# Photovoltaic Modeling and Analysis under Partial Shading Condition

[1]Dhavalgiri A Goswami, [2]Prof V.N.Modi,
[1] PG Student, L.D. College of Engineering, Ahmedabad, India,
[2] Professor, Electrical Engineering, Gujarat Technological University, Ahmedabad, India

**Abstract :** This paper, the study of PV system is carried out and the effect partial shading is reduction the energy output of PV system under partial shading conditions, A unshaded PV array exhibits only one peak in Power –Voltage characteristics , but in the case of partial shading condition the PV array exhibits multiple peaks in the Power Voltage characteristics, out of which one is the global peaks and the rest are the local peaks, the existing (conventional) MPPT techniques fails to extract the maximum power from the system because of the inability to distinguish between local peak and global peak. To validate a 120W PV system has been considered and the simulation results obtained by using MATLAB / SIMULINK.

**Index Terms - PV module, Partial shading, one diode model, Local maxima, Global maxima**

## I. Introduction

Nowadays solar energy is the world's fastest growing renewable energy source for Electricity generation. Ministry of New and Renewable Energy of government of India has made a target of 100GW to increase its capacity of electricity production using solar energy. Solar energy has been well recognized as environmentally friendly, socially beneficial and economically competitive for electricity production. As the solar power technologies evolve from one to another breakthrough, so the solar power plants are increasing its penetration in the power system in continuously and rapidly. Modeling of PV cell involves the valuation of the I–V and P–V characteristics curves to match the real cell under various environmental conditions. The most popular method is to utilize the electrical equivalent circuit, which is primarily based on single-diode model. It comprises of a linear independent current source in parallel to a diode [1–4]. The model only requires three parameters to completely characterize the I–V curve, namely short-circuit current (Isc), open circuit voltage (Voc) and diode ideality factor (a). A development of this model is done by the inclusion of one series resistance, Rs [5–10]. In literature, it is popularly known as the Rs-model. Due to its simplicity and computational efficiency, the Rs is by far the most widely used model in PV system simulation [6]. However it exhibits serious deficiencies when subjected to temperature variations; its accuracy is known to deteriorate at high temperature. Further extension of the Rs-model, called as the Rp-model, which includes an additional shunt resistance Rp was introduced [11–15].

### 1. Modified equivalent circuit for a solar cell

An ideal solar cell can be considered as a current source wherein the current produced by the solar cell is proportional to the solar irradiance intensity falling on cell. Electrical circuit representing a solar cell is shown in figure 1The optical loss is represented by the current source itself, where the photo generated current Iirr is proportional to the irradiance input. The recombination losses are represented by diode connected anti parallel to the current source. There are ohmic losses in the cell occur due to the series and shunt resistance denoted by RS and RP respectively. As the name suggests, the series resistance is due to the solar cell in the path of current flow, therefore, RS is shown in current path and the shunt resistance is referred as the leakage path of current in a solar cell and, therefore, it is represented in parallel with current source.

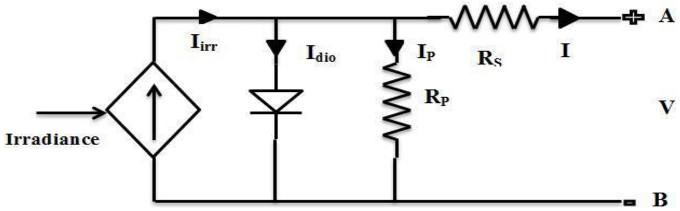


Fig. 1 Modified equivalent circuit for a solar cell

### 1.1 Current-Voltage Relationship for a Single Solar Cell

According to Kirchhoff's current law,

$$I = I_{irr} - I_{dio} - I_p$$

Where, Iirr is the photo generated current or irradiance current, which is generated when sunlight strikes on cell. Iirr varies linearly with solar irradiance for a certain cell temperature. Current flowing through the anti-parallel diode is represented by Idio, and this component of current induces the non-linear characteristics of the solar cell. IP is shunt current flow through shunt resistor RP branch; it is also called as leakage current. Substituting relevant expressions for Idio and IP, we get,

