Performance Analysis of a PV Fed Modified SEPIC Converter under Variable Climatic Condition

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Abstract

This study proposes a PV fed modified SEPIC converter controlled by P&O MPPT controller. The need of power converter in the field of Microgrid and renewable resource power generating system is indispensable. Particularly the usage of Transformerless converters is kept increasing and the advancement of power electronics lead to modifications in power converters. Such action results in designing of compact sized converters with fewer components to obtain high output power. In accordance with that, this study proposes a modified SEPIC converter to tackle any change in input or load demand. Furthermore, the simplest P&O MPPT controller aids in regulating the operation of converter to balance the load demand. The analysis of this proposed study is carried out by adjusting the irradiance of solar panel at constant temperature to analyse the effectiveness of the converter. This proposed converter reached maximum voltage and current gain of 597.3V and 18.7A, respectively. Hence, the results proven that this converter performed better than several other converters.

Keywords: PV Module, Modified SEPIC Converter, P&O MPPT Controller, Transformerless Converter, Duty Ratio.

1. Introduction

Solar energy plays a major role in renewable energy generation systems. The abundant sunlight, compact size, and lower maintenance cost make this a viable solution to handle the energy crisis [1]. Even though, the sunlight is converted into electricity at most levels is questionable. While photonic energy is converted into electrical energy, factors such as poor designing of DC-DC converter and inverter, and environmental conditions majorly impact the process. It is hard to manage and produce under poor climatic conditions. However, improving the voltage gain by introducing an efficient DC-DC converter is a suitable solution to overcome that issue [2]. On the other hand, the designing of a control technique to enhance the performance converter is crucial. Because the converter output is based on the duty ratio given to the converter's switch. In general, the PV array power generation varies with changes in temperature and irradiance. Under higher temperatures and irradiance, the output of the system will be high. In case, any change occurs within it will degrade the output gain. Other than the converter, the design consideration of the MPPT control system is phenomenal. The purpose of the MPPT controller is to generate a gate pulse to switch the converter to attain the desired output [3].

Usually, the output of the PV system differs by the climatic conditions; but, obtaining the desired voltage gain under such conditions with traditional circuit configuration is complex. Hence, this study proposes a PV-fed modified SEPIC converter to utilise solar energy to get maximum output power. This converter is designed with fewer components to obtain high gain under low switching loss. Unlike the traditional SEPIC converter, this proposed converter can produce high output voltage at a minimum duty ratio. Several MPPT techniques are in use and they are open circuit voltage method [4], short circuit current method [5], perturb and observe (P&O) method [6], incremental conductance method [7], and fuzzy logic algorithm [8]. This study employs a P&O MPPT controller that helps in tracking maximum power point (MPP) to get desired output power under severe climatic conditions.

The rest of this study is arranged as follows: The study on modelling of PV array, deigning of proposed converter and MPPT algorithm employed in this study is discussed in section 2. The simulation results are discussed in section 3. Later, this study is concluded in the section 4.

2. Materials & Methods

The design of the PV-fed fed-modified SEPIC converter is represented in Figure 1. A PV array produces an enormous amount of power under good climatic conditions. But it may vary when change in irradiance or cell temperature. To tackle this and obtain maximum power under various environmental impacts is phenomenal. Under change in load demand, the generating of power which has been enough to satisfy the requirement is necessary. It is uncommon with the usage of traditional SEPIC converter to get such a desired amount of output power. So, this study employs a modified SEPIC converter with less component count. To get maximum power, the converter has to be operating at a high duty ratio which impacts the efficiency of the model. Even though the voltage gain is acceptable, it undergoes high switching stress. Moreover, regulating the duty ratio based on the load demand creates complexity in designing the controller. Considering this, a P&O MPPT algorithm approach is proposed in this study. In case any disturbance in solar irradiance or temperature is observed, this algorithm tracks MPP and enhances the voltage gain of the solar system by varying the duty ratio of this converter. A comprehensive study of this work is discussed as follows:

