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# SIMULATION OF EXACT MAXIMUM POWER POINT TRACKING OF PARTIALLY SHADED PV STRING USING CURRENT EQUALIZATION THEORY

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## ABSTRACT

Maximum power point tracking (MPPT) algorithms are among the most important research topic related to photovoltaic (PV) system. Conventional MPPT method give effective results and easy to perform under uniform irradiation condition. However, as more than one local maxima is formed under partial shaded conditions so these methods are not absolutely successful. So, output power becomes lower than the absolute maximum. Conventional MPPT is designed to track the MPP will be trapped at the local MPP. Therefore, one of the challenges is to continuously track the absolute MPP while the environmental factors such as solar irradiation, PV temperature and partial shaded condition are rapidly changing. Also, in these partially shaded conditions, series connection of PV modules gives lowest current in PV string. This reduces the output power of PV string. To achieve maximum output power , a converter is connected in parallel with each PV module provides the extra (equalization) current in parallel with the shaded module to make the string current equal to the maximum string current. The equalization current supports the PV module to have its voltage regulated at a value that corresponds to its MPP voltage. This technique is known as DMPPT (Distributed MPPT) method.

**KEYWORDS**: MPPT, current compensation, DMPPT, partial shading, photovoltaic module.

## INTRODUCTION

The renewable energy has increased much attraction these days because it can be recycled. The solar energy can be transform in to electrical energy, more effective than other renewable sources. However, compare to hydro, wind, geothermal, the solar energy are not widely used worldwide, due to high initial cost of solar cell. So, it is essential to recover as much energy as possible [11]. Individually from the quickly decreasing reserves of fossil fuels in the world, another major factor working against fossil fuels is the pollution related with their combustion. Contrastingly, renewable energy sources are well-known to be much cleaner and produce energy without the harmful effects of pollution unlike their conventional equivalents [9].

The tapping of solar energy owes its origins to the British astronomer John Herschel who notably used a solar thermal collector box to cook food during an excursion to Africa. Solar energy can be utilized in two major ways. First, the captured heat can be used as solar thermal energy, with applications in space heating. Another alternative is the transformation of incident solar radiation to electrical energy, which is the most usable form of energy. This can be achieved with the help of solar photovoltaic cells or with concentrating solar power plants [9].

However, the generation of electric power with the photovoltaic (PV) array is a method of “direct energy conversion” then it does not include intermediate stages like some of the other popular non-conventional energy sources. The voltage and current generated by a single solar cell is of no practical meaning since it is very small. Hence PV cells are attached in series to form a module. These modules are connected in series and parallel to form a PV array. In terrestrial applications, there is a possibility of partial shading of the PV array due to shadows of buildings, trees and clouds. The non-shaded portions of a PV array will be illuminated more than the shaded regions of the array. The reducing of the intensity of solar illumination on the shaded PV cells causes a decrease in power generation from these cells. Even a small shaded portion can cause a considerable reduction in the overall output power of the array. Whereas the short circuit current, reduces considerably during shading, the open circuit voltage does not change much.

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### A) Principle of Solar Cell

Solar cells comprise of a p-n junction fabricated in a thin layer of semiconductor. The semiconductor electrons can be placed in either the valence band or conduction band. Initially, all the electrons in the semiconductor fill up the valence band but when sunlight hits the semiconductor, some electrons gain enough energy to move from the valence band to the conduction band. The electrons in the conduction band then begin to move freely producing electricity. The electron leaving the valence band leaves a positively charged hole after and now that the valence band is no longer full, it aids the current flow. Most solar cells are doped to reduce the energy necessary for the electron to move from the valence band to the conduction band [10].

The amount of energy from sunlight, called photons, that is absorbed by a solar cell determines its efficiency. A photon can be reflected, absorbed or it can pass through a semiconductor. Since only the photons that are absorbed contribute to the electrical energy, it is significant to reduce the percentage of photons that pass through and that are reflected. An anti-reflective covering is usually applied to the surface of the solar cell to reduction the number of photons that are reflected. This reduces the percentage of photons that are reflected but some photons are still able to pass right through the semiconductor material [10].

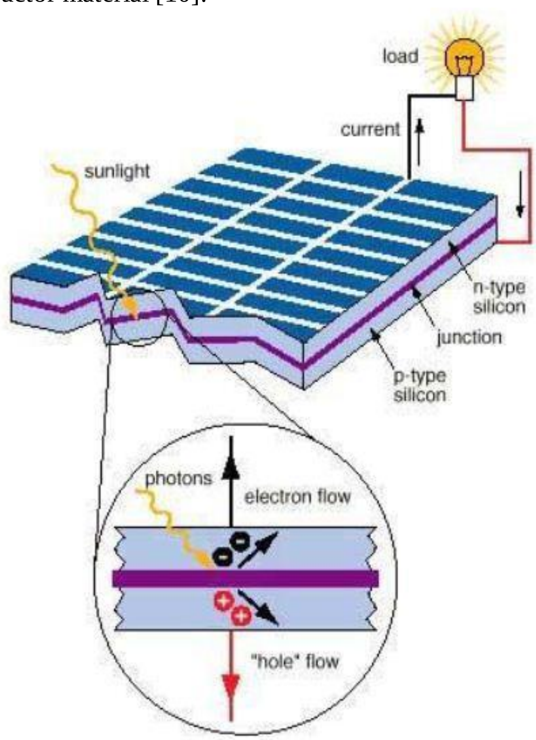


*Fig. 1: Principle of Solar Cell*

### B) Equivalent circuit of Solar cell

Fig. 2 shows the simplest equivalent circuit of a solar cell, which is a current source in parallel with a diode. The output of the current source is directly proportional to the light falling on the cell. The diode determines the I-V characteristics of the cell [9].

