PV Fed Modified SEPIC Converter

B.V.N.V.Shiv Kanth, C.V.S.Sainath, G.Sandeep

Abstract— In this paper utilization of a modified Single Ended Primary Inductance Converter (SEPIC) for control of photovoltaic power using Maximum Power Point Tracking (MPPT) control mechanism is presented. The main aim of the project is, SEPIC converter is to be used along with a Maximum Power Point Tracking control mechanism. The MPPT is liable for extracting the maximum possible power from the photovoltaic and feed it to the load via the SEPIC converter which steps up the voltage to required level. Voltage multiplier technique is applied to a traditional SEPIC converter. The multiplier technique provides new operation characteristics and a high static gain. The theoretical analysis, design procedure and simulation results are shown in this paper. The results are compared with a traditional SEPIC converter.

Index Terms— voltage multiplier, DC-DC power conversion, Single Ended Primary Inductance Converter (SEPIC), Maximum Power Point Tracking (MPPT), Modified SEPIC Converter , Photo Voltatic (PV) Cell ,Modified SEPIC Converter.

1 INTRODUCTION

One of the major concerns in the power sector is the day-to-day growing power demand but the absence of enough resources to meet the power demand using the conventional energy sources. Demand has enlarged for renewable sources of energy to be employed along with conventional systems to meet the energy demand. Renewable sources such as solar energy and wind energy are the foremost energy sources which are being employed in this regard.

Solar energy is plentifully available that has made it possible to harvest it and utilize it correctly. Solar energy can be a standalone generating unit or can be a grid connected generating unit depending on the obtainability of a grid nearby. Thus it is used to power rural areas where the obtainability of grids is very low.

In order to challenge the present energy disaster one has to develop a capable manner in which power has to be extracted from the incoming solar radiation. The conversion mechanisms on power have been greatly reduced in size in the earlier few years [1]-[2]. The expansion in power electronics and material science has helped engineers to come up very small but powerful systems to withstand the high power demand. But the drawback of these systems is the enlarged power density. Development has set in for the use of multi-input converter units [3] that can successfully handle the voltage fluctuations. But due to great production cost and the low efficiency of these systems they can hardly participate in the competitive markets as a key power generation source.

The constant growth in the enlargement of the solar cells manufacturing technology would absolutely make the use of these technologies possible on a wider basis [4]-[8]. The use of the latest power control mechanisms called the Maximum Power Point Tracking (MPPT) algorithms has led to the progress in the efficiency of operation of the solar modules and thus is active in the field of consumption of renewable sources of energy.

2. MODELLING OF PV MODULE

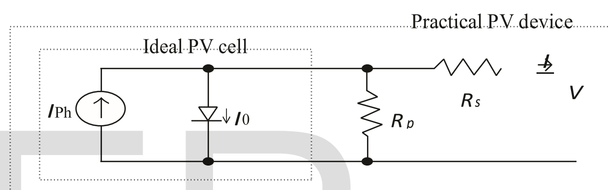

Fig. 1. PV cell modeled as diode circuit.

2.1 Definition

A photovoltaic system is a system which practices one or more solar panels to transform solar energy into electricity. It consists of various components, comprising the photovoltaic modules, electrical and mechanical connections and mounting.

2.2 Photo voltaic cell

PV cells are finished of semiconductor materials, like silicon. For solar cells, a thin semiconductor wafer is specifically treated to form an electric field, positive on one lateral and negative on the other. When light energy hits the solar cell, electrons are hit free from the atoms in the semiconductor material. This electricity can be utilized to power a load. A PV cell can either be spherical or square in structure.

2.3 Photo voltaic module

Due to the low voltage produced in a PV cell (around 0.5V), several PV cells are coupled in series (for high voltage) and in parallel (for high current) to form a PV module for preferred output. Isolated diodes may be required to avoid reverse currents, in instance of total

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shading or partial, and at night. The p-n junctions of mono-crystalline silicon cells may have suitable reverse current features and these are not essential. Reverse currents unwanted power and can also cause to overheating of shaded cells. Solar cells become less effective at greater temperatures and installers attempt to deliver good aeration after solar panels.

2.4 Photo voltaic array

The power that single module can harvest is not enough to meet the necessities of home or business. Most PV arrays use an inverter to transform the DC power into alternating current that can power the loads, motors, lights etc. The modules in a PV array are commonly first connected in series to gain the preferred voltages; the separate modules are then connected in parallel to allow the system to produce more current.

