

# Design and Simulation of Boost Converter under Partial Shading Conditions

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**ABSTRACT:** This paper discusses the dc to dc boost converter which is solar powered can work in both Standard and partial shading conditions according to the requirement. The main purpose of this paper is to design a converter to glow a bulb of 12W DC power source, supplied by Photovoltaic (PV) Cells. To operate at maximum efficiency using Maximum Power Point Tracking (MPPT) algorithm the system is controlled. The P & O algorithm is installed on a controller. The solar panel model is simulated in MATLAB/SIMULINK followed by the dc –dc converter is presented and waveforms obtained are discussed. In this paper the most common topologies of PV array configurations are series, parallel, series-parallel and TCT are discussed. The modules are tied in parallel and then connected in series in TCT configuration. This configuration reduces the mismatch losses and gives optimum output. A PV array has the optimum operating point known as MPPT which varies depending on cell solar insolation level and temperature. The performance of the complete system model under varying insolation levels and under partial shading conditions of solar panel is discussed.

**KEYWORDS:** Boost converter, MPPT, Partial shading, P & O algorithm.

## I. INTRODUCTION

In the recent past years, due to environment pollution and energy crisis, the photovoltaic cells becomes more significant using electrical generation system. The environmental issues such as the greenhouse effect and air pollution can substantially reduce by the photovoltaic power generation systems (Prashant Upadhyay and Bheru Das Vairagi, et al.,2014) [1]. Solar energy can be converted directly into electrical energy in a photovoltaic system. Photovoltaic cells are the basic component of photovoltaic system. Solar modules are formed by grouping cells in parallel and in series. To form arrays modules are grouped in series and parallel. Cells connected in parallel increase the output current while cells connected in series increase the output voltage [1]. When solar energy strikes the solar cell electric current is produced. The conversion of solar energy into electricity is highly dependent on the associated temperature changes and the sun irradiation levels (Rozana Alik, et al., 2017) [2]. It has a nonlinear current-voltage (I-V) characteristic. But, there is a maximum power point (MPP) on its power-voltage (P-V) characteristic at which cell produces maximum power. The output power of PV module depends on solar temperature and irradiation. Partial shading (PS) is one of the major cause of reduced the efficiency of PV module. Partial shading is caused by several factors such as building, cloud, snow and tree [3]. PV modules in the array receives different solar irradiation in partial shading conditions. Therefore, there are multiple peaks on the P-V and I-V characteristics of the PV array, so power losses occur in the system. One of the solution to this problem is to use different PV array configuration schemes (Okan Bingol and Burcin Ozkaya, 2018) [3]. Mismatch losses occurs due to partial shading. Due to these losses the energy yield of photovoltaic (PV) systems can reduce considerably. The presence of shade on PV panels causes masks which block or part of the direct sun radiation, so there is a loss of energy received by the cells. Moreover, when a solar cell is shaded it becomes equivalent to resistor which consumes the energy generated by its neighbouring cells. The absorbed energy is converted into heat which raises the temperature of the cell and damages. This is known as hot spot effect and this problem can be solved by using bypass diodes (Faiza Belhachat and Cherif Larbes, 2018) [4]. Different PV array configuration schemes are discussed such as series (S), parallel (P), series-parallel (SP), Total-Cross-Tied (TCT). The PV cells are constructed from the interconnection of PV modules under different partial shading conditions. The results from these configurations under different cases are discussed. TCT connection is best under the partial shading conditions. This proposed scheme for PV is implemented on  $3 \times 3$  PV array for that single diode photovoltaic model is used. To control the terminal voltage of the PV system in various solar radiation conditions at optimal values DC-DC converter is used. To maximize the power output of the PV system DC-DC converter is used with MPPT algorithm.

II. LITERATURE SURVEY

[1] PV Panel:

The diode model is most widely used. The equivalent circuit of single diode model is shown in below figure.