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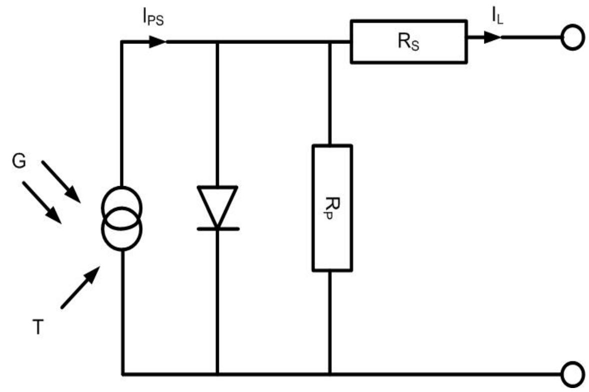


*Fig. 2: circuit of solar cell*

The equations which describe the I-V characteristics of the cell are
The output current from the photovoltaic array is

$I_L = I_{PS} - I_d$ (1)

$I_d = I_o (e^{qVd/kT} - 1)$ (2)

Where, Io is the reverse saturation current of the diode and its depends on temperature,
$I_{PS}$ is the photo current and it's also depends on temperature,
$I_L$ is the load current,
q is the electron charge ($1.6 * 10^{-19}$C),
Vd is the voltage across the diode,
k is Boltzmann constant ($1.38 * 10^{-23}$ $m^2Kg/s^2K$),
G is the irradiance and Ips photo current depends on it and
T is the junction temperature in Kelvin (K)
From above equation

$I = I^{PS} - I_o (e^{qVd/kT} - 1)$ (3)

Using suitable approximations,

$I = I_{PS} - I_o (e^{q((V+ILRs)/nkT)} - 1)$ (4)

Where, V is the PV cell voltage,
$R_S$ is the series resistance, which gives more accurate shape between the maximum power point and the open circuit voltage,
$R_P$ is the shunt resistance in parallel with the diode and
n is the diode ideality factor [9].

### C) Solar Characteristics

The I-V characteristics of a typical solar cell are as shown in the Fig. 3. When the voltage and the current characteristics are multiplied we get the P-V characteristics as shown in Fig. 4. The point indicated as MPP is the point at which the panel power output is maximum [9].

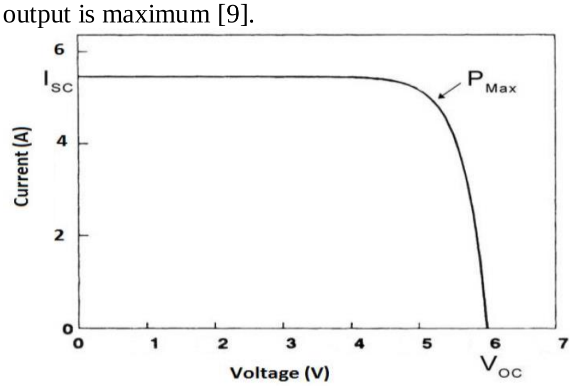


*Fig. 3: I-V Characteristics*

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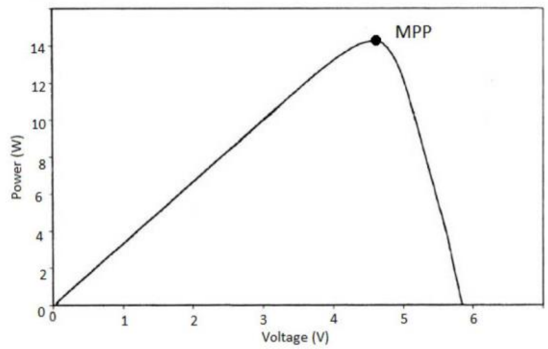


*Fig. 4: P-V Characteristics*

## MPPT TECHNIQUE FOR PARTIAL SHADING CONDITION

The attaching of solar energy using PV modules comes with its own problems that arise from the change in insolation conditions. These changes in insolation conditions severely affect the efficiency and output power of the PV modules. A great deal of research has been done to improve the efficiency of the PV modules. A number of methods of how to track the maximum power point of a PV module have been proposed [10].

A MPPT is used to extract maximum power from the solar PV module. And this power transfer to the load. Fig. 6 shows the basic block diagram of MPPT. A DC-DC converter (step up/step down) is used to transfer maximum power from solar PV module to load. A DC-DC converter acts as interface between the load and solar PV module. By changing the duty cycle the load impedance as seen by the source is varied and matched at the peak point of the peak power with the source so as to transfer the maximum power [5].