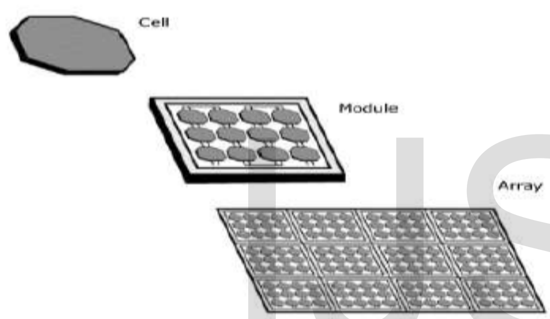

Fig. 2.Photovoltaic system.

2.5 Characteristics of PV cell

An ideal is demonstrated by a current source in parallel with a diode. Still no solar cell is ideal and so shunt and series resistances are added to it. R_s Stands the intrinsic series resistance whose value is very small. R_p Stands the equivalent shunt resistance which has a very great value.

Relating Kirchhoff's law to the node I_{ph} where, diode, R_p and R_s meet, we get

$$I_{ph} = I_{RP} + I_D + I \quad (1)$$

We get the succeeding equation for the photovoltaic current

$$I = -I_{RP} - I_D + I_{ph} \quad (2)$$

Where, is the Insolation current, I is the Cell current, R_p stands the Parallel resistance, R_s stands the series resistance. Photo current I_{ph} of the photovoltaic module be influenced by linearly on the solar irradiation and is too influenced by the temperature according to the succeeding equation:

$$I_{ph} = [I_{scr} + Ki^{*}(Tk - \text{Tref})] * \lambda/1000 \quad (3)$$

Where I_{ph} [A] is the light-generated current at the nominal Situation (25◦C and 1000W/m^2), $k_i$stands the short-circuit current/temperature coefficient (0.0017A/K), T_k and $T_{ref}$are correspondingly, the actual and reference temperatures in K, λ stands the irradiation on the device surface (W/m^2), and the nominal irradiation is 1000W/m^2.
Module reverse saturation current , I_{rs} is known by

$$I_{rs} = \frac{I_{scr}}{(\exp(qVOC/NSkAT) - 1)} \quad (4)$$

Where q stands the electron charge (1.6 × 10−19 C), V_{oc} stands the Solar module open-circuit voltage (21.24V), N_S stands the number of cells connected in series, k stands the Boltzmann constant (1.3805 × 10−23 J/K), and A stands the ideality factor 1.6.

The basic equation that defines the current output of PV module of single diode model is specified by

$$I_{pv}=N_P * I_{ph} - N_P * I_O (\exp\{q * (v_{ph} + I_{ph}{}^{*}R_s)/ N_s {}^{*}A^{*} k^{*} T\} - 1)- V_{pv}+(I_{pv}{}^{*}R_s)/ R_{sh} \quad (5)$$

Where N_P and N_s are, respectively, the number of parallel and Series networks of cells in the given photovoltaic module V_{pv}=V_{oc} =12V, R_s stands the equivalent series resistance of the module, and R_p stands the equivalent parallel resistance.

3. PROPOSED CONVERTER TOPOLOGY

The power circuit of a traditional SEPIC converter is shown in Fig. 3. The step-up and step-down static gains of SEPIC converter is an interesting operation characteristic for wide input voltage applications. The circuit diagram of SEPIC converter with voltage multiplier technique is shown in Fig. 4. The modified SEPIC converter is obtained by placing the capacitor C_2 and diode D_2. Design parameters and the static gain of the traditional SEPIC converter are changed with this modification on topology.

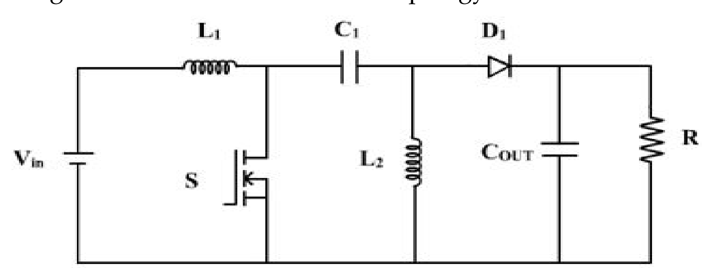

Fig. 3.Traditional SEPIC converter.

In the modified SEPIC converter, the capacitor C_2 is charged with the output voltage. Therefore, when the switch is conducting, the voltage applied to the inductor L_2 is higher than the voltage obtained from a traditional SEPIC converter.

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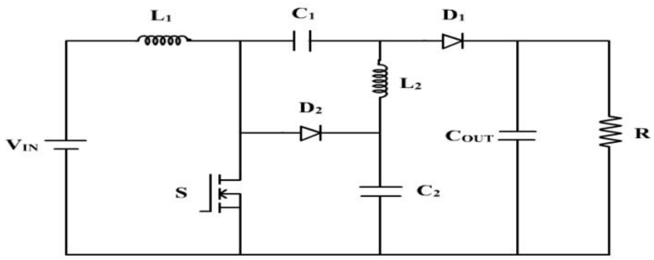


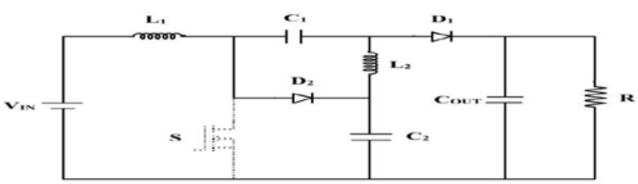
Fig. 4.Voltage multiplier SEPIC converter.