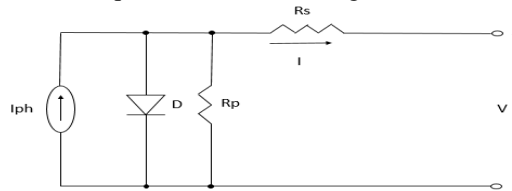


Fig. 1 Equivalent circuit of PV cell

The above circuit consists of a photo current ( $I_{ph}$ ), a diode (D), a parallel resistance ( $R_p$ ) represents the leakage current and a series resistance ( $R_s$ ) represents an internal resistance of the PV cell [3].

The voltage-current characteristic equation of a PV cell is given as follows,

$$I = I_{ph} - I_0 \left[ \exp\left(\frac{q}{kTA}(V + IRs) - 1\right) - \frac{V+IRs}{Rp} \right] \dots\dots\dots (1)$$

Where  $I_{ph}$  is light generated current,  $I_0$  is the cell saturation of dark current,  $T$  is the cell's operating temperature in Kelvin (K),  $k$  is the Boltzmann constant ( $1.381 \times 10^{-23}$  J/K),  $q$  is the electron charge ( $1.602 \times 10^{-19}$  C). The photovoltaic current mainly depends on the solar irradiation and temperature give as,

$$I_{ph} = [I_{sc} + K_I(T-T_{ref})] G/G_n \dots\dots\dots (2)$$

Where  $I_{sc}$  is the short circuit current,  $K_I$  is the short circuit current temperature coefficient,  $T_{ref}$  is the reference temperature,  $G$  is the solar irradiation and  $G_n$  is the nominal solar irradiation in  $W/m^2$ . The saturation current can be expressed as,

$$I_0 = I_{0,n} \left(\frac{T_{ref}}{T}\right)^3 \exp\left[\frac{qE_g}{Ak} \left(\frac{1}{T_{ref}} - \frac{1}{T}\right)\right] \dots\dots\dots (3)$$

Where  $I_{0,n}$  is the nominal saturation current,  $E_g$  is the band gap energy. In order to produce desired output power, PV cells are connected in a module of series and parallel configuration [4].

**PV module:**

1Soltech1STH-215-P is used to carry out the simulation in MATLAB/Simulink. The specifications of this module is given below

Table 1 Specifications of Soltech PV module

| Characteristics                               | Specifications |
|---|----------------|
| Maximum power (W)                             | 213.15W        |
| Open circuit voltage (Voc)                    | 36.3V          |
| Voltage at maximum power point $V_{mp}$ (V)   | 29             |
| Temperature coefficient of $V_{oc}$ (%/deg.c) | -0.36099°C     |
| Cells per module                              | 60             |
| Short circuit current $I_{sc}$                | 7.84A          |
| Current at maximum power point ( $I_{mp}$ )   | 7.35A          |
| Temperature coefficient of $I_{sc}$ (%/deg.c) | 0.102°C        |

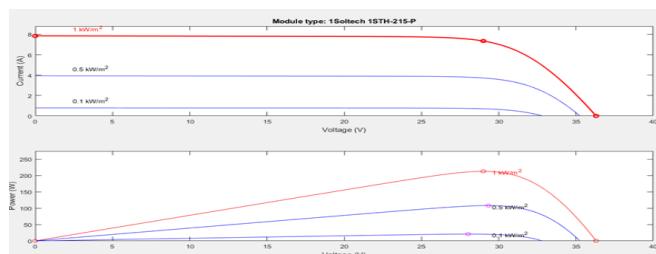


Fig. 2 IV & PV characteristics of Soltech PV module

This PV module is used to simulate the different configurations under partial shading conditions. Curve in the figure shows the change in output current of solar cell with the variation in output voltage and vice versa.

**[2] MPPT:**

Maximum power point tracking is most commonly used technique in photovoltaic solar systems. It is used in these systems to minimize power extraction under all conditions.