There are various methods to track maximum power of PV module, which is described below:

i. Perturb and Observe (P&O)

ii. Incremental Conductance (IC)

iii. Fuzzy Logic Control

iv. Ripple correlation control

v. Peak current control

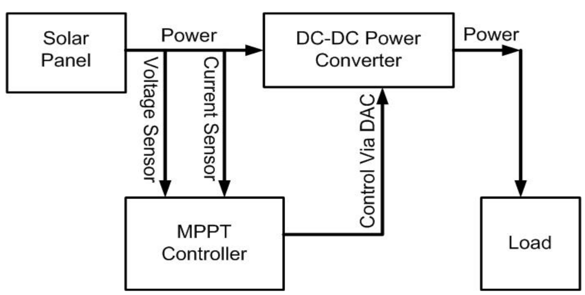


*Fig. 5: Basic Block Diagram of MPPT*

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**(i) Perturb and Observe (P&O)**

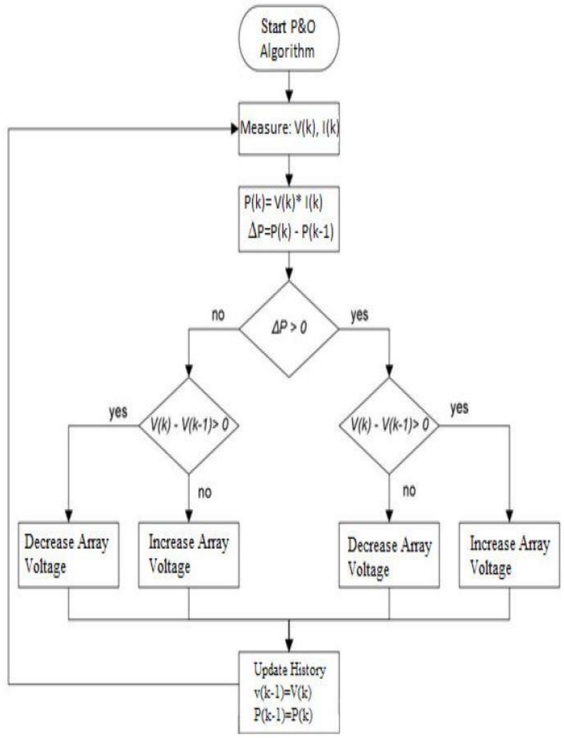


***Fig. 6: Flow chart of P&O method***

In this algorithm a slight perturbation is introduce. This perturbation causes the power of the solar module changes. If the power increases due to the perturbation then the perturbation is continued in that direction. After the peak power is reached the power at the next instant decreases and hence after that the perturbation reverses [6].

When the steady state is reached the algorithm oscillates around the peak point. In order to keep the power variation small the perturbation size is kept very small. A PI controller then acts moving the operating point of the module to that particular voltage level. It is observed that, there some power loss due to this perturbation also the fails to track the power under fast varying atmospheric conditions. But still this algorithm is very popular, simple and easy to implement [6].

**(ii) Incremental Conductance**

The disadvantage of the perturb and observe method to track the peak power under fast varying atmospheric condition is overcome by IC method. The IC method can determine that the MPPT has reached the MPP and stop perturbing the operating point. If this condition is not met, the direction in which the MPPT operating point must be perturbed can be calculated using the relationship between dI/dV and –I/V. This relationship is derived from the fact that dP/dV is negative when the MPPT is to the right of the MPP and positive when it is to the left of the MPP [6].

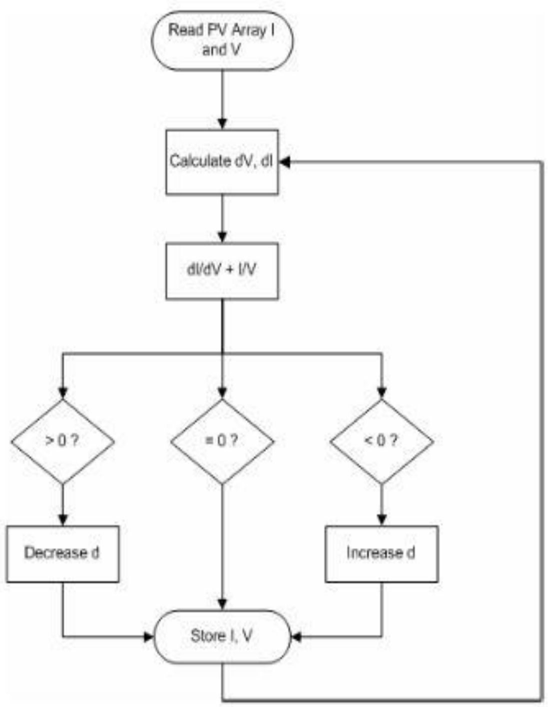


*Fig. 7: Flow chart of IC method*

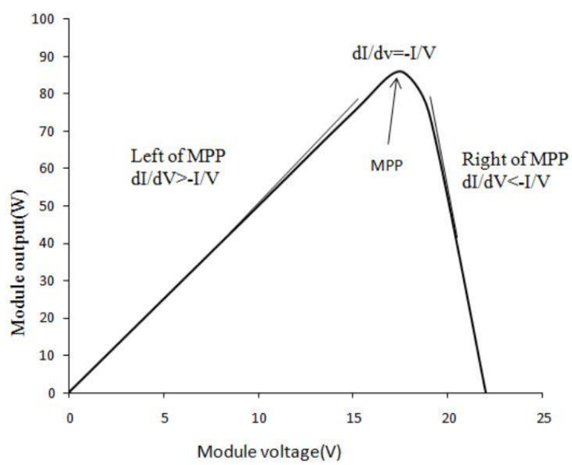


*Fig. 8: Graph Power versus Voltage for IC Algorithm*

## EXTRACTION OF MAXIMUM POWER DURING PARTIAL SHADING CONDITION

**A) Use of bypass diodes in parallel with the PV modules**

With bypass diodes, shaded PV modules are completely bypassed such that the un-shaded modules in the string can continue to provide power. This strategy increases the overall power yield but leads to:

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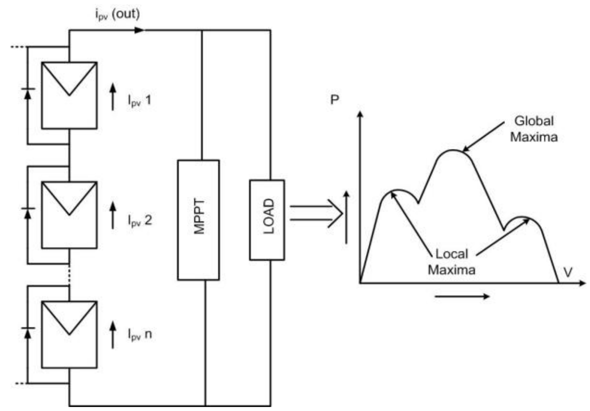


*Fig. 9: PV module with bypass Diode*

(i) Complete loss of power from partially shaded module and
(ii) Appearance of multiple peaks in the power-voltage characteristics because of which MPPT becomes complex as shown in Fig. 4. Though, techniques for tracking the 'global' Maximum Power Point (GMPP) have been proposed for such conditions, they only provide approximate solutions [3].

**B) Distributed MPPT**

Mismatch in the characteristics of PV modules due to non-uniform solar radiation, temperature and manufacturing inequalities leads to a significant power loss in PV systems. When subjected to partial shading conditions, various PV modules of an n module string tend to generate different currents (I PVn). But PV modules connected in series must carry the same current, which should correspond to the maximum current (Istr-max) generated by any PV module of the string [3].

To ensure this, a DC-DC converter is connected in parallel to each PV module. The DC-DC converter derives its input power from the capacitor connected at the overall output of the PV array. For an n module string, the n str-max the converter provides the extra (equalization) current equal to (I) to make the string current equal to I str-max. The module voltage is appropriately regulated to a value corresponding to its MPP (Maximum Power Point) voltage with the DC-DC converter while providing the necessary equalization current as shown in Fig. 10. This scheme has the following advantages:

(iii) It does not result in the formation of multiple peaks (as with the use of bypass diode) in the power-voltage characteristics of the overall array output, thus enabling the conventional MPPT algorithms (e.g. hill climbing method) to work satisfactorily.
(iv) More efficient because each DC-DC converter supplies only the balance (equalization) current, thereby resulting in negligible losses [4].

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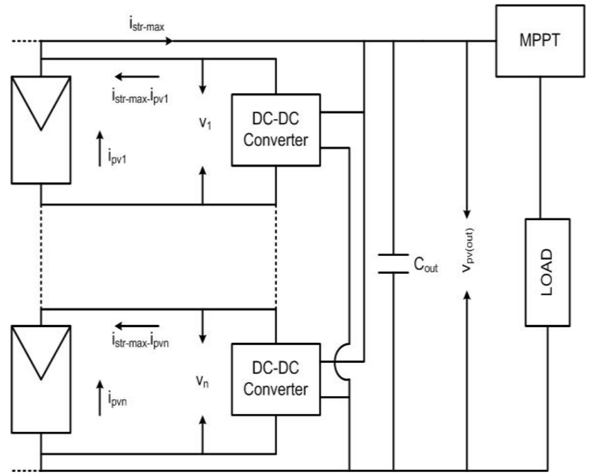


*Fig. 10: Distributed MPPT*

**C) Flyback converter as DC-DC converter**

Fig. 11 shows the typical diagram of flyback converter. As may be seen from the circuit diagram of Fig. 11, when switch 'S' is on, the primary winding of the transformer gets connected to the input supply with its dotted end connected to the positive side. At this time the diode 'D' connected in series with the secondary winding gets reverse biased due to the induced voltage in the secondary (dotted end potential being higher). Thus with the turning on of switch 'S', primary winding is able to carry current but current in the secondary winding is blocked due to the reverse biased diode [14].

Mode-1: The flux established in the transformer core and linking the windings is entirely due to the primary winding current. This mode of circuit has been described here as Mode-1 of circuit operation. Fig. 12 shows (in bold line) the current carrying part of the circuit and Fig. 13 shows the circuit that is functionally equivalent to the fly-back circuit during mode-1. In the equivalent circuit shown, the conducting switch or diode is taken as a shorted switch and the device that is not conducting is taken as an open switch. This representation of switch is in line with our assumption where the switches and diodes are assumed to have ideal nature, having zero voltage drops during conduction and zero leakage current during off state [14].