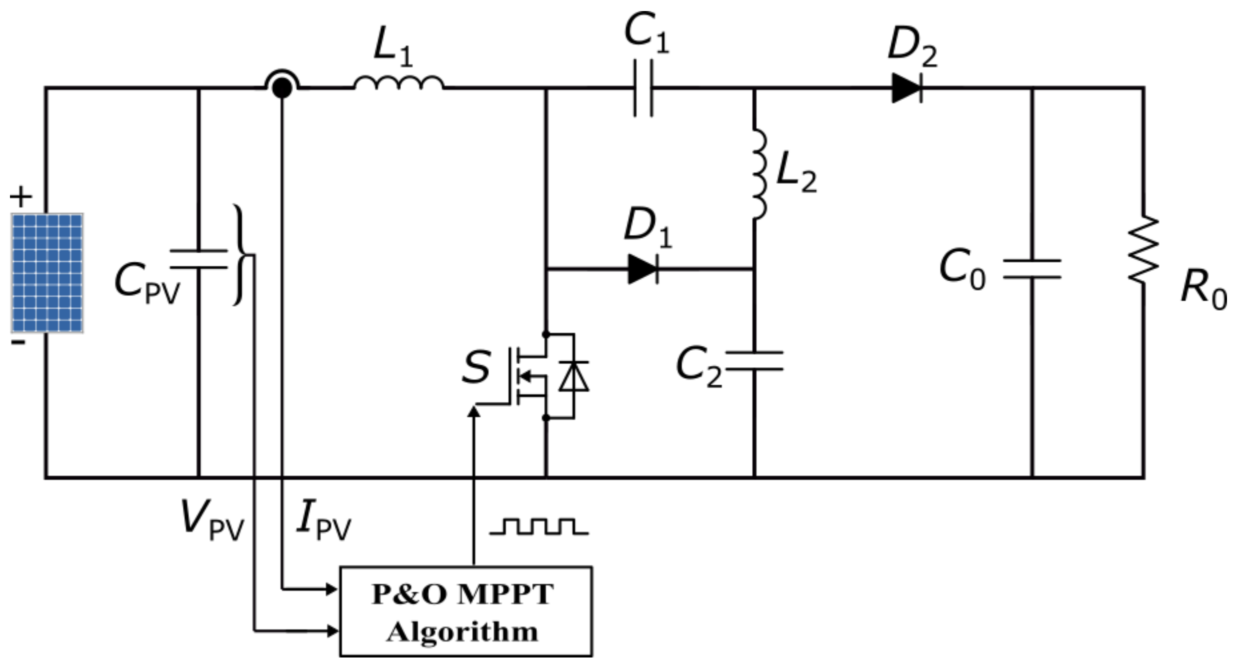


Fig.1.A schematic diagram of proposed study

A. Designig of PV module

A key element of the solar system is the PV cell. The group of cells creates a PV module; the combination of PV modules creates a panel and the number of panels creates a PV array. The PV array encompasses the arrangement of cells in series and parallel combinations. The series combination maximises the voltage gain. Likewise, the parallel combination maximises the current gain in the module. The PV power generation is based on two major factors namely solar irradiance and temperature. In practice, the solar cell can be modelled by a photonic current (Iph) and a shunt resistance (Rsh) representing leakage current and inserted in parallel with an inverted diode (ID), and a series resistance (Rs) representing the internal loss due to the current flow, which is depicted in figure 2. The current (I) generated by a solar cell has been represented as,

$$I = I_{ph} - I_D - I_{sh} \tag{1}$$

Using shockley diode equation, the value of I_D has been written as,

$$I_D = I_O\left(exp\left[\frac{q(V + IR_S)}{mkT_C}\right] - 1\right) \tag{2}$$

The mathematical expression for determing current in a solar cell as per the model is represented as,

$$I = I_{ph} - I_O\left(exp\left[\frac{q(V + IR_S)}{mkT_C}\right] - 1\right) - \frac{(V + IR_S)}{R_{sh}} \tag{3}$$

whereas, I_O-diode saturation current, q-elementary charge and it values 1.6×10^{-19}C, k-Boltzmann constant it is mneasured to be 1.38×10^{-23}J/K, m-diode quality factor, V-voltage of solar cell, T_C-absolute temperature.