$$I = I_{irr} - I_0\left[e^{\left(\frac{q(V+IR_S)}{nkT}\right)} - 1\right] - \frac{V + IR_s}{R_P}$$

where q is the electronic charge (q =1.602 × $10^{-19}$ C), k is the Boltzmann constant (k =1.3806503 × $10^{-23}$ J/K), n is the ideality factor or the ideal constant of the diode, T is the temperature of the cell, I0 is the diode saturation current or cell reverse saturation current

**1.2 Current-Voltage Relationship For A Pv Module**

A PV module is represented by a number of solar cells connected in series. The number of solar cells connected in series for one module is represented by NS . The output current IM and output voltage VM of the module (when NS solar cells are connected in series to build up a module) have the following relationship,

$$I_M = I_{irr} - I_0\left[e^{\left(\frac{q(V_M+I_MN_SR_S)}{N_SnkT}\right)} - 1\right] - \frac{V_M + I_MN_sR_s}{N_sR_P}$$

This equation can be expanded to any number of cells in series (NS), and thus is not restricted to one module. If there are NM Number of modules connected in series, and there are NC cells in each, then $N_s = N_MN_C$

**1.3 Current-Voltage Relationship for a Photovoltaic Array**

In an array, there are many PV modules are connected in series and parallel, It is important to consider the effects of these connections We began with the current-voltage relationship for a single solar cell, connected the cells in series to form a string, and now develop the current-voltage relationship for groups of strings connected in parallel (an array). the output current IA and output voltage VA of a PV array with NS cells in series and NP strings in parallel is found from the following equation,

$$I_A = N_PI_{irr} - N_PI_0\left[e^{\left(\frac{q(V_A+I_AN_SR_S)/N_P}{N_SnkT}\right)} - 1\right] - \frac{V_A + I_AN_sR_s/N_P}{N_sR_P/N_P}$$

**1.4 Important Model Parameters**

Prior to derivation of the module-to-array model, it is necessary to discuss the important model parameters and how they change with operating conditions of PV system.

Ideality factor "n" is assumed to be related only to the material of the solar cell and independent of temperature and solar irradiation. It is unit less and defines the extent of idealness of a PV cell. As it does not depends on operating condition, the value of n will not change the value of n compared to the value of nref at Standard Reference Conditions (SRC) is given by, $n = n_{ref}$

Where, the solar irradiation is Gref = 1000 W/m$^2$ and the cell temperature is Tref = 298 K or Tref = 25◦C at SRC

The photo current (Iirr) depends on the solar irradiance G and cell temperature T and is given by, Where, Iirr, ref is the photo current at SRC.

$$I_{irr} = I_{irr,ref}\left(\frac{G}{G_{ref}}\right)\left[1 + \alpha_T(T - T_{ref})\right]$$

Diode Saturation Current I0 is primarily depend on the temperature of the cell,

$$I_0 = I_{0,ref}\left(\frac{T}{T_{ref}}\right)^3 e^{\left[\frac{E_{g,ref}}{kT_{ref}} - \frac{E_g}{kT}\right]}$$

$I_{0,ref}$, the third unknown parameter in this model is the diode saturation current for the cell temperature at SRC, Tref . Eg is the band gap energy defines the value for Eg for silicon to be,

$$E_g = 1.16 - 7.02 * 10^{-4}\left[\frac{T^2}{T - 1108}\right]$$

Variation in cell temperature occurs due to changes in the ambient temperature as well as changes in the insulation. Where, Tamb is the ambient temperature and NOCT represents the nominal operating cell temperature provided by the manufacturer. G represents the solar irradiation at the ambient temperature.