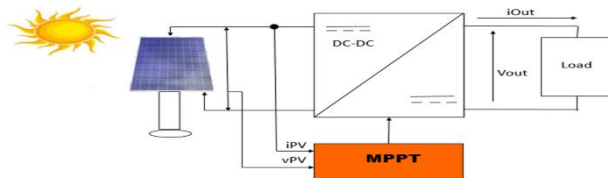


Fig. 3 MPPT

The main problem faced by MPPT is the efficiency of power transfer from solar cell. The power transfer depends on amount of sunlight received by the solar panel as well as on the electrical characteristics of the load [5]. With variation in the amount of sunlight, load characteristics that gives the highest power transfer efficiency varies to keep the power transfer at highest efficiency. This load characteristic point is referred to as the maximum power point (MPP). Maximum power point tracking can be obtained by using different methods, they are:

- Perturb and Observe (P&O)
- Incremental Conductance
- Fuzzy logic controller
- Parasitic Capacitance

**Perturb and Observe (P&O) algorithm:**

- The P&O algorithm is a simple and powerful tracking method for MPPT. This algorithm is an iteration based approach to MPPT.
- The P & O algorithm is operated by periodically increasing and decreasing the terminal current or the voltage and then output power obtained is compared with power obtained in previous perturbation cycle.
- If the power increases then one continuous increasing the voltage or current in the same direction. If the power decreases then continue vary the voltage or current in the reverse direction [5].

**Boost converter:**

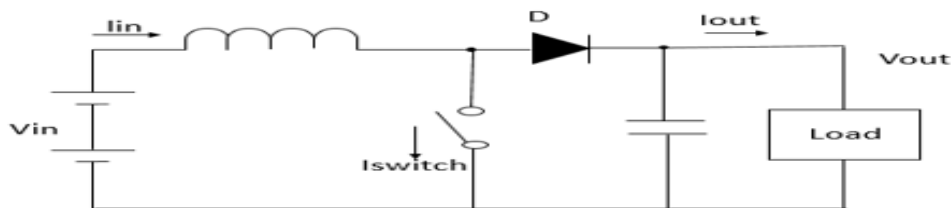


Fig. 4 Equivalent circuit of boost converter

In the boost converter inductor in the input circuit resists sudden changing input current. The inductor stores energy when the switch in open condition and when the switch is closed it discharges the energy.

**III. METHODOLOGY**

**Partial Shading:**

The condition at which efficiency and stability of photovoltaic (PV) system are affected is known as partial shading. Multiple peaks rise in the PV characteristic curve during partial shading conditions. Mismatch losses occurs due to partial shading which can reduce the energy yield of the photovoltaic cell. The presence of shade causes on PV panels causes masks which block all or part of the direct sun radiation, due to this the energy loss will occur on the cell [5]. Due to this absorbed energy that is converted into heat which raises the temperature of the cell and damages it. This

phenomenon is called as the hot spot effect and fortunately, this problem can be solved by using bypass diodes. In the same manner partial shading of a single module in a module series will limit the power of the whole PV array. The effect of shading has been widely used on the PV characteristics [6]. The different patterns are used to design the DC-DC converter. P & O algorithm is used to design the converter. There are four different cases are studied under partial shading conditions which gives the less output also the effect of partial shading on the PV and IV characteristics is also given. For shading patterns different configurations are used such as series, parallel, series-parallel & TCT (total cross tied).

**[1] Series configuration:**

**Case 1:**

In this case the PV11, PV12, PV13, PV21, PV22 & PV23 modules receives the insolation  $200\text{W/m}^2$  respectively. PV31 receives the insolation  $600\text{W/m}^2$ . PV32 receives the insolation  $800\text{W/m}^2$ . And PV33 receives the insolation  $1000\text{W/m}^2$ . The voltage generated by the PV cell increases with the increase in the insolation received by the cells. That is PV cell with insolation with  $1000\text{W/m}^2$  generates more voltage than the cell with insolation of  $800\text{W/m}^2$ . The cell with insolation of  $600\text{W/m}^2$  generates lesser voltage compared to the cell with  $800\text{W/m}^2$ . Finally the least amount of voltage is generated by the PV cell having insolation of  $200\text{W/m}^2$ .