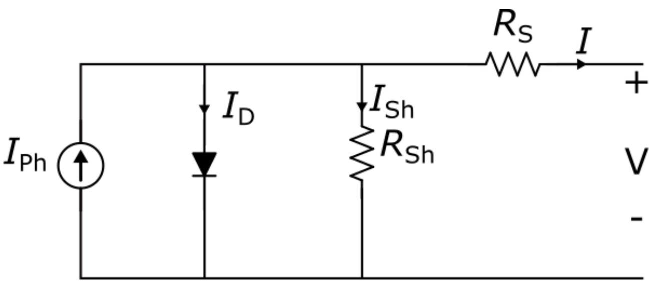


Fig.2.Equivalent circuit of Solar cell

The current at maximum power point (I_{MPP}) has been written as,

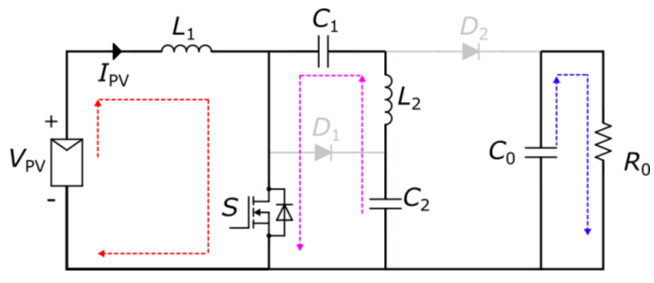
$$I_{MPP} = I_{ph} - I_O\left(exp\left[\frac{q(V_{MPP} + I_{MPP}R_S)}{mkT_C}\right] - 1\right) - \frac{(V_{MPP} + I_{MPP}R_S)}{R_{sh}} \tag{4}$$

whereas, V_{MPP}-maximum panel voltage. Also, the power at maximum power point (P_{max}) is determined by,

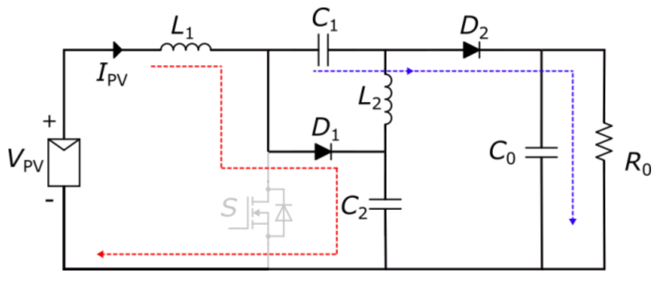
$$P_{max} = V_{MPP}\left\{I_{ph} - I_O\left(exp\left[\frac{q(V_{MPP} + I_{MPP}R_S)}{mkT_C}\right] - 1\right) - \frac{(V_{MPP} + I_{MPP}R_S)}{R_{sh}}\right\} \tag{5}$$

B. Modified SEPIC Converter

This converter encompasses a pair of inductors (L_1 and L_2), a switch (S), a pair of diodes (D_1 and D_2), and three capacitors (C_1, C_2, and C_3) which is depicted in figure 1.



(a)



(b)

Fig.3.Equivalent circuit for (a) mode 1 operation (b) mode 2 operation

Mode 1: Initially, the switch, S is kept closed and both diodes are reverse-biased. So, the input current flows through L1 and energises it. The capacitor C2 de-energises completely by energising the inductor, L2 and input capacitor, C1 and. Furthermore, the load resistance R0 is energised by the output capacitor, C0. The relation between input voltage and output current is written as,

$$\left.\begin{aligned} V_{L_1}(t) = V_{pv} \\ V_{L_2}(t) = V_{c_2} - V_{c_1} \\ C_0 \frac{dV_o}{dt} = iC_0 = \frac{-V_{out}}{R_o} \end{aligned}\right\} \quad (6)$$

Mode 2: At this stage, Switch, S is kept open and both diodes start conducting. The capacitor, C2 is energised through D1 by de-energising the inductor, L1. Moreover, the capacitor, C1 and inductor L2 de-energised to energise the output capacitor, C0. The voltage and current across the inductor and output capacitor are represented as,

$$\left.\begin{aligned} V_{L_1}(t) = V_{pv} - V_{c_2} \\ V_{L_2}(t) = -V_{c_1} \\ C_0 \frac{dV_o}{dt} = iC_0 = i_{L_2} - \frac{V_{out}}{R_0} \end{aligned}\right\} \quad (7)$$