$$T = T_{amb} + \left(\frac{NOCT - 298K}{0.8}\right)$$

The following relationship relating the shunt resistance to irradiation at operating conditions and SRC, The series resistance is assumed to be independent of temperature and irradiation at both operating conditions and SRC $R_S = R_{S,ref}$ The series resistance is the sum of resistance due to all the components that come in the path of the current. This includes the base, emitter and semiconductor-metal contact and joints between cells. It is desirable to have the value of series resistance as low as possible. The shunt resistance is due to the leakage across the P-N junction. As the series resistance of cell increases, more and more voltage drop occurs within the cell and its I-V characteristics start to deviate from ideal one. For very large value of RS, one gets the straight line with reduced short circuit current but open circuit voltage remains same.

$R_S = R_{S,ref}$ Ideally, the value of shunt resistance RP should be very large, in the range of several hundred ohms. In case of resistance RP, low value of RP affects the open circuit voltage but not short circuit current.

$$\frac{R_P}{R_{P,ref}} = \frac{G}{G_{,ref}}$$

## 2. ANALYSIS OF PV ARRAY UNDER PARTIAL SHADED CONDITIONS

A number of series/parallel connected Solar Photovoltaic (SPV) modules are used to form a solar array for a desired voltage and current level. The major challenge in using a SPV source containing a number of cells in series is to deal with its nonlinear internal resistance. The problem gets all the more complex when the array receives non-uniform irradiance (partially shading). In a solar array spread over vast area, it is likely that shadow may fall over some of its cells due to tree leaves falling over it, birds or bird litters on the array, shade of a neighboring construction etc.

In a series connected string of cells, all the cells carry the same current. Even though a few cells under shade produce less photon current but these cells are also forced to carry the same current as the other fully illuminated cells. The shaded cells may get reverse biased, acting as loads, draining power from fully illuminated cells. If the system is not appropriately protected, hot-spot problem can arise and in several cases, the system can be irreversibly damaged.

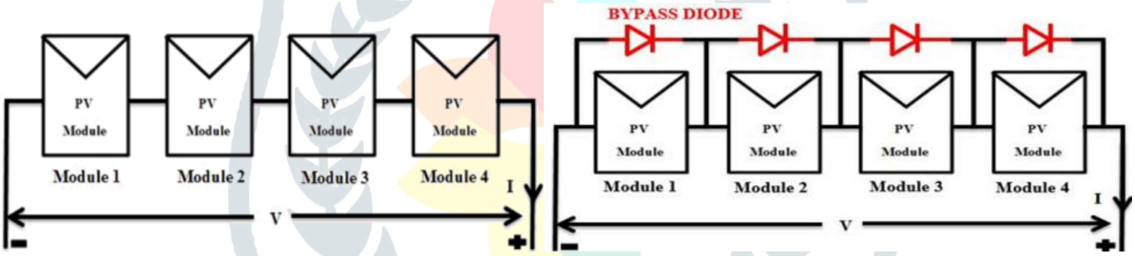


Fig. 2 Four modules connected in series (a) without Bypass diode (b) with bypass diode

Nowadays there is an increasing trend to integrate the PV arrays at the design level in the building itself. In such cases it is difficult to avoid partial shading of array due to neighboring buildings throughout the day in all the seasons. In conventional PV systems, those shadows lower the overall generation power to a large degree. Hence the PV installation cost is increased, because the number of PV modules must be increased, and as a result, PV power generation will be less attractive. This makes the study of partial shading of modules a key issue. Moreover it is very important to understand the characteristics of SPV under partial shaded conditions to use SPV installations effectively under all conditions.