**Case 2:**

In this case the PV11, PV22, & PV33 modules receives the insolation  $200\text{W/m}^2$ . PV12 & PV23 receives the insolation  $600\text{W/m}^2$ . PV21 & PV32 receives the insolation  $800\text{W/m}^2$ . PV13 & PV31 receives the insolation  $1000\text{W/m}^2$ . The voltage generated by the PV cell increases with the increase in the insolation received by the cells. That is PV cell with insolation with  $1000\text{W/m}^2$  generates more voltage than the cell with insolation of  $800\text{W/m}^2$ . The cell with insolation of  $600\text{W/m}^2$  generates lesser voltage compared to the cell with  $800\text{W/m}^2$ . Finally the least amount of voltage is generated by the PV cell having insolation of  $200\text{W/m}^2$ .

**Case 3:**

In this case PV11, PV21 & PV32 modules receives the insolation  $800\text{W/m}^2$ . PV12, PV13 & PV23 receives the insolation  $200\text{W/m}^2$ . PV22 & PV33 receives the insolation  $600\text{W/m}^2$ . And the PV31 receives the insolation  $1000\text{W/m}^2$ . That is PV cell with insolation with  $1000\text{W/m}^2$  generates more voltage than the cell with insolation of  $800\text{W/m}^2$ . The cell with insolation of  $600\text{W/m}^2$  generates lesser voltage compared to the cell with  $800\text{W/m}^2$ . Finally the least amount of voltage is generated by the PV cell having insolation of  $200\text{W/m}^2$ .

**Case 4:**

In this case PV11, PV21 & PV31 receives the insolation  $200\text{W/m}^2$ . PV12, PV22 & PV31 receives the insolation  $600\text{W/m}^2$ . PV13 & PV23 receives the insolation  $800\text{W/m}^2$ . And PV33 receives the insolation  $1000\text{W/m}^2$ .

