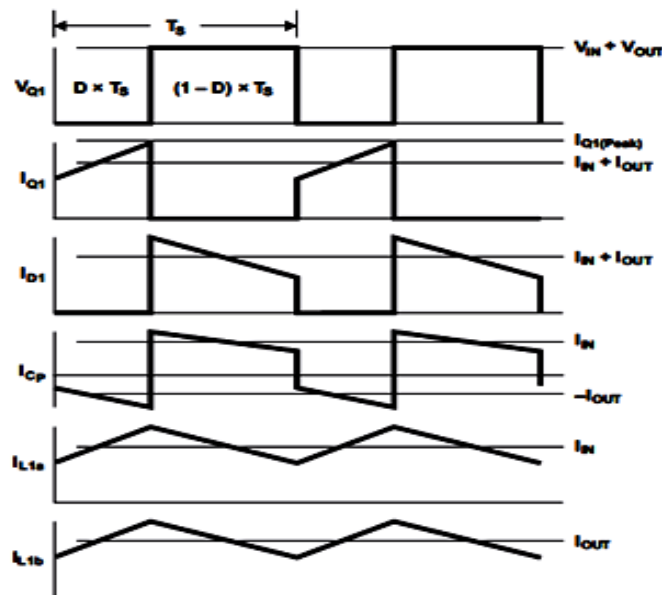**Fig. 4.** SEPIC Converter mode 2 Q_1 off

Fig. 5. Waveform of SEPIC Converter

A non polarized capacitor should be used, as the voltage across the capacitor C_p reverse direction every cycle. Capacitor C_p and inductor L_{1b} helps the SEPIC converter to operate both in buck and boost mode. The operation of converter in buck or boost mode is determined by its duty cycle. The output voltage V_0 is $V_{out} - V_{in}$. The average

voltage across C_p is V_{in}. When V_{out} is greater than twice V_{in} the output voltage of the converter V_0 will be greater than the input voltage and converter voltage will be less than input voltage when V_{out} is less than twice V_{in}.

Damage to the inductors can be prevented by making use of extremely fast switching diodes like schottky diodes which avoids generation of high voltage spikes across the inductor. Converter efficiency can be increased and the converter ripple can be reduced by making use of inductors with low series resistance which allows less energy to be dissipated as heat. This helps to transfer more input power to load. Capacitance with low ESR should be used for C_p and C_{in} so as to prevent heat built up in the circuit and reduce ripple in the circuit due to change in direction of current frequently in it.
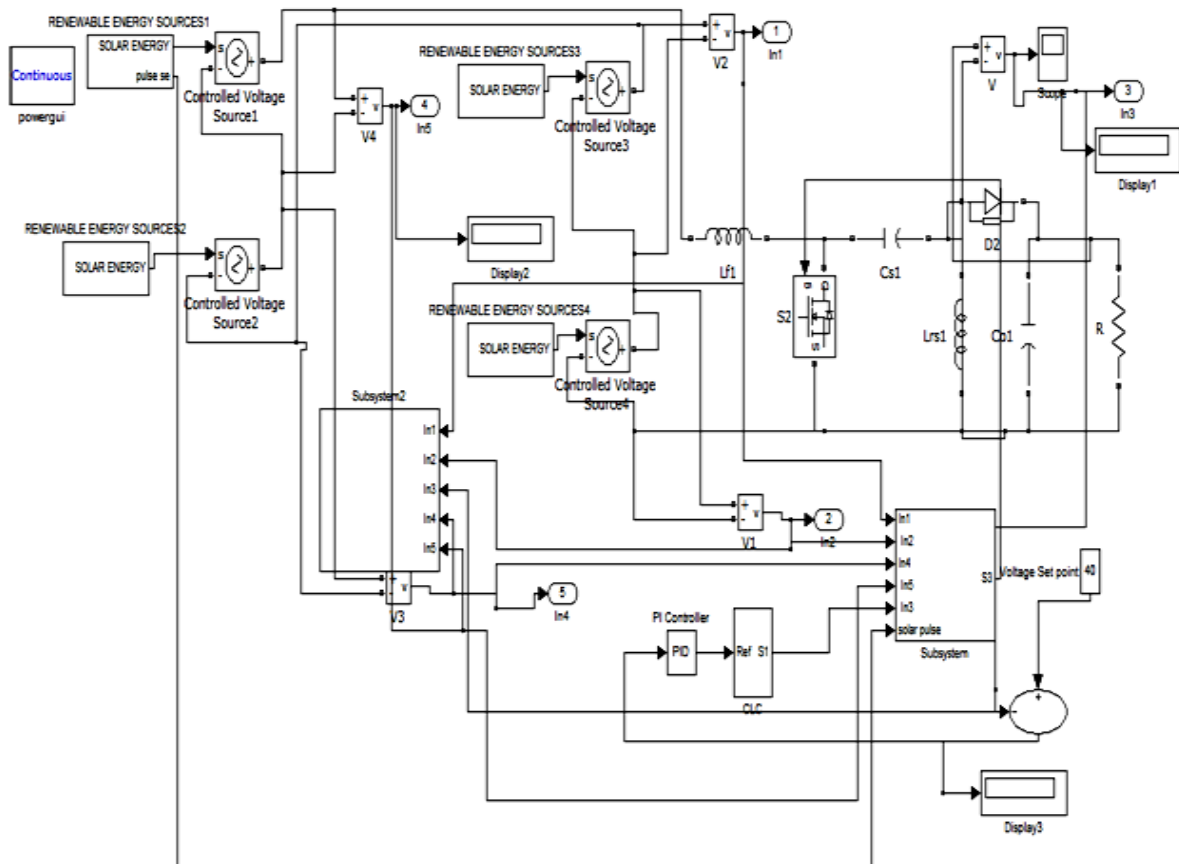
3. Simulation Circuit