Steady state analysis

Applying inductor volt-second balance and capacitor charge balance, the succeeding results are obtained:

$$\left.\begin{aligned} V_{L_1}(t) &= 0 \\ V_{L_2}(t) &= 0 \\ iC_0(t) &= 0 \end{aligned}\right\} \qquad (8)$$

The voltage across Switch and diodes are expressed as,

Switch, S	$\frac{V_{out}}{1+D}$
Diode, D_1	$\frac{V_{out}}{1+D}$
Diode, D_2	$\left(\frac{1-D}{1+D}\right)V_{out}$

Using eqn (6 to 8), the relationship among the source voltage, voltage across capacitor, and output voltage is derived.

$$V_{c_1} = \left(\frac{D}{1-D}\right)V_{pv} \qquad (9)$$

$$V_{c_2} = \left(\frac{1}{1-D}\right)V_{pv} \qquad (10)$$

$$V_{out} = \left(\frac{1+D}{1-D}\right)V_{pv} \qquad (11)$$

This converter has lower switching stress that aids in selecting switching elements with low ratings. It is crucial in lowering switching and conduction losses, which maximising the system's overall performance.

C. MPPT Algorithm

Any change in temperature or solar irradiance resulting in a change in the power of the panel requires an MPPT algorithm. The goal of the MPPT algorithm is to obtain maximum power from the panel by making them operate at the most efficient voltage.

P&O MPPT algorithm

It is simple and easier to implement because it tracks MPP by measuring the value of current and voltage observed at the output terminals of an array. This algorithm undergoes several iterations for tracking the MPP. This technique introduces a minute perturbation which makes a change in PV power. The output obtained by the panel is observed continuously and inspected with preceding values. The duty ratio of the converter is varied to maximise or minimise the output voltage of the PV array to compute the MPP. Once perturbation is over, the voltage obtained increases in parallel with output power than the preceding value. This procedure recapitulates and alters the duty ratio in an ascending direction to predict the improved MPP. The duty ratio is lowered to minimise the perturbation, the power produced at this stage is lesser than the preceding values, and this process is repeated till it reaches MPP. The voltage fluctuates consistently in a steady state, which makes ripples in output voltage and causes power loss. Thus, high perturbation makes a faster dynamic response as well as creates an oscillation in the output. Hence, low perturbation causes low dynamic response and has less impact on the output voltage. The flowchart of the P&O MPPT algorithm is depicted in figure 4.

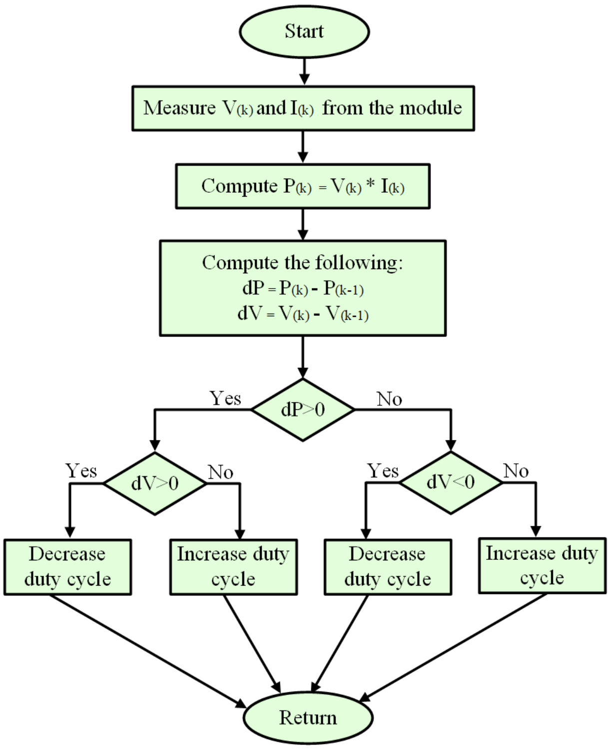


Fig.4.P&O MPPT algorithm

Initially, the PV array's operating voltage is slightly regulated and the power obtained is calculated. The value of P is directed in a positive direction, the current operating point is near the MPP and then a lot of modifications were done in such direction. The operating point is presumed to be a departure from the MPP. If the power is directed towards the negative and the perturbation direction is backward to approach the MPP. This algorithm doesn't react faster to the change in irradiation level, because of perturbation; it changes the MPP and results in the selection of the wrong MPP. The advantages of this algorithm are simple, easy to implement, considerably low implementation cost and more accurate than other algorithms.