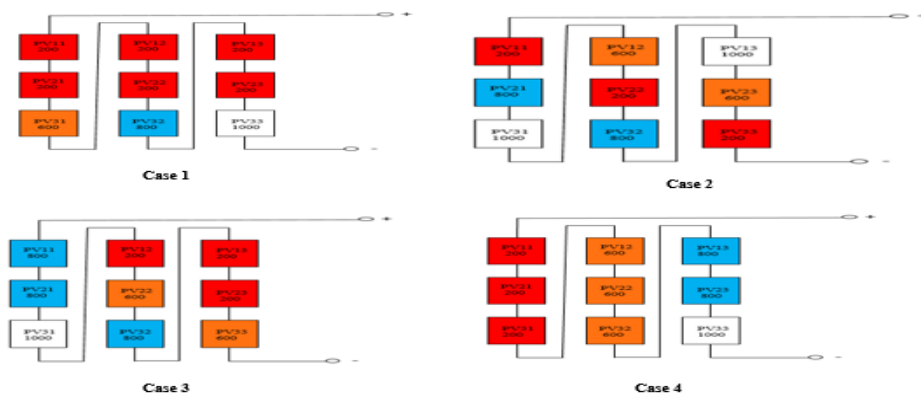


Fig. 5 Different cases for series configuration

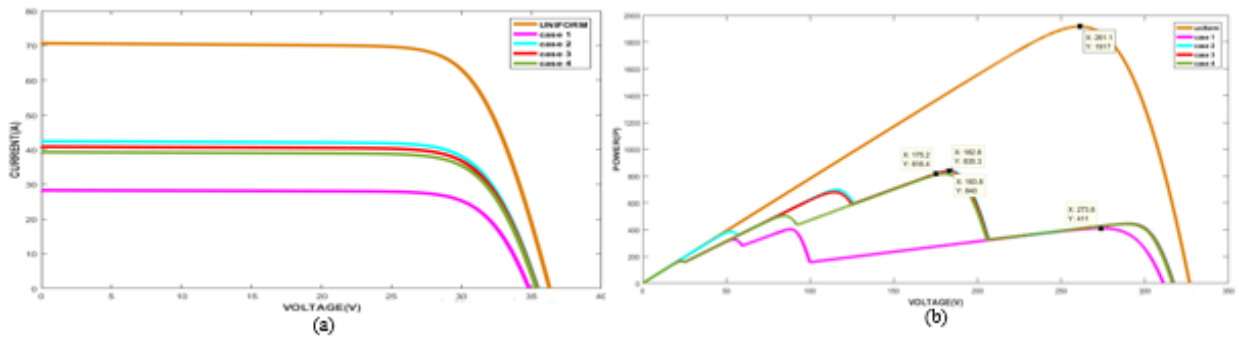


Fig. 6 (a) & (b) IV & PV characteristics of series configuration

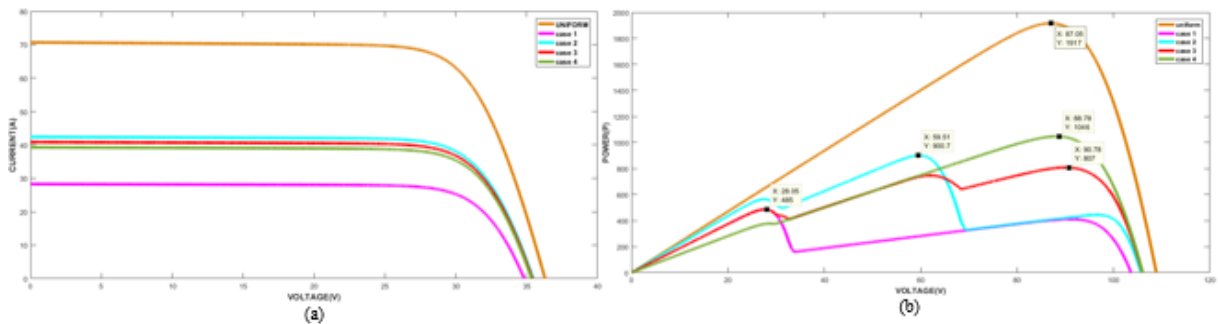


Fig. 7 (a) & (b) IV & PV characteristics of parallel

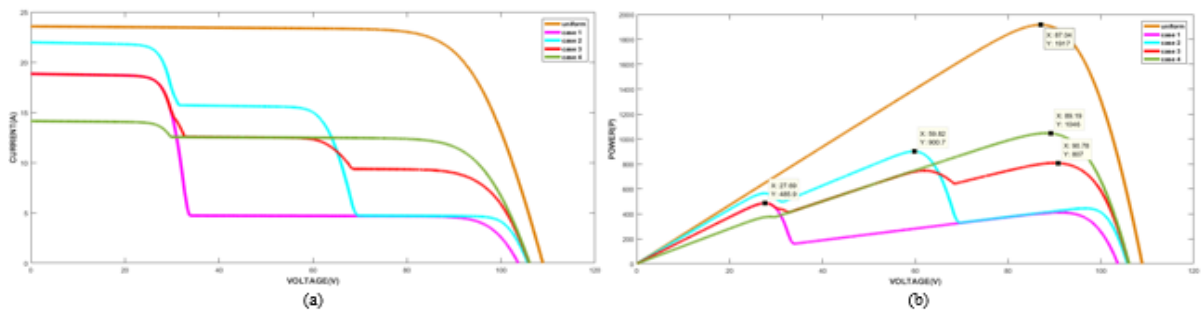


Fig. 8 (a) & (b) IV & PV characteristics of series-parallel

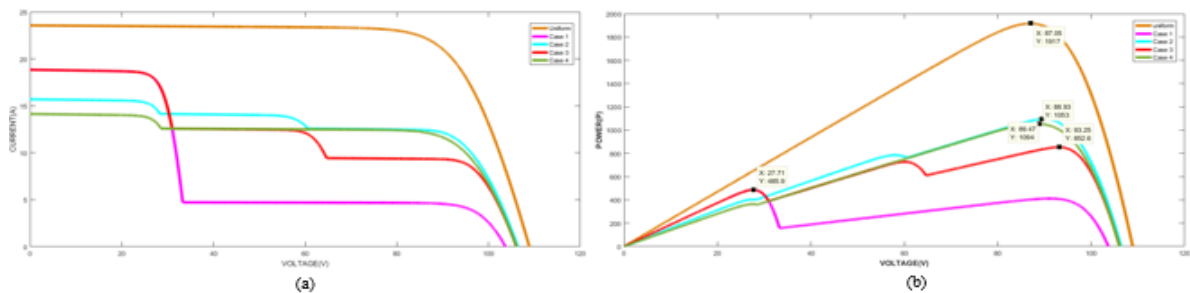


Fig. 9 (a) & (b) IV & PV characteristics of TCT



The effect of partial shading on parallel, series-parallel and TCT is given in below table.