Fig .6. Simulation circuit

Simulation is performed, and the outputs are compared for equal and unequal voltages.

CASE1: Different voltage: $V_1 = 9V$ & $V_2 = 4V$.

CASE2: Same voltage: $V_1 = V_2 = 9V$.
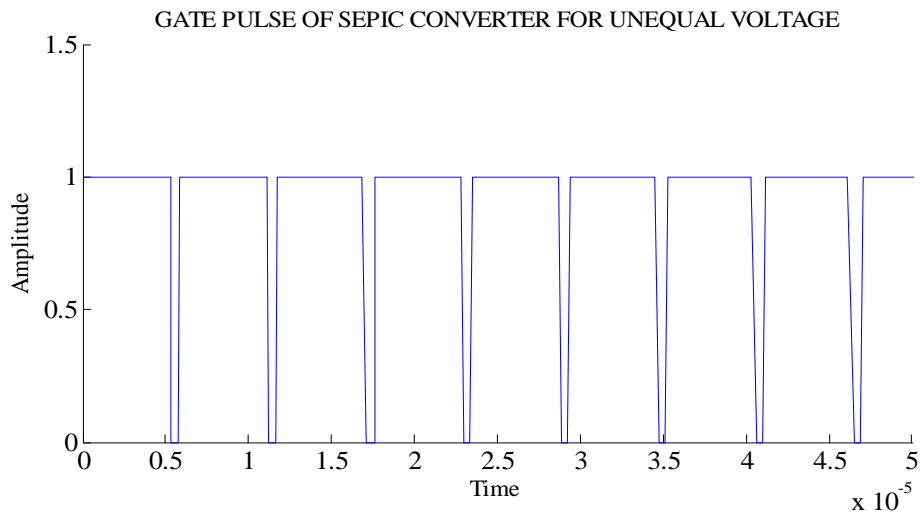
A. Case1: Results for different input voltage