## II. Results And Discussion

PV Module of 30 W is considered and simulated using MATLAB / Simulink. To get a desired output power from PV module the PV modules are connected in series and parallel as per requirement. In this work 36 solar cells connected in series to construct a one solar module. The PV panel of simulation different cases is considered. In those cases there is effect of irradiance, effect of temperature, effect of partial shading, effect of bypass diode also considered.

| **Reference Parameter** | **Value** |
|---|---|
| **Open circuit Voltage (Voc)** | 19.24V |
| **Short-circuit Current(Isc)** | 2.42A |
| **Voltage at MPP (Vmp)** | 14.37V |

| | |
|---|---|
| **Current at MPP (Imp)** | 2.20A |
| **Temp. coefficient.** | 0.0013 |

Table.1 Reference Parameter

### 3.1 Case 1: Simulation Result For Pv Module At Different Irradiance Level

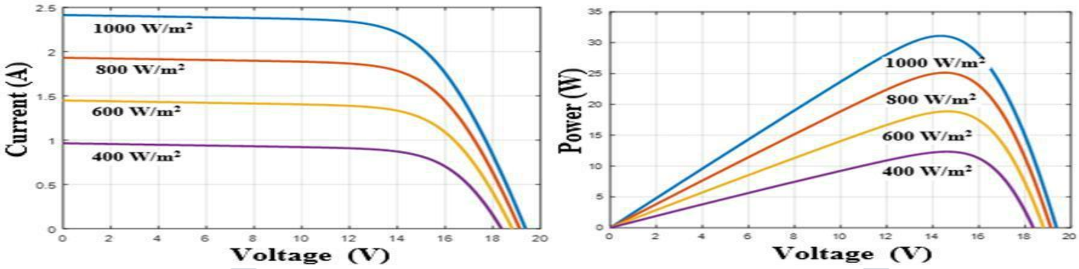


Figure. 3 I-V and P-V characteristics of PV module at different irradiance level

As from figure 3 it's clear that for different irradiance level the short circuit current also changes accordingly. As increase in irradiance level of the PV module as a result short circuit current of PV module also increases.

### 3.2 Case 2: Simulation Result For Pv Module At Different Temperature Level

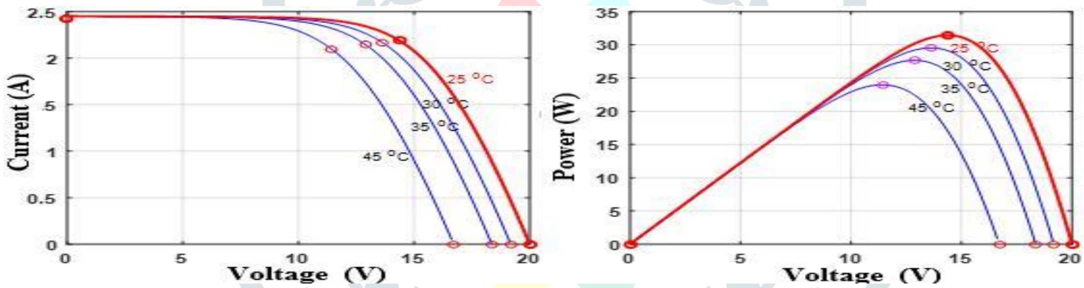


Figure.4 I-V and P-V characteristics at different temperature level

From figure 4 as increase in temperature the open circuit voltage a decreases and power also decreases with increases in temperature.

### 3.3 Case 2: Simulation results of four modules connected in Series

In this case four PV modules are connected in series with same having same irradiance level = 1000 W / m$^2$ as well as same temperature level = 298. For more voltage connect the PV module in series. Figure 7.6 shows that if modules are connected in series than voltage across the array also increases but current flows from that array remain same.