Table 2 Power values of different configurations

| Configurations  | Uniform | Case 1 | Case 2 | Case 3 | Case 4 |
|-----------------|---------|--------|--------|--------|--------|
| Series          | 1917W   | 411W   | 840W   | 835W   | 816.4W |
| Parallel        | 1917W   | 768.6W | 1155W  | 1114W  | 1072W  |
| Series-parallel | 1917W   | 485W   | 900.7W | 807W   | 1046W  |
| TCT             | 1917W   | 485.9W | 1049W  | 852.6W | 1053W  |

**DC-DC converter:**

The DC-DC converter is used to supply a regulated DC output with the given DC input. The PV panel used for this designed purpose is the user defined module. The specifications of this module is given below.

Table 3 Specifications of user-defined PV module

| Characteristics                          | Specifications |
|--|----------------|
| Maximum power (W)                        | 0.75W          |
| Open circuit voltage (Voc)               | 3.6V           |
| Voltage at maximum power point Vmp (V)   | 3V             |
| Temperature coefficient of Voc (%/deg.c) | -0.36099°C     |
| Cells per module                         | 1              |
| Short circuit current Isc                | 0.297A         |
| Current at maximum power point (Imp)     | 0.25A          |
| Temperature coefficient of Isc (%/deg.c) | 0.102°C        |

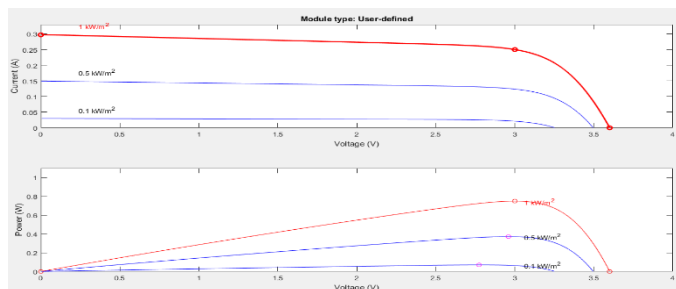


Fig. 10 IV & PV characteristics of user-defined PV module

IV and PV characteristics of user defined module is given in above figure. This characteristics include the 1000W/m<sup>2</sup>, 500W/m<sup>2</sup>& 100W/m<sup>2</sup> insolation respectively.

**Boost converter design:**

The boost converter has been designed for minimum worst input voltage (6.7V) and it can be seen that the designed satisfies the required output voltage by the load. The switching frequency is 10 KHz. LED of 12V with power consumption of 3W is used as the load for the design.

Table 4 Converter design values

| Input voltage(V) | Switching frequency(F <sub>s</sub> ) | Load(L) | Power(W) | Duty cycle(D) | Ripple factor(ΔI) | Inductor(L) | Capacitor(C) |
|------------------|--------------------------------------|---------|----------|---------------|-------------------|-------------|--------------|
| 6.7 V            | 10 KHz                               | 12 V    | 3 W      | 0.4416        | 0.0125 A          | 0.02366 H   | 9.2013e-5 F  |

IV. EXPERIMENTAL RESULTS

**Under uniform condition:**

In this condition all the PV cells receives the equal insolation 1000W/m<sup>2</sup>. Due to the standard insolation all cells receives the equal energy.