GATE PULSE OF SEPIC CONVERTER FOR UNEQUAL VOLTAGE

Fig . 7. Case 1 SEPIC Converter Gate Pulse
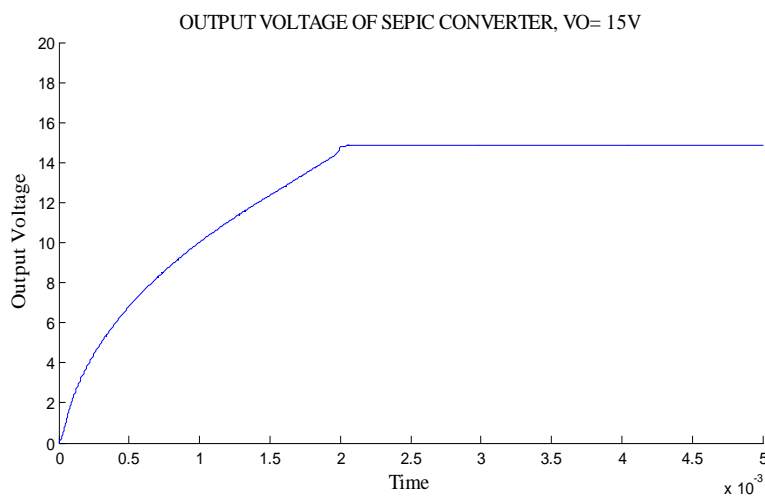
OUTPUT VOLTAGE OF SEPIC CONVERTER, VO= 15V

Fig. 8. Case1 SEPIC Converter voltage output

The Fig. 8 shows Case1 SEPIC converter output voltage. It maintains the output voltage approximately at 15V. This output voltage is given to boost converter. The Boost converter output voltage is 31.96Vwhich is shown in Fig. 9. The Fig.10 shows the current output from boost converter which is 3.1A.
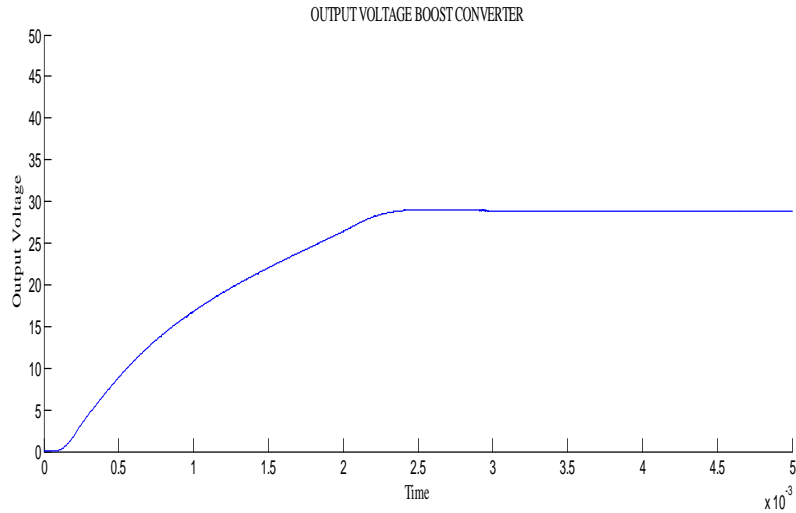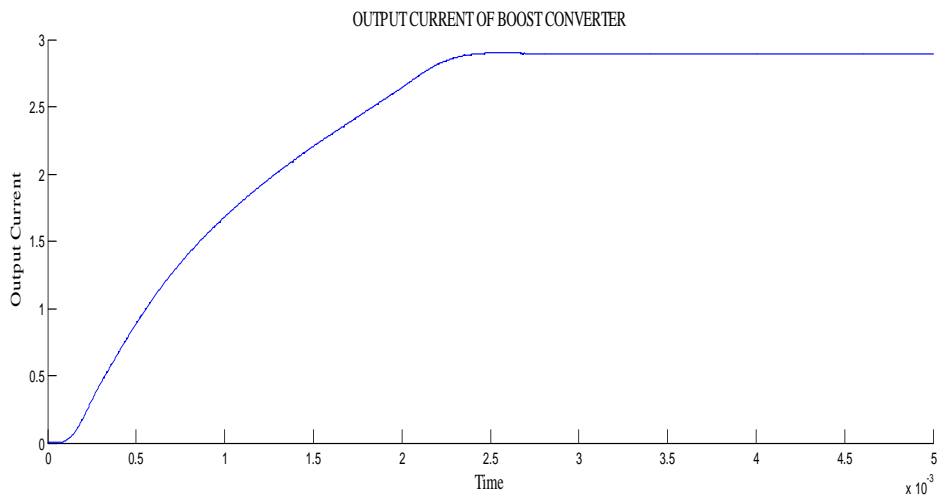
OUTPUT VOLTAGE BOOST CONVERTER