4. OPERATION MODES OF CONVERTER

Assume modified SEPIC converter is operating in continuous conduction-mode operation. Based ON and OFF position of the switch S it consists of two modes of operation:

Mode-I [T0, T1]: At time T0, the switch S is in off state as shown in Fig. 5(a). The energy stored in inductor L_1 is transferred to the load through the diode D_1 and capacitor C_1, and also to the capacitor C_2 through the diode D_2. Hence, voltage across capacitor C_2 is equal to the voltage across switch. The energy which is stored in the inductor L_2 is transferred to the load through the output diode D_1.

Mode-II [T1, T2]: At the time T1, switch S is in conduction as shown in Fig. 5(b). Diodes (D_1 & D_2) are blocked, and inductors (L_1 & L_2) stores energy. The input voltage is applied to the inductor L_1 and the voltage (V_{C1}– V_{C2}) is applied to inductor L_2. Hence the voltage across C_2 is greater than voltage across C_1.



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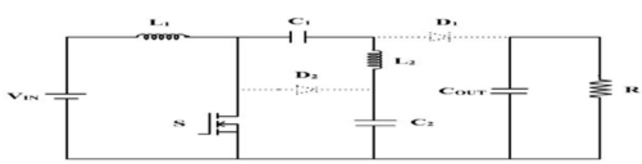

(b)

Fig. 5. Operation modes of converter. (a) When S in OFF state. (b) When S in ON state.

5. THEORETICAL ANALYSIS OF CONVERTER

The theoretical analysis and design procedure obtained for a modified SEPIC converter is given in this section. The theoretical analysis of modified SEPIC converter are compared with a traditional SEPIC converter and a boost converter. Theoretical waveforms of modified SEPIC converter is shown in Fig. 6.

5.1 Gain

At steady state, the average inductor voltage is zero. Hence, the relation for the inductor L_1 is given by equation (6)

$$\frac{T_{on}}{T_{off}} = \frac{(v_{c2}-v_{in})}{v_{in}} \qquad (6)$$

By cross multiplying equation (6), we get

$$v_{in} * T_{on} = (v_{c2} - v_{in}) * T_{off} \qquad (7)$$

Let assume

$$\alpha = \frac{T_{on}}{T} \qquad (8)$$

Where α is known as duty cycle, T_{on} is known as on time, T_{off} is known as off time and T is known as total time period.

Substituting eq. (8) in equation (7), we get

$$v_{in} * \alpha = (v_{c2} - v_{in}) * (1-\alpha) \qquad (9)$$

The relation between input voltage v_{in} and voltage across capacitor v_{C2} is represented in equation (10)

$$\frac{v_{c2}}{v_{in}} = \frac{1}{(1-\alpha)} \qquad (10)$$

When the switch S is turned-off, both the diodes D_1 and D_2 are in on state and the output voltage v_{out} is given by equation (11)

$$v_{out} = v_{C2} + v_{C1} \qquad (11)$$

By using volt-sec principle at steady state, voltage across inductor L_2 is zero. The following equations (12) and (13) are obtained as follows

$$(v_{C2} - v_{C1}) * T_{on} = (v_{out} - v_{C2}) * T_{off} \qquad (12)$$

Substituting equation (8) in equation (10), we get

$$(v_{C2} - v_{C1}) * (\alpha) = (v_{out} - v_{C2}) * (1-\alpha) \qquad (13)$$

The voltage across capacitor v_{c1} is given in equation (12)

$$v_{c1} = v_{out} - v_{C2} \qquad (14)$$

Substituting eq. (10) and eq. (14) in eq. (11), gain of the modified converter is given by equation (15),

$$\frac{v_{out}}{V_{in}} = \frac{(1+\alpha)}{(1-\alpha)} \qquad (15)$$

The static gain for this converter varies depending on the duty cycle.

Gains with respect to various duty cycles of a traditional SEPIC converters, a modified SEPIC converter and a boost converter are presented in TABLE 1, 2 and 3. Expression for duty ratios of a traditional SEPIC, a modified SEPIC and a boost converter is given in the TABLE 4. Comparisons of gain with respect to various duty cycles for a modified SEPIC, a traditional SEPIC, a boost converter are shown in Fig.7.