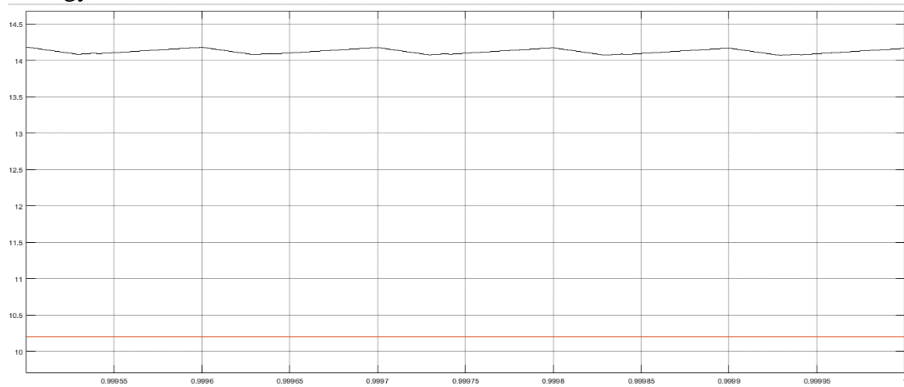


Fig.11 Input and output voltage under uniform condition

The above graph represents the output voltage that is 14.21V. The desired load voltage is 12V & in this case the voltage is greater than the load voltage so that the solar LED bulb will glow. Also the graph represents the output current that is 0.2961A. The desired load current is 0.25A.

**Case 1:**

In case1 PV11 to PV23 receives the insolation 200W/m<sup>2</sup>. PV31 receives the insolation 600W/m<sup>2</sup>. And PV32 & PV33 receives the insolation 800W/m<sup>2</sup>& 1000W/m<sup>2</sup> respectively.

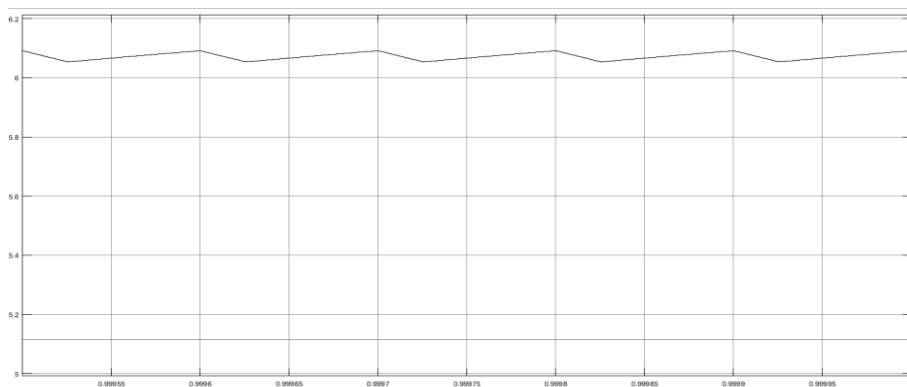


Fig.12 Input and output voltage of case 1

The above graph represents the output voltage that is 6.091V. The case1 is not satisfying the load requirement. The desired load voltage is 12V & in this condition the voltage is less than the load voltage so that the solar LED bulb will not glow. Also graph represents the output current that is 0.1269A. The desired load current is 0.25A. The case1 is not satisfying the load current requirement so that the solar LED bulb will not glow.

**Case 2:**

In case2 PV11, PV22 & PV33 receives the insolation 200W/m<sup>2</sup>. PV12 & PV23 receives the insolation 600W/m<sup>2</sup>. PV21 & PV32 receives the insolation 800W/m<sup>2</sup>. PV13 & PV31 receives the insolation 1000W/m<sup>2</sup> respectively.

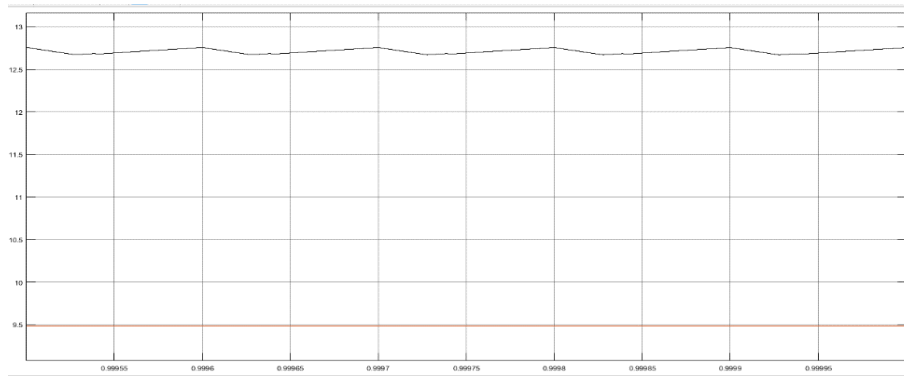


Fig.13 Input and output voltage of case 2

The above graph represents the output voltage that is 12.71V. The case2 is satisfying the load requirement. The desired load voltage is 12V & in this case the voltage is greater than the load voltage so that the solar LED bulb will glow. Also graph represents the output current that is 0.2647A. The desired load current is 0.25A. The case2 is satisfying the load current requirement so that the solar LED bulb will glow.