Fig.9. Case 1 BOOST Converter voltage output

OUTPUT CURRENT OF BOOST CONVERTER

Fig.10. Case 1 BOOST Converter current output

B. Case2: Results for equal input voltage

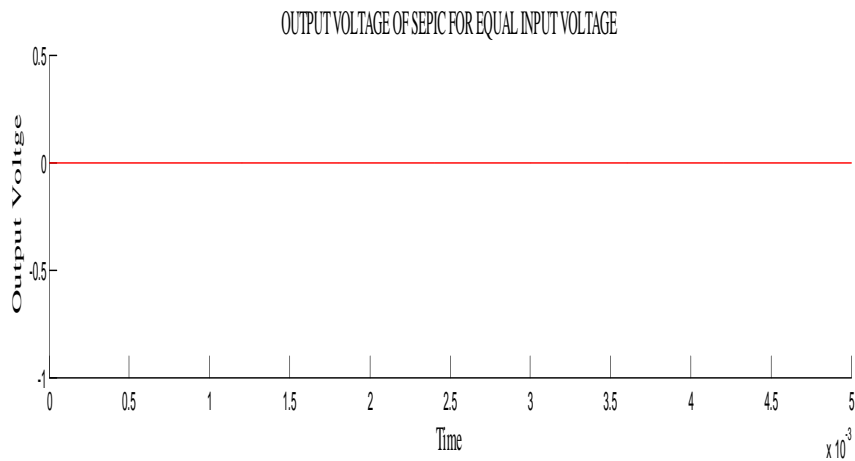OUTPUT VOLTAGE OF SEPIC FOR EQUAL INPUT VOLTAGE

Fig. 11. Case 2 SEPIC Converter Gate Pulse

Fig. 11 shows zero output from SEPIC converter. When two input voltage from PV modules are equal the micro controller does not generate any pulse for the SEPIC converter. The converter will be idle and the PV output is directly fed to the boost converter in this case.
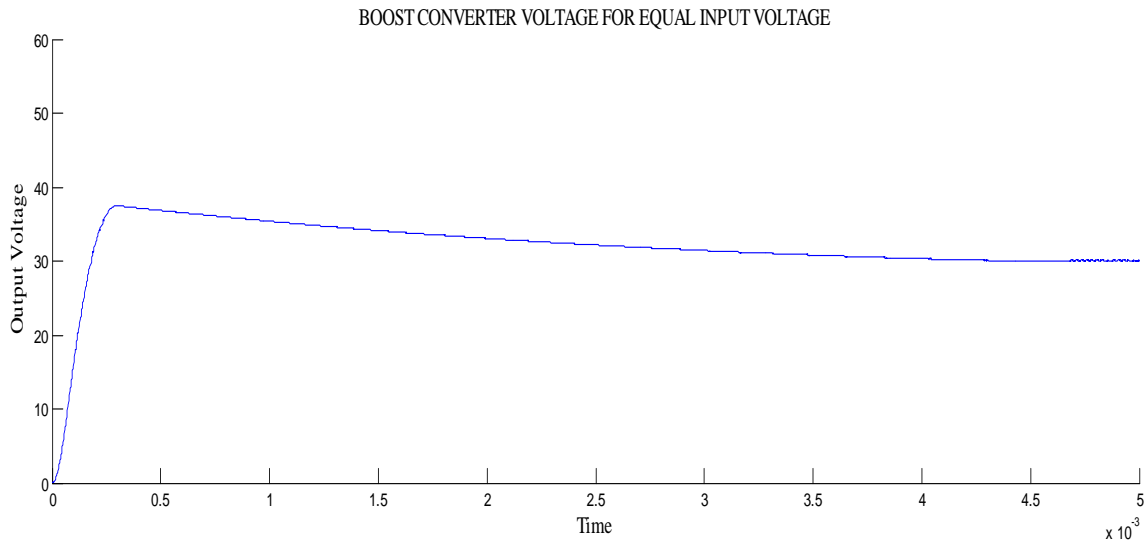
BOOST CONVERTER VOLTAGE FOR EQUAL INPUT VOLTAGE