TABLE 1
VARIATION IN GAINS FOR DIFFERENT DUTY CYCLES FOR A TRADITIONAL SEPIC CONVERTER

Duty cycle	*gain*
0.1	0.11
0.2	0.25
0.3	0.42
0.4	0.66
0.5	1
0.6	1.5
0.7	2.33
0.8	4
0.9	9

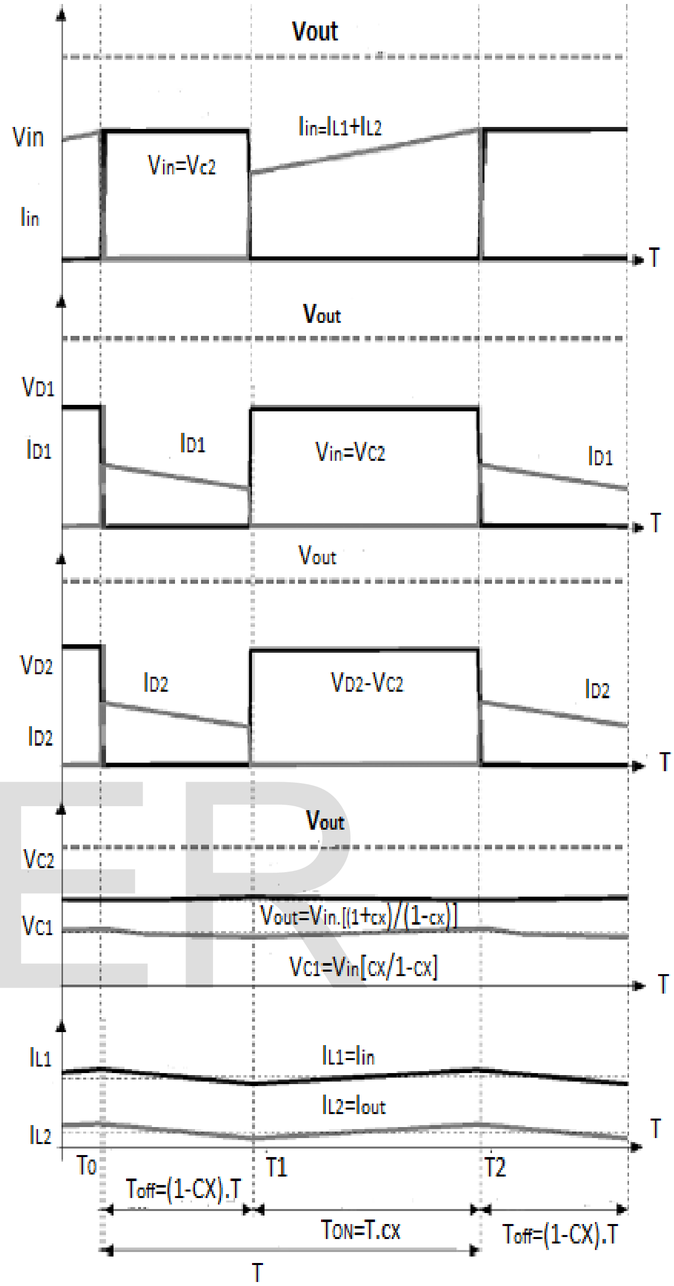

Fig. 6.Theoretical waveforms of modified SEPIC converter.

TABLE 2

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VARIATION IN GAINS FOR DIFFERENT DUTY CYCLES FOR A MODIFIED SEPIC CONVERTER

Duty cycle	*gain*
0.1	1.22
0.2	1.5
0.3	1.85
0.4	2.33
0.5	3.0
0.6	4
0.7	5.66
0.8	9
0.9	19

TABLE 2
VARIATION IN GAINS FOR DIFFERENT DUTY CYCLES FOR A BOOST CONVERTER

Duty cycle	*gain*
0.1	1.11
0.2	1.25
0.3	1.42
0.4	1.66
0.5	2
0.6	2.5
0.7	3.33
0.8	5
0.9	10

TABLE 4
COMPARISION OF DUTY CYCLE RATIOS

Boost converter	*SEPIC converter*	*Proposed SEPIC converter*
$\alpha = 1 - \frac{v_{in}}{v_{out}}$	$\alpha = \frac{v_{out}}{v_{out} + v_{in}}$	$\alpha = \frac{v_{out} - v_{in}}{v_{out} + v_{in}}$

Fig. 7.Variation in gains.

Modified SEPIC converter has a better gain compared to a boost converter and a SEPIC converter. A plot of variation in gains of a modified SEPIC, a boost and a traditional SEPIC converter is shown in Fig. 7 for a better understanding.