3. Result and Discussion

The Simulink modelling of this study is carried out with the aid of MATLAB software. To evaluate the performance of this model, it is tested under a constant temperature of 25°Celsius and different irradiance values of 500 W/m2, 800 W/m2, 1000 W/m2, and 500 W/m2, respectively. The pictorial representation of the change in irradiance value is depicted in Figure 5 (a). From 0 to 1.5 sec, the irradiance level is maintained at 500 W/m2, during 1.5 to 2.5 sec the irradiance is maintained at 800 W/m2. Moreover, the irradiance value is shifted to 1000 W/m2 for period of 2.5 to 3 sec. Later, it is settled to 500 W/m2. Figure 5 (b) shows the temperature is kept constant at 25°Celsius. The following table 1 describes the design specifications of the PV array.

Table 1 Design Parameters of PV array

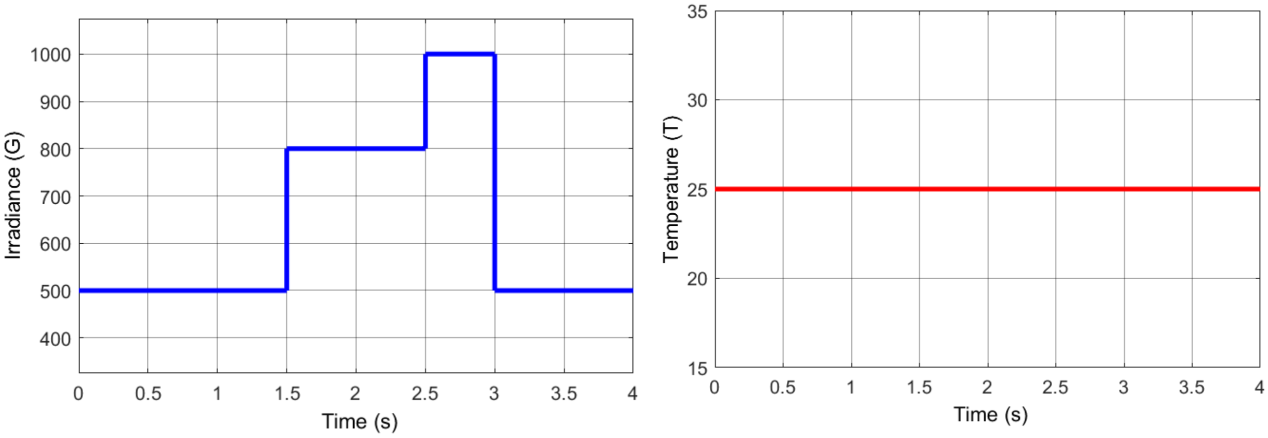
Parameters	Description
Maximum Power	270 W
Maximum Voltage	30.8 V
Maximum Current	8.77 A
Open Circuit Voltage	37.9 V
Short Circuit Current	9.07 A
Cells per module	60
Parallel string	4
Series connected modules per string	11

Generally, the power produced by the PV system varies as per the temperature and irradiance. This study proves this fact by experiencing sudden variations in voltage and current gain of the PV array which is represented in Figure 6. Figure 6 (a) shows that the PV array initially produced a voltage of 346.17V. Once the irradiance level is changed, a voltage fluctuation is observed and then it obtains a voltage gain of 352.06V. After reaching a maximum irradiance of 1000 W/m2, the voltage gain observed at terminals of PV array values 341.06V. Later, the irradiance is settled at 500 W/m2, the panel maintains a voltage gain of 346.17V. Also, figure 6 (b) shows the change in current produced by the PV array at different irradiance levels. During 0 to 1.5 sec, it produces 16.08A, next it is raised to 28.4A. Afterwards, it reaches a maximum current gain of 36A at a time interval of 2.5 to 3 sec. Again it reaches 16.08A and maintains throughout the cycle.