Fig. 12. Case 2 BOOST Converter voltage output

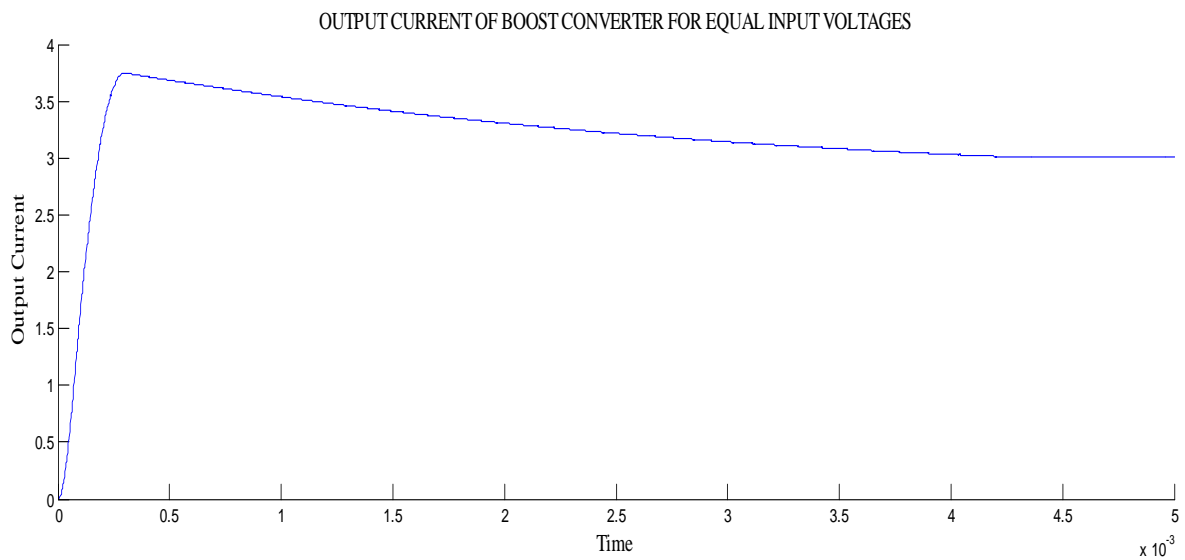OUTPUT CURRENT OF BOOST CONVERTER FOR EQUAL INPUT VOLTAGES

Fig .13. Case 2 BOOST Converter current output

The Fig.12 shows the output voltage of boost converter for case2. This output voltage is used to supply the resistive load. The output voltage obtained by simulation is 34.32V. Fig. 13 shows the output current of BOOST converter when voltages are equal is 3.4A. For equal input voltage SEPIC converter is in OFF condition.   The results are compared in table 1

Table 1 Simulation results

Cases	PV MODULE OUTPUT VOLTAGE	OUTPUT VOLTAGE FROM SEPIC CONVERTER
Different voltage	V_1=9V & V_2 = 4V	15.0 V
Equal Voltage	V_1=V_2=9V	0 V

Table 2 Comparison of different input voltages

VOLTAGE		SIMULATION		
V1	V2	0utput of SEPIC	Output Voltage of Boost	Output Current of Boost
9	9	No operation	34.32V	3.4A
2	9	15V	31.85V	3.1A
9	4	15V	31.96V	3.1A
5	9	15V	31.99V	3.1A