5.2 Design of inductances L_1- L_2 and input current ripple

The maximum input current ripple plays a vital role in determining the input inductance. By using the function of maximum input current ripple, input inductance value is obtained. The equation for determining the input current ripple is same for boost, traditional SEPIC, and the modified SEPIC converters, input current ripple is denoted as ΔI_{L1} is given in (16) when the power switch is in on state

$$\Delta I_{L1} = \frac{(v_{in} * \alpha)}{(L_1 * F)} \qquad (16)$$

By cross multiplication of equation (16), we get

$$\Delta I_{L1} * F * L_1 = v_{in} * \alpha \qquad (17)$$

Where *F* is the switching frequency.

Input inductance value is equal to 1mH which is obtained from equation (19). The input inductance value is determined for the converter conducting at the peak of the input voltage v_{in}. At this operation point, converter has duty cycle of α = 40 percent, the input voltage is equal to v_{in} = 12 V, and the input current ripple ΔI_{L1} considered by taking (23/100) of the I_{PEAK} peak input current. Hence, the input current ripple is obtained as follows

$$\Delta I_{L1} = I_{PEAK} * \frac{23}{100} \qquad (18)$$

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The calculated input inductance is equal to

$$L_1 = \frac{(v_{in} * \alpha)}{(L_1 * \Delta I_{L1} * F)} \qquad (19)$$

By substituting the values in equation (19) input inductance value is given in (20)

$$L_1 = 247\ u\text{H} \qquad (20)$$

The input inductance value for inductor L_1 = 247 uH. The inductance value for inductor L_2 is equal to the inductance value for inductor L_1 i.e., L_2= 247uH.

5.3 Design of capacitance C_1- C_2

Here the capacitors C_1 is known as series capacitor, C_2 capacitor is known as the multiplier Capacitor. C_2 changes with the input voltage and at the same time, capacitor C_1 also changes with the input voltage. Capacitor charge variation is denoted with ΔQc. Circulating current present in both capacitors C_1, C_2 are equal. When the switch is in conduction period, the current in the inductor L_2 current is equal to the C_2 and C_1 capacitances. The capacitor charge variation ΔQc is given in (21)

$$\Delta Qc = (\alpha * \Delta I_{L1} * T) \qquad (21)$$

Capacitor voltage ripple ΔV_C is obtained by using the relation Q=C*V is given in (22)

$$\Delta V_C = \frac{(\Delta Qc)}{(C)} \qquad (22)$$

$C_1$and C_2 capacitances both are having the same value is given below in equation (23)

$$C_1 = C_2 = \frac{(\Delta I_{L2} * \alpha)}{(\Delta V_C * F)} \qquad (23)$$

By substituting the values in equation (23) capacitance value is given in (24)

$$= 1u\ F \qquad (24)$$

The capacitance values for C_1 and C_2 of the modified SEPIC converter is equal to C_1=C_2= 1 uF.

5.4 Design of output capacitor C_{out}

The output capacitor C_{out} is also known as filter capacitor The output capacitance value depends mainly on the supply frequency F_g, the output power p_{out} and the low frequency output voltage rippleΔV_{out}.Taking an output voltage ripple equal to (1/100) of the output voltage(27.15V), the output capacitance is obtained by equation.

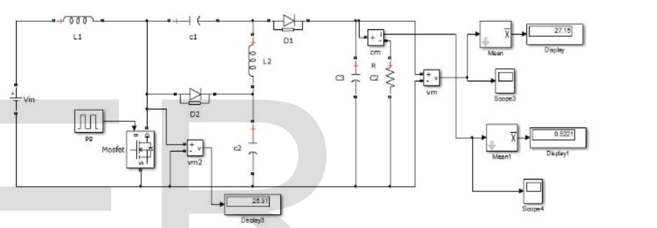
$$C_{out} = \frac{(p_{out})}{(2 * 3.14 * F_g * 2 * v_{out} \Delta V_{out})} \qquad (25)$$

By substituting the values in equation (25) output capacitance C_{out} value is given in (26)

$$C_{out} = 1000u\ F \qquad (26)$$

6. SIMULATION RESULTS OF PV FED MODIFIED SEPIC CONVERTER

The simulation results of PV fed modified SEPIC converter are obtained for an input of 12V and the output of 27.15V, at 40 percent duty cycle with 14.15W power at switching frequency of 25 KHz.