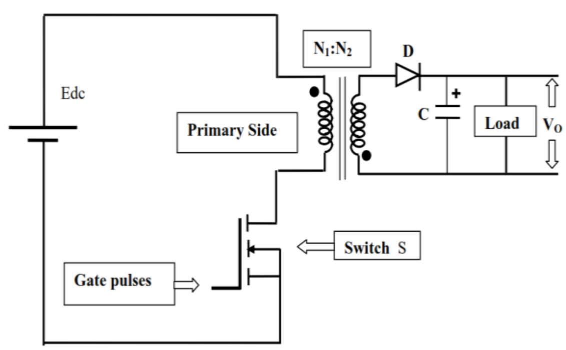


*Fig. 11: Flyback Converter*

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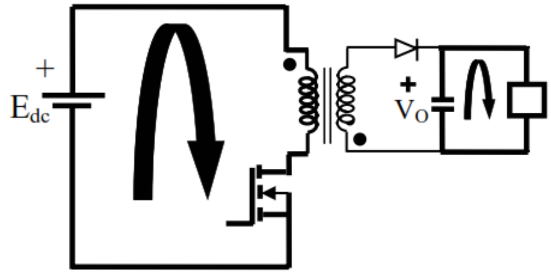


*Fig. 12: Current path during Mode-1 of circuit operation*

Mode-2: Mode-2 of circuit operation starts when switch ‘S’ is turned off after conducting for some time. The primary winding current path is broken and according to laws of magnetic induction, the voltage polarities across the windings reverse. Reversal of voltage polarities makes the diode in the secondary circuit forward biased. Fig. 14 shows the current path (in bold line) during mode-2 of circuit operation while Fig. 15 shows the functional equivalent of the circuit during this mode [14].

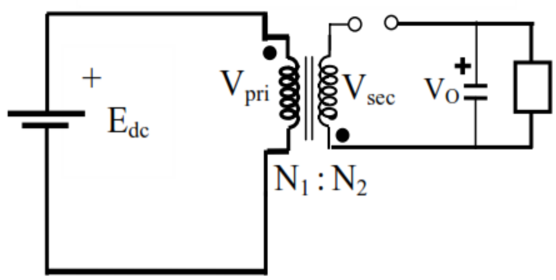


*Fig. 13: Equivalent circuit in Mode-1*

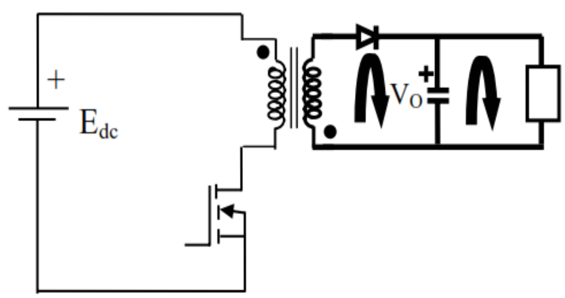


*Fig. 14: Current path during Mode-2 of circuit operation*

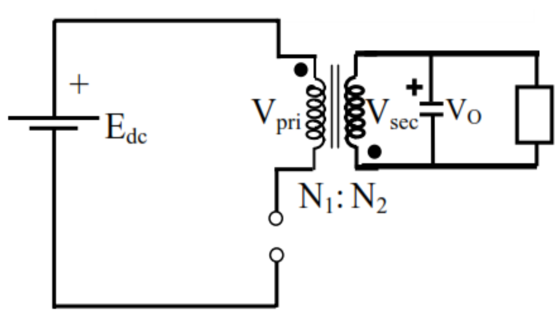


*Fig. 15: Equivalent circuit in Mode-2*

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Fig. 16 shows the waveforms of flyback converter. In the figure, first waveform shows the primary winding current. It increases when switch on and decreases when switch off. Second waveform shows the secondary winding current. It increases when switch off and decreases when switch on. Third waveform shows the voltage across primary winding. It is positive when switch on and negative when switch off. At last fourth waveform shows the output voltage which is constant [13].

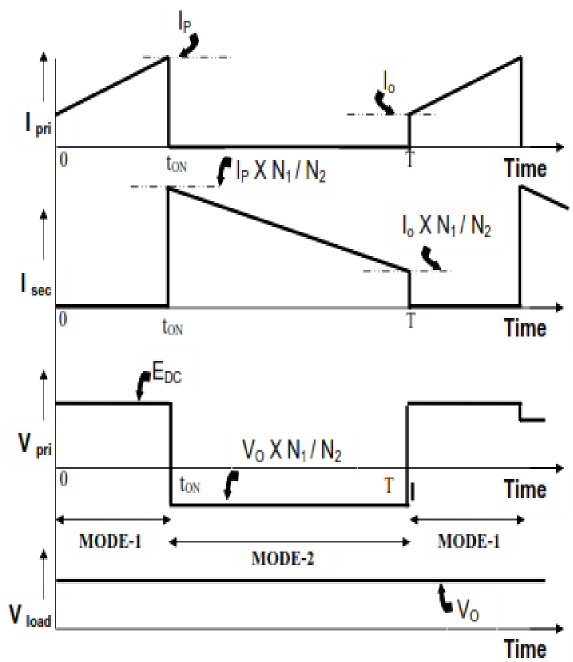


*Fig. 16: Fly-back waveforms*

## SIMULATION AND RESULT

*Table 1. Specification of Solarex MSX 60 at 250C*

| | |
|---|---|
| Open circuit voltage | 21 (V) |
| Short circuit current | 3.7 (A) |
| Voltage at maximum power | 17 (V) |
| Current at maximum power | 3.5 (A) |
| Maximum power | 60 (W) |

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### A) Simulation of PV model