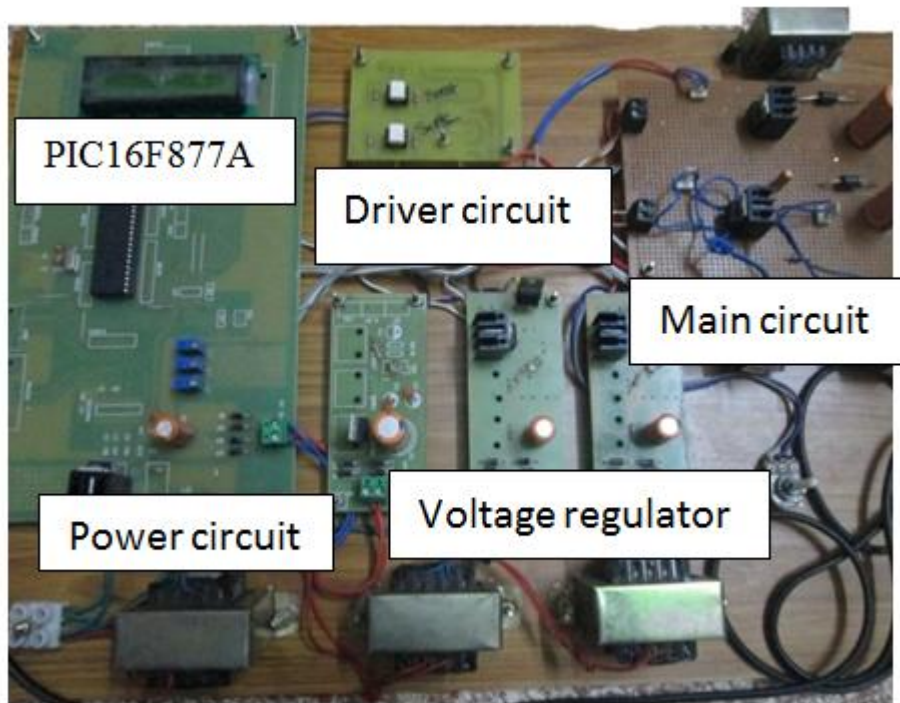**C. Hardware circuit**
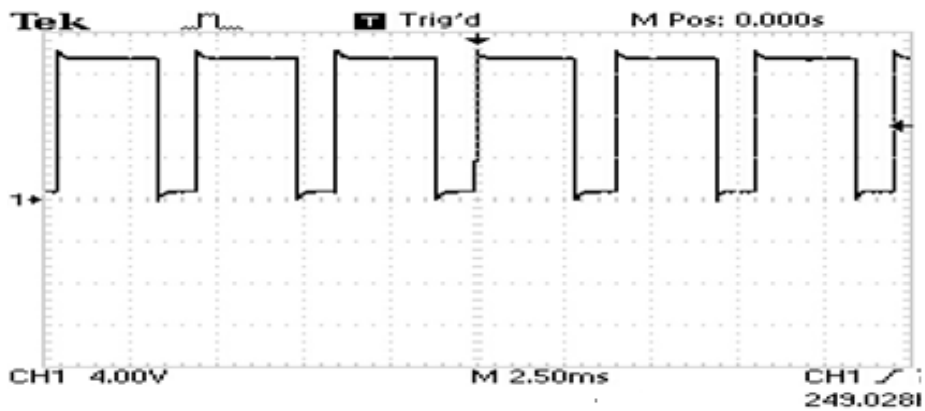

Fig. 14. Hardware circuit

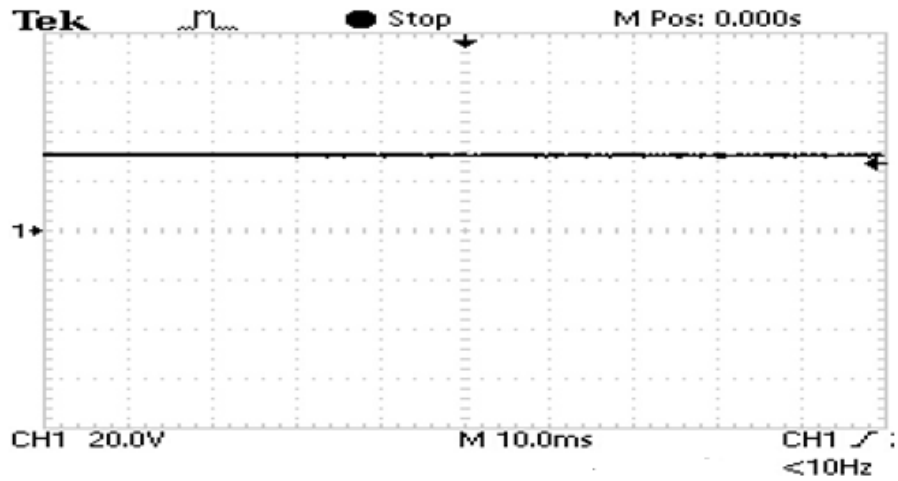**Fig. 15.** Case1 DSO gate pulse output from SEPIC converter