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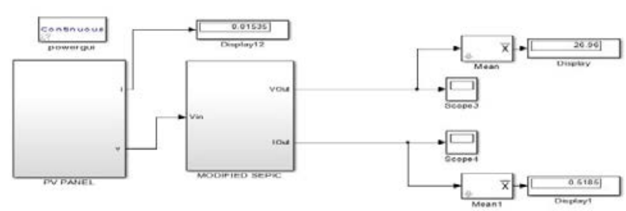

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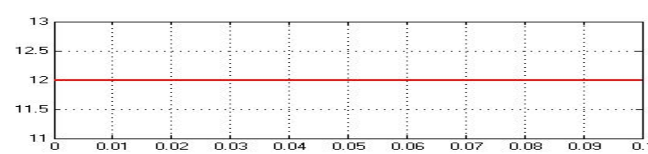

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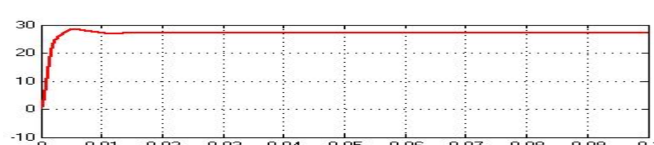

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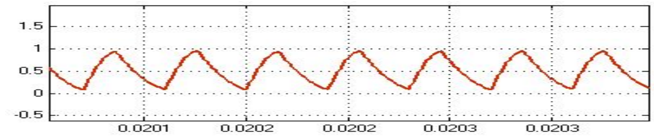

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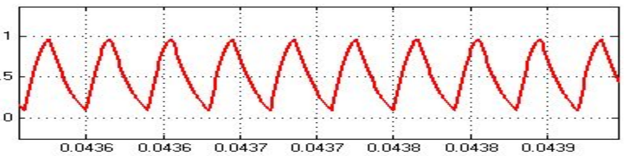

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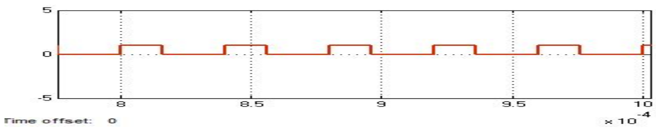

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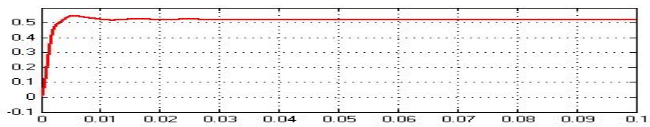

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Fig. 8. Simulation results of modified SEPIC converter. (a) Mat lab model of modified SEPIC converter. (b) Mat lab model of modified SEPIC converter along with PV fed. (c) Input voltage waveform. (d) Output voltage waveform. (e) Current through inductor L_1 waveform. (f) Current through inductor L_2 waveform. (g) Firing pulses across switch. (h) Output current waveform.

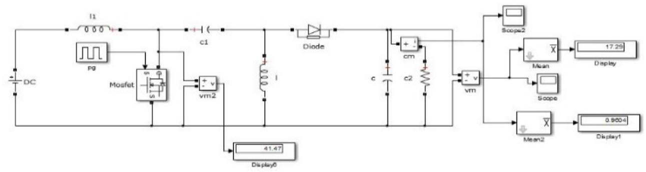
TABLE 5
PARAMETERS OF MODIFIED SEPIC CONVERTER

Components	*specifications*
INPUT VOLTAGE(Vin)	12 V
OUTPUT VOLTAGE(Vo)	27.15V
L1,L2	247 uH,247 uH
C1,C2,Cout	1 uF,1 uF,1000 uF
LOAD RESISTOR(Ro)	58 OHMS
MOSFET	1
DIODE(D1,D2)	2
POWER	14.1W
DUTY CYCLE	40%

Parameters of modified SEPIC converter is shown in TABLE 5. Simulation results of modified SEPIC converter validates our study.

7. SIMULATION RESULTS OF PV FED TRADITIONAL SEPIC CONVERTER

The simulation results of PV fed traditional SEPIC converter are obtained for an input of 12V and the output of 7.79V, at 40 percent duty cycle with power rating of 3.9W at switching frequency of 25 KHz.



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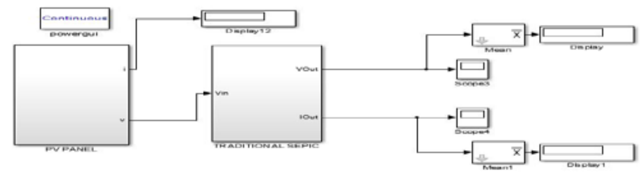

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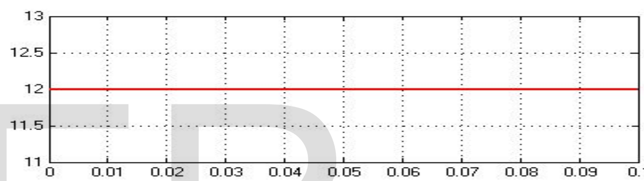

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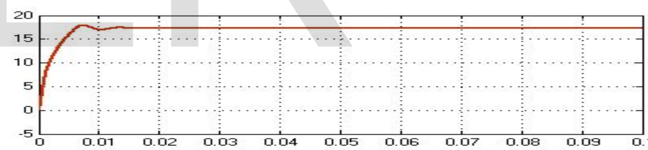