This voltage and current measured at the PV array output terminal is fed to the MPPT controller. It helps in enhancing input voltage and current given to the converter by regulating the duty ratio of the converter thereby choosing maximum MPP which is shown in Figure 7. This control technique adjusts the converter's operation as per the change in input and load demand. It shows that this converter is operated at a low duty ratio and it considerably decreases the risk of switching stress. In comparison with other MPPT techniques including the incremental conductance method [9], this MPPT algorithm is simple and easy to implement.

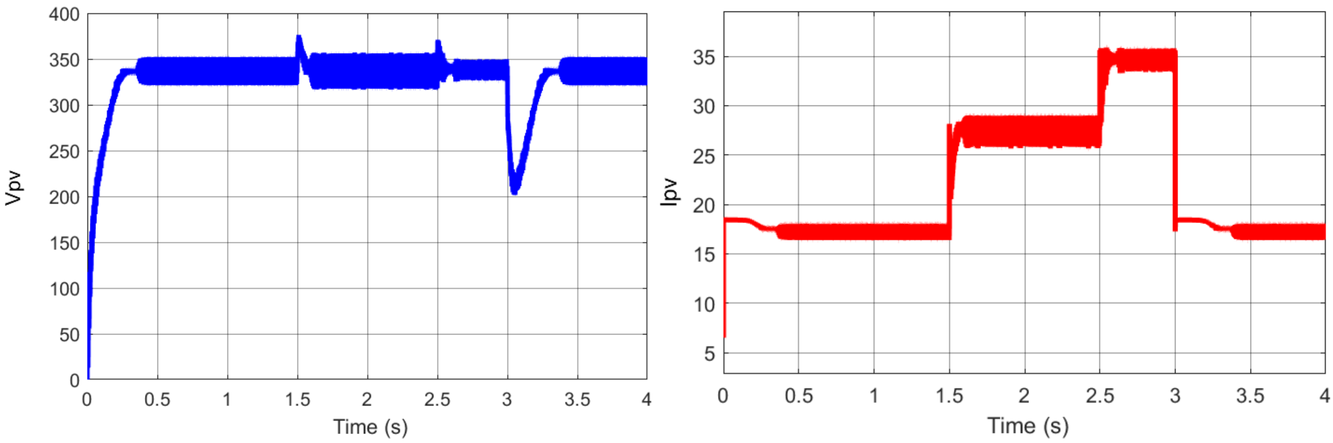
As shown in Figure 8, the output voltage and current of the proposed modified SEPIC converter are varied which states that the change in duty ratio causes a change in voltage and current. During 0 to 1.5 sec, this converter reached a low voltage and current gain of 423V and 14.30A as shown in Figure 8 (a). To change the duty ratio, the converter's voltage and current gain are increased linearly. When the duty ratio is increased as per the tracking of MPP, the converter's output is boosted without suffering switching stress. Here, figures 8 (a) and 8 (b) show voltage oscillation and current oscillation is observed when a change in duty ratio occurs. The increase in duty ratio maximises the output voltage and current of 523V and 27.61A. It is noted that this proposed converter obtained maximum output voltage and current of 597.3V and 18.7A under a change in input power. Again, the output falls to reach the same as that of the start point. In this way, the converter maximises the output to tackle any change in input.

Table 2 compares the design parameters of the modified SEPIC converter with several other approaches in terms of component count, switching stress, and voltage gain.



(a) (b)

Fig.5.Parameters of PV array (a) Variation in Irradiance (b) Constant temperature



(a) (b)