Fig. 16. Case1 DSO Voltage output of SEPIC Converter

Fig.14 shows the hardware circuit. The Fig 15 shows Case1 gate pulse given to SEPIC converter. The results are taken from the DSO. This pulses indicates that the converter is in active stage when two voltages are different.
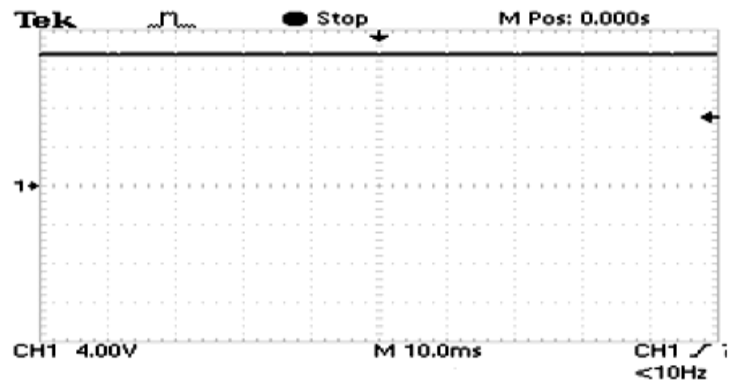

Fig. 17. Case1 DSO Voltage output of Boost Converter

The Fig. 17 shows Case1 voltage output of Boost converter which is 28.9V obtained from hardware circuit using DSO. This output voltage is used to supply the load.
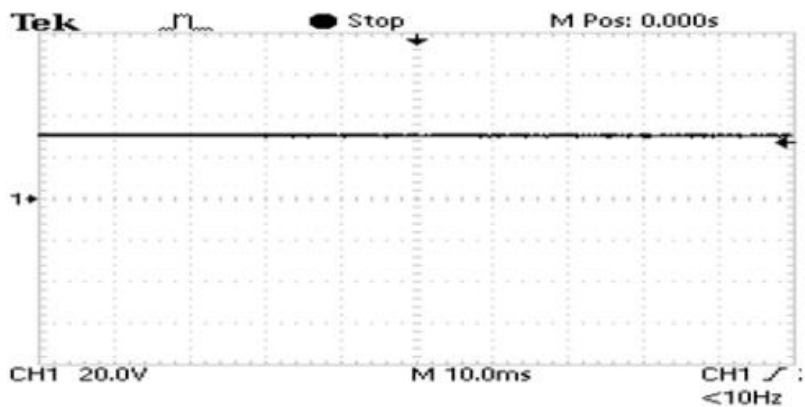

Fig. 18. Case2 DSO Voltage output of BOOST Converter

The figure 18 shows Case2 hardware output voltage of Boost converter obtained from DSO which is 27.8V.

VOLTAGE		SIMULATION OUTPUT		HARDWARE OUTPUT	
V_1	V_2	Output of SEPIC(V)	Output of BOOST (V)	Output of SEPIC(V)	Output of BOOST (V)
9	4	15	31.96	14.6	28.9
9	7	15	31.95	14.7	27.6
9	9	No operation	34.32	Standstill	27.8

Table 3 Comparison of simulation and hardware results for various voltages

Table 3 shows the comparison of simulation and hardware results for various input voltages. Table 4 gives the output voltage and current for various load.

Table 4 Comparison of voltage and current by varying the resistive load

RESISTIVE LOAD(ohm)	OUTPUT VOLTAGE(V)	OUTPUT CURRENT(A)
10	28.9	3.1
20	30.1	1.14
30	30.94	1.031
40	31.34	0.783
50	31.59	0.63
60	31.76	0.52

4. Conclusion

In realistic conditions due to partial shading and pollution the output of PV system gets reduced even if perfect components are used for its design. This paper introduces a module level DC/DC SEPIC converter which is active only when there is a difference between the substrings or modules output power exist. The operating time of the converter is less and the system reliability increases by connecting such converters in PV system. As the power difference is alone fed to the converter a low cost, low efficiency converter can be used to eliminate the effects of partial shading in PV systems. The simulated result of the converter is compared with the hardware results. Maximum performance of the system is found irrespective of the changes in physical condition.

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