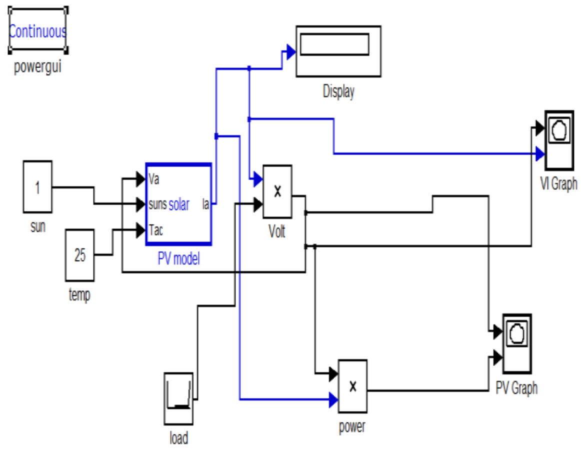


*Fig. 17: Simulation of PV model*

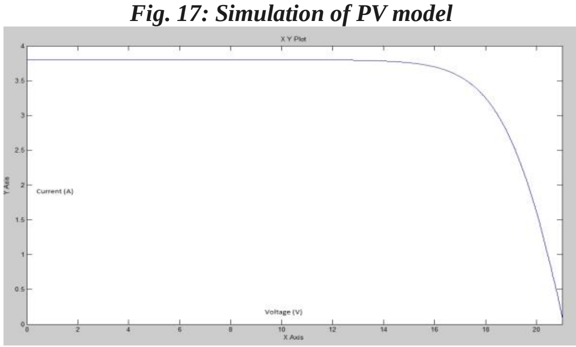


*Fig. 18: I-V curve of PV model*

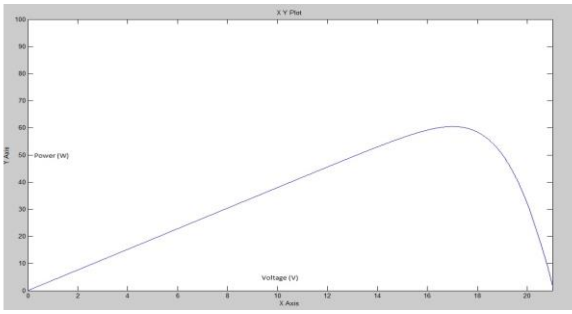


*Fig. 19: P-V curve of PV model*

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**B) Simulation result with different irradiance**

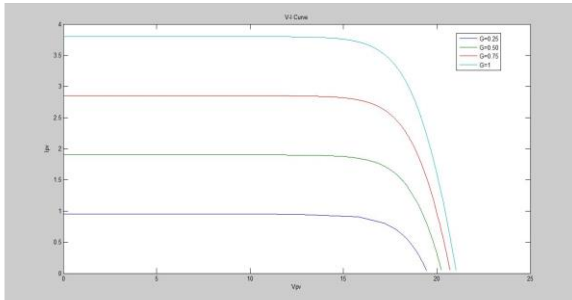


*Fig. 20: I-V curve of PV model with different irradiance*

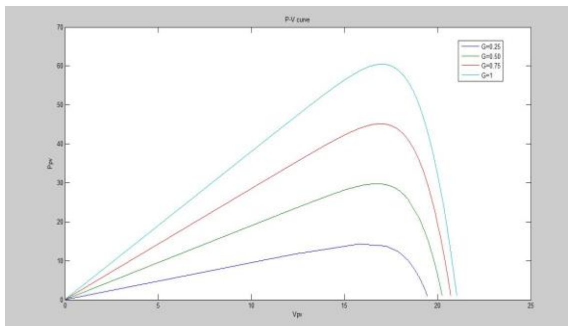


*Fig. 21: P-V curve of PV model with different irradiance*

*Table 2. P-V Power and P-V Current at different irradiance*

| Irradiance Level | Power (Watt) | Current (Amp) |
|---|---|---|
| 1 | 60 | 3.8 |
| 0.75 | 45 | 2.85 |
| 0.5 | 30 | 1.9 |
| 0.25 | 15 | 0.95 |

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**C) Simulation of PV with P&O MPPT method**