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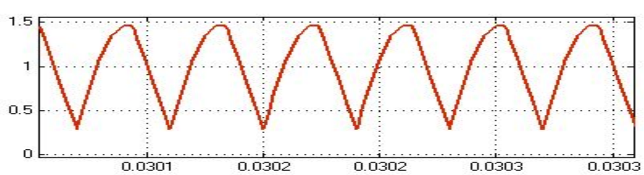

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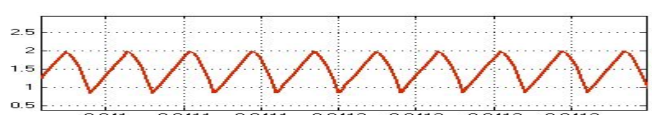

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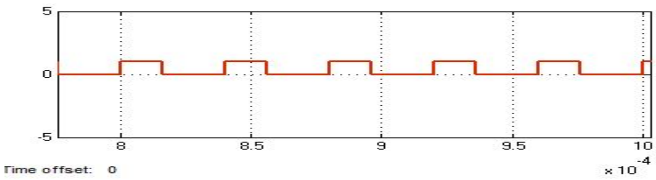

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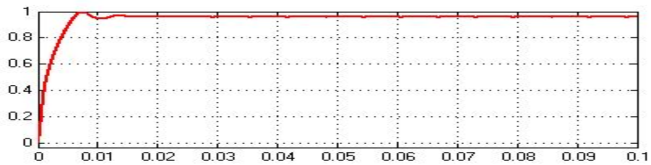

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Fig. 9. Simulation results of traditional SEPIC converter. (a) Mat lab model of traditional SEPIC converter. (b) Mat lab model of traditional SEPIC converter along with PV fed. (c) Input voltage waveform. (d) Output voltage waveform. (e) Current through inductor L_1 waveform. (f) Current through inductor L_2 waveform. (g) Firing pulses across switch. (h) Output current waveform.

TABLE 6
PARAMETERS OF TRADITIONAL SEPIC CONVERTER

components	*specifications*
INPUT VOLTAGE(Vin)	12 V
OUTPUT VOLTAGE(Vo)	7.79V
L1,L2	247 uH,247 uH
C1,Cout	1 uF,1000 uF
LOAD RESISTOR(Ro)	18 OHMS
MOSFET	1
DIODE(D1)	1
POWER	3.9W
DUTY CYCLE	40%

Parameters of traditional SEPIC converter is shown in TABLE 6. Simulation results of traditional SEPIC converter validates our study.

8. MPPT CONTROL ALGORITHM

The effectiveness of a solar cell is very small. In directive to rise the efficiency, approaches are to be assumed to match the source and load correctly. One such technique is the Maximum Power Point Tracking (MPPT). This is a method used to achieve the extreme possible power from a variable source. There are various techniques used for maximum power point tracking a few are the Perturb and Observe (P&O), Incremental Conductance (IC), Fuzzy Logic, and so on. The P&O algorithm is very common and simple.

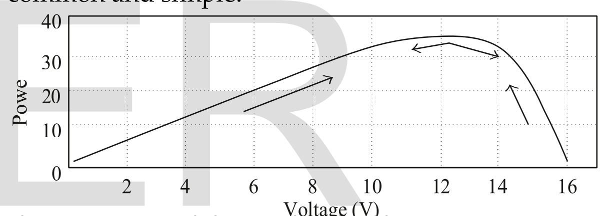


Fig. 10. Power graph for P and O algorithm.

In P&O algorithm, a small perturbation ($\Delta D = 0.01$) is introduced in the system. This perturbation origins the power of the solar module to vary. If the power increases due to the perturbation, then the perturbation is sustained ($D + \Delta D$) in that direction. Once the peak power is reached, the power at the resulting instant decreases and afterwards that the perturbation reverses ($D - \Delta D$).

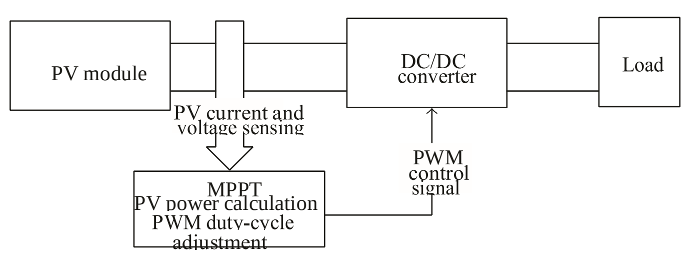


Fig. 11. DC-DC converter for operation at the MPPT.