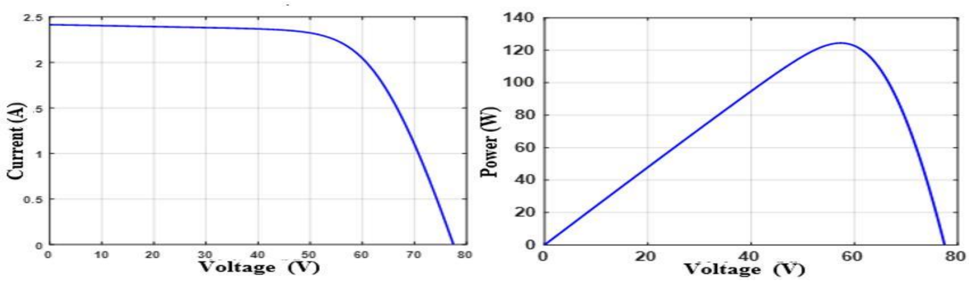


Figure. 5 I-V and P-V characteristics of four module connected in series

### 3.4 Case 2: Simulation Results Of Four Modules Connected In Parallel

In this case four PV modules are connected in parallel with same having same irradiance level = 1000 W / $m^2$ as well as same temperature level = 298 K. if modules are connected in parallel than current from the array also increases but voltage of array remain same.

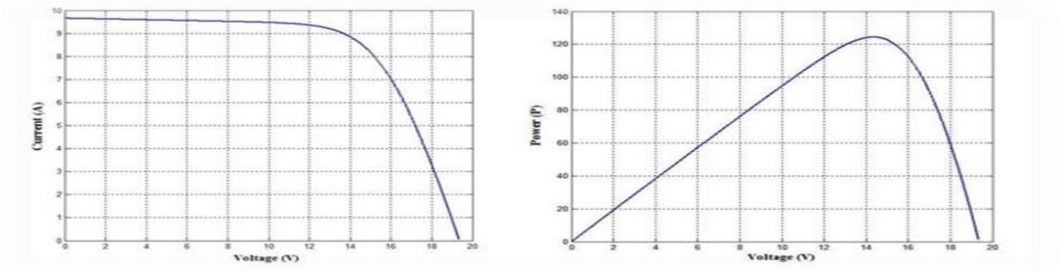


Figure. 6 I-V and P-V characteristics of four modules connected in parallel

### 3.5 Case 2: Simulation Results Of Four Modules Connected In Series With Different Irradiance Without Bypass Diode

In this case four modules are considered connected in series with different irradiance level but temperature remain same of value = 298 K and irradiance level of Module 1, Module 2., Module 3 and Module 4 having 1200 W/ $m^2$, 1000 W/$m^2$ , 800 W/$m^2$, 500 W/$m^2$ respectively. series with different irradiance than short circuit current value set by the module which having minimum irradiance level. The short circuit current and power output of the array also reduces.

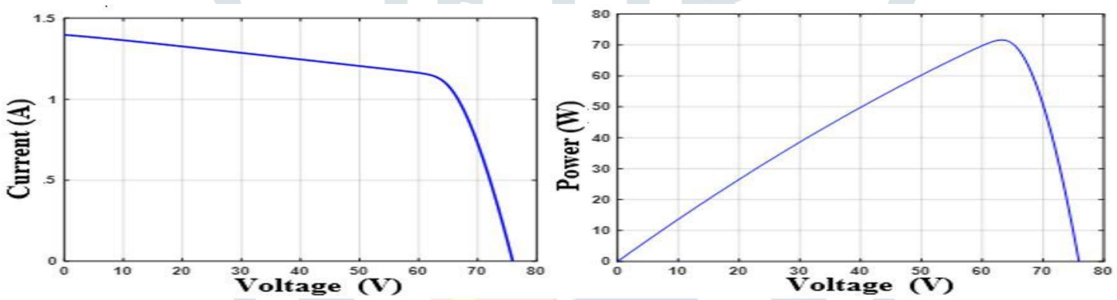


Figure. 7 I-V and P-V characteristics of four module connected in series with different irradiance without bypass diode

### 3.6 Case 2:Four modules connected in series with different irradiance without bypass diode

Module 1, Module 2., Module 3 and Module 4 having 1200 W / $m^2$, 1000 W / $m^2$ , 800 W / $m^2$, 500 W / $m^2$ respectively. Here bypass diode also connected in parallel with module which mitigates the effect of hot spot.