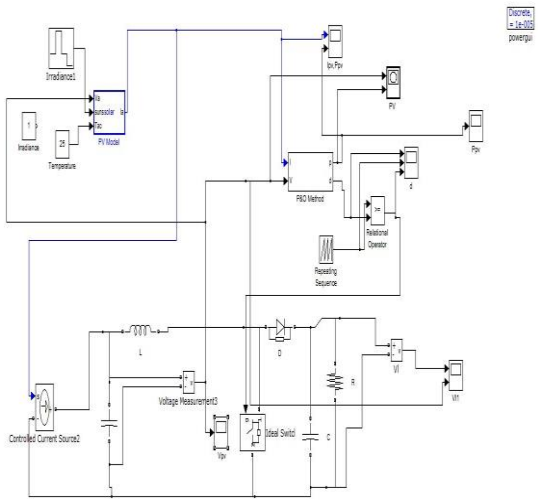


*Fig. 22: P&O MPPT method for varying Irradiation*

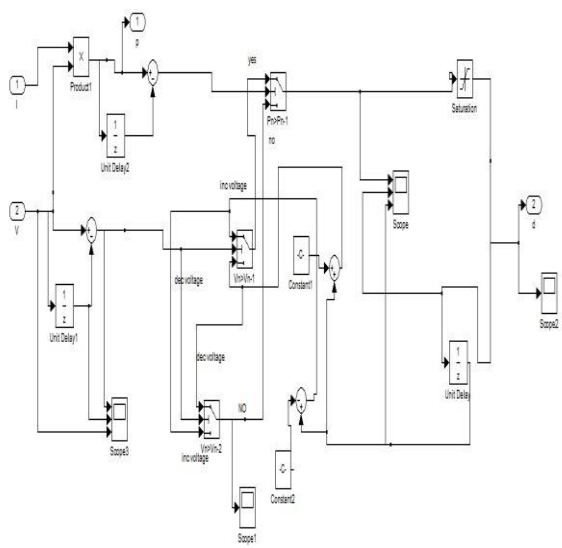


*Fig. 23: Sub system of P&O method*

**Series connected PV cell with bypass diode**

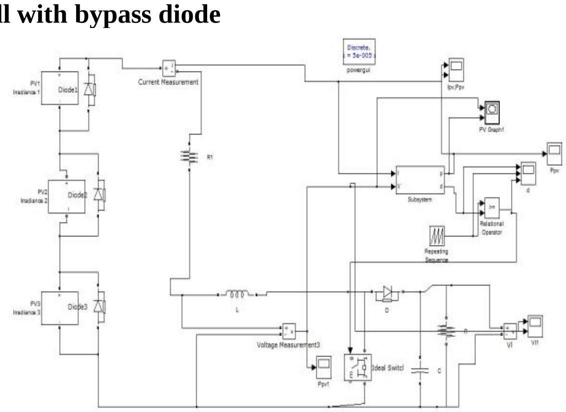


*Fig. 24: Simulation of series connected PV cell*

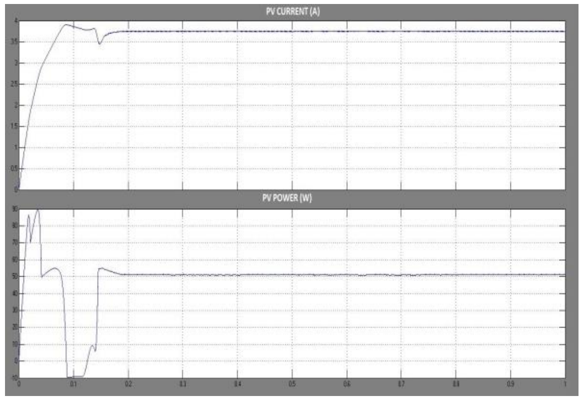


*Fig. 25: Output current and power of series connected PV cell*

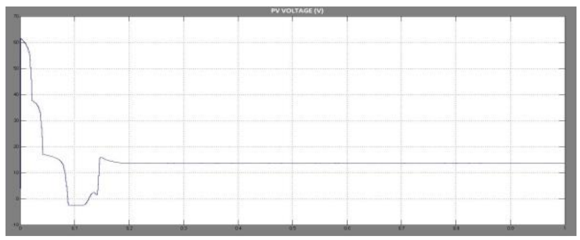


*Fig. 26: Output voltage of series connected PV cell*

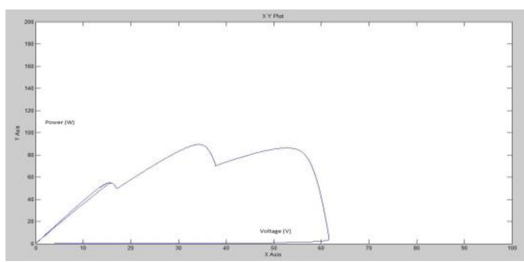


*Fig. 27: Power V/S Voltage graph*

**Flyback converter as DC-DC converter**

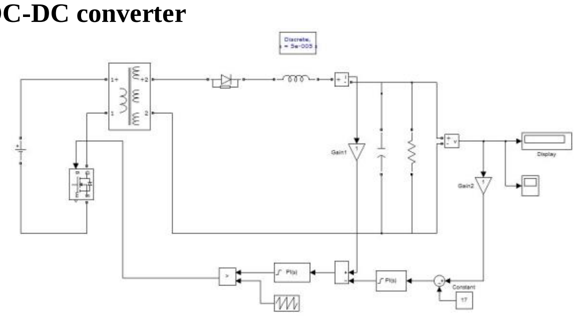


*Fig. 28: Sub of Flyback converter as DC-DC converter*

**D) Distributed MPPT Simulation**

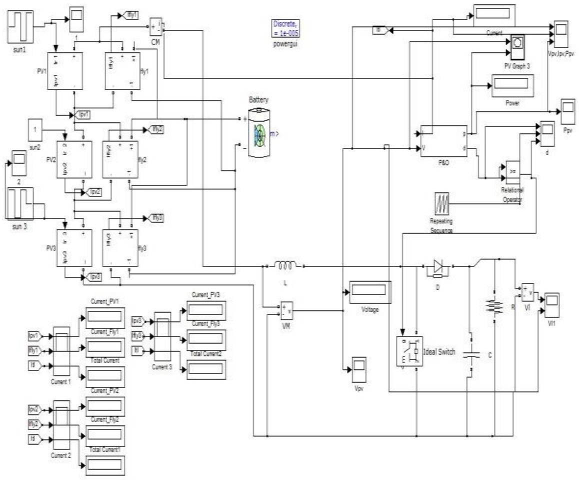

*Fig. 29: DMPPT model with three PV modules*

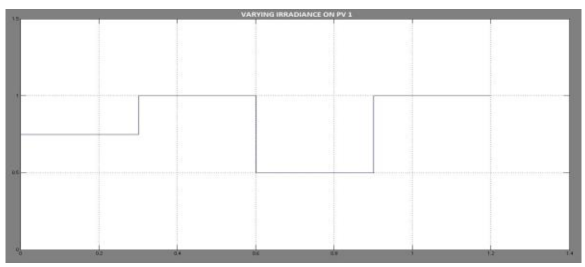


*Fig. 30: Varying irradiance on module 1*

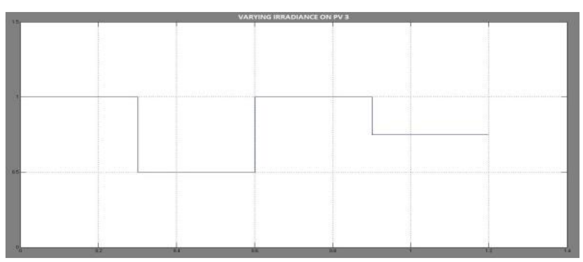


*Fig. 31: Varying irradiance on module 3*

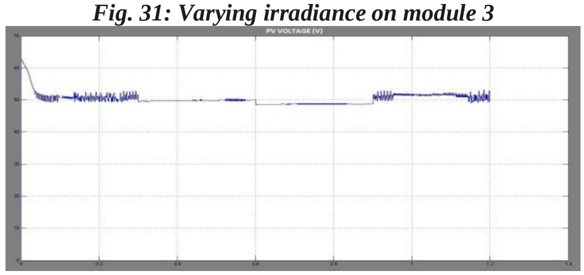