With the deviation of irradiation and temperature, the power output of PV module differs constantly. The maximum power point tracking (MPPT) algorithm is used for extracting the maximum power from the solar PV module and transfer that power to the load A DC-DC converter (step up/step down), aids the purpose of transmitting maximum power from the PV module to the load and performances as an interface among the load and the module.

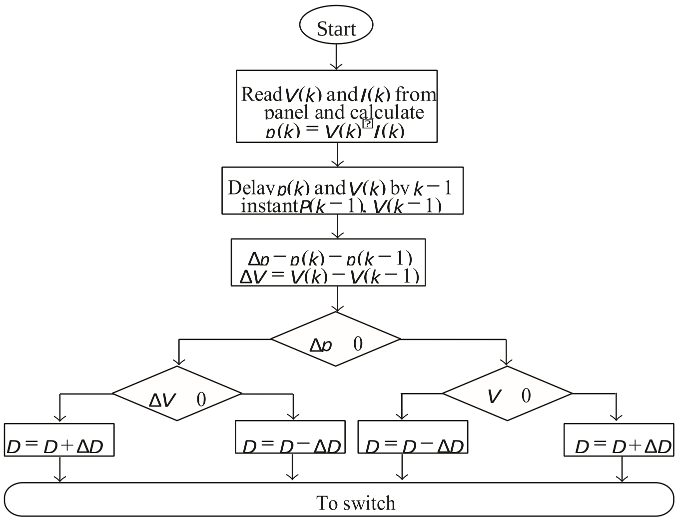
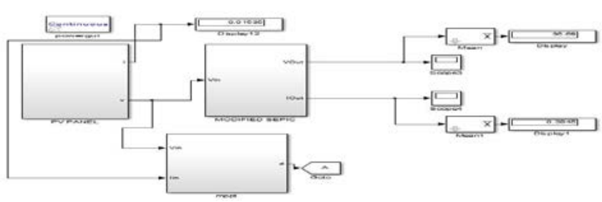


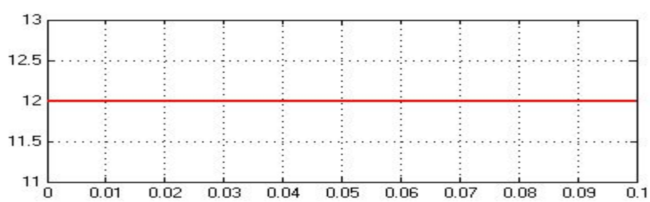
Fig. 12. Flow chart of P&O MPPT algorithm.

9. SIMULATION RESULTS OF PV FED MODIFIED SEPIC CONVERTER WITH MPPT

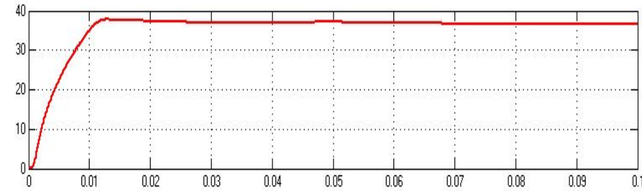
The simulation results of PV fed modified SEPIC converter with MPPT are obtained for an input of 12V and the output of 36.69V, at 50 percent duty cycle with 14.15W power at switching frequency of 25 KHz.



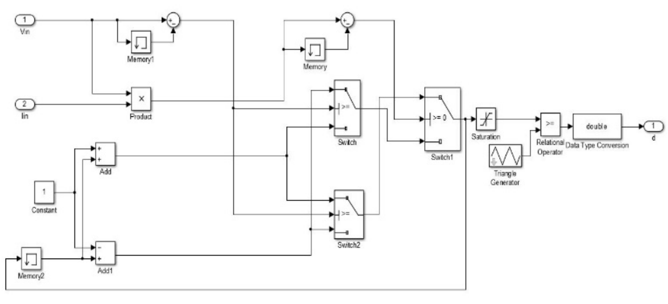
(a)



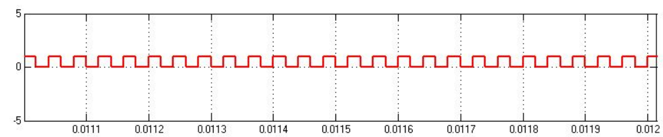
(b)



(c)



(d)



(e)

Fig. 13. Simulation results of modified SEPIC converter. (a) Mat lab model of modified SEPIC converter along with PV fed and MPPT controller. (b) Input voltage waveform. (c) Output voltage waveform. (d) MPPT Simulink block. (e) Firing pulses across switch.

10. CONCLUSION

From the results, it is clear that a modified SEPIC converter has higher circuit complexity than a SEPIC converter and a boost converter. The main advantage of modified SEPIC converter circuit it has high gain for a given duty cycle. The simulation results validates our study.

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