Fig.6.PV array waveform of (a) Voltage (b) Current

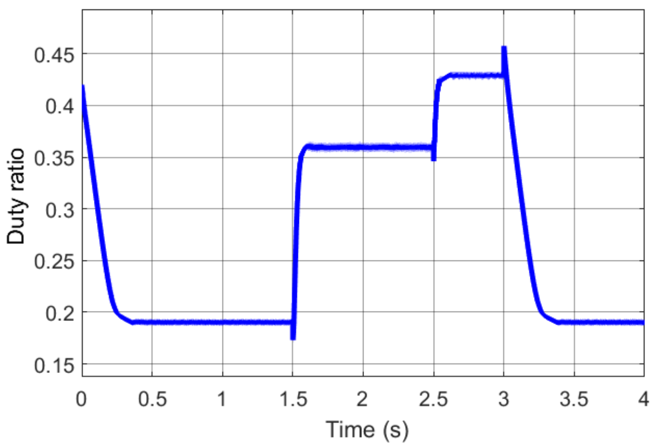
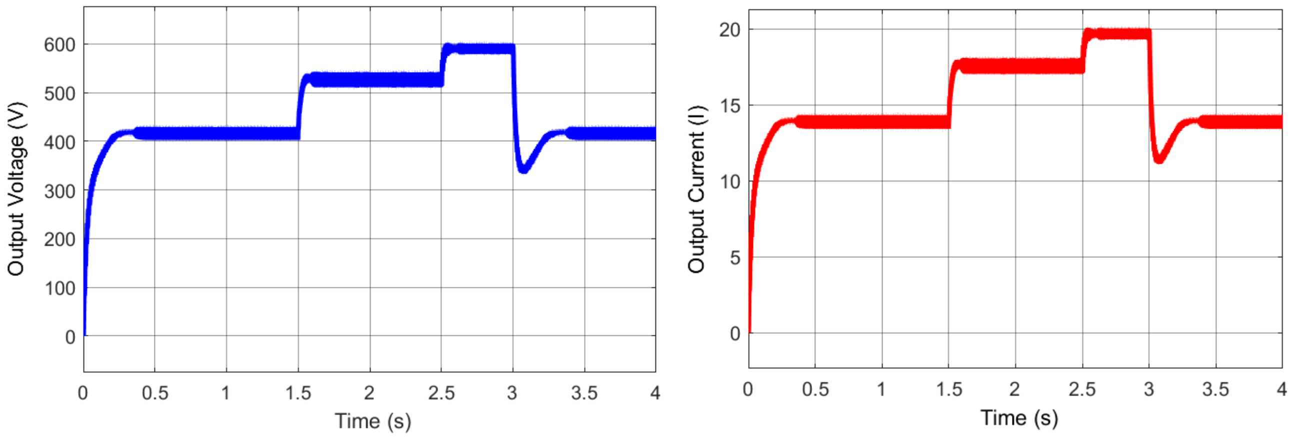


Fig.7.Duty ratio



(a) (b)

Fig.8.Output waveform of modified SEPIC converter (a) Voltage gain (b) current gain

Table 2 Comparison of modified SEPIC converter with other topologies

References	Components				Switch Voltage Stress	Voltage gain $\left(\frac{V_{Out}}{V_{in}}\right)$
	D	L	S	C		
[10]	2	1	1	3	$\frac{V_{in}}{1-D}$	$\frac{1+n}{1-D}$
[11]	6	2	2	4	$\frac{V_o}{1-D}$	$\frac{3}{1-D}$
[12]	4	1	1	4	$\frac{V_o}{3-D}$	$\frac{3-D}{1-D}$
[13]	3	2	2	3	$\frac{D^2-3D+3}{(1-D)^2}$	$S_1=\frac{V_O(1-D)^3}{D^2-3D+3}$ $S_2=\frac{V_O(1-D)^2}{D^2-3D+3}$
Proposed work	2	2	1	3	$\frac{V_{out}}{1+D}$	$\left(\frac{1+D}{1-D}\right)$

4. Conclusion

The operation of the PV-fed modified SEPIC converter is analysed in this study. To validate its effectiveness, the solar irradiance is varied from 500 W/m2, 800 W/m2, 1000 W/m2, and 500 W/m2 at a constant temperature of 25°Celsius is maintained. Accordingly, the voltage and current produced by the PV array are varied. This proposed converter manages the change in input voltage and significantly improves the output voltage and current. This converter experiences maximum output voltage and current of 523V and 27.61A at input voltage and current of 341.06V and 36A. The P&O MPPT is simple but the response time is comparatively low. Such drawback has been rectified using this proposed converter because it regulates the voltage and current gain instantly, once the control technique changes the gate pulse based on the MPP. Relatively this converter has gain voltage gain.

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