*Fig. 32: Total Voltage*

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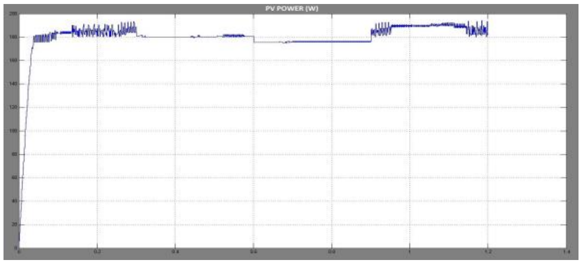


*Fig. 33: Total Power*

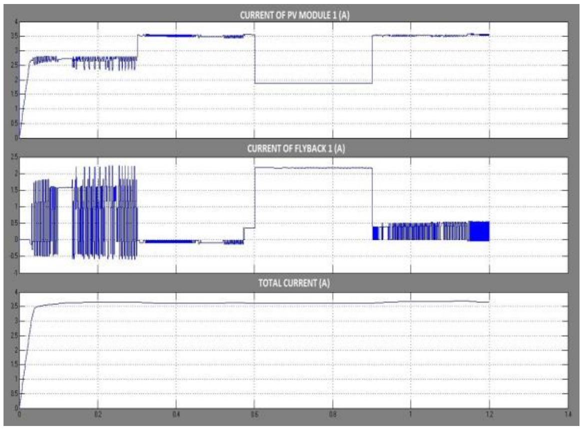


*Fig. 34: PV module 1, Flyback 1 and Total Current*

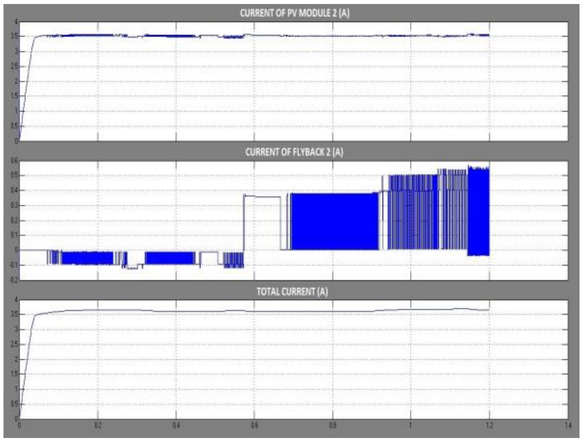


*Fig. 35: PV module 2, Flyback 2 and Total Current*

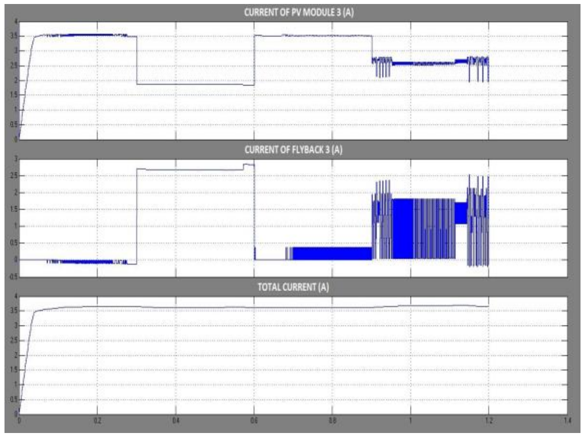


*Fig. 36: PV module 3, Flyback 3 and Total Current*

## CONCLUSION

From the simulation, it can be concluded, the disadvantage of bypass diode is overcome by the use of DMPPT technique in partially shading condition. In this technique in partial shading condition, PV modules which are under shadow, is fed by the flyback converter. Flyback converter feeds balance current in to those shaded modules. The resultant power does not reduce and it does not result in the formation of multiple-peaks. So, from the simulation it can be concluded that under partially shading condition, DMPPT gives better output and work efficiently.

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