**Case 3:**

In case3 PV11, PV21 & PV32 receives the insolation 800W/m<sup>2</sup>. PV12, PV13 & PV23 receives the insolation 200W/m<sup>2</sup>. PV22 & PV33 receives the insolation 600W/m<sup>2</sup>. And PV31 receives the insolation 1000W/m<sup>2</sup>.

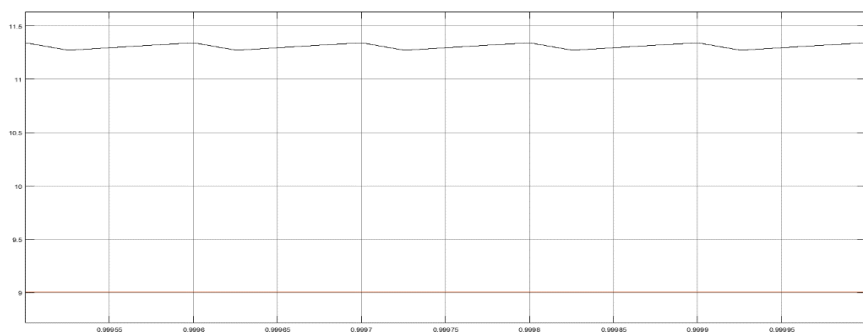


Fig. 14 Input and output voltage of case 3

The above graph represents the output voltage that is 11.34V. The case3 is not satisfying the load requirement. The desired load voltage is 12V & in this condition the voltage is less than the load voltage so that the solar LED bulb will not glow. The above graph represents the output current that is 0.2363A. The desired load current is 0.25A. The case3 is not satisfying the load current requirement so that the solar LED bulb will not glow.

**Case 4:**

In case4 PV11, PV21 & PV31 receives the insolation 200W/m<sup>2</sup>. PV12, PV22 & PV32 receives the insolation 600W/m<sup>2</sup>. PV13 & PV23 receives the insolation 800W/m<sup>2</sup>. PV33 receives the insolation 1000W/m<sup>2</sup>.

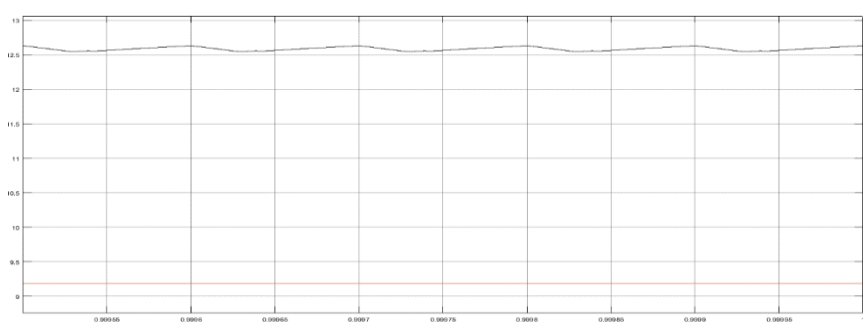


Fig.15 Input and output voltage of case 4



The above graph represents the output voltage that is 12.63V. The case4 is satisfying the load requirement. The desired load voltage is 12V & in this case the voltage is greater than the load voltage so that the solar LED bulb will glow. Also graph represents the output current that is 0.2632A. The desired load current is 0.25A. The case4 is satisfying the load current requirement so that the solar LED bulb will glow.

## V. CONCLUSION

In this paper boost converter has been designed in MATLAB/SIMULINK software by using P & O algorithm. Various PV configurations such as Series, Parallel, Series-Parallel and TCT are studied for  $3 \times 3$  matrix for uniform irradiance and partial shading conditions. Appropriate PV configuration can be selected as per the voltage and current requirement of the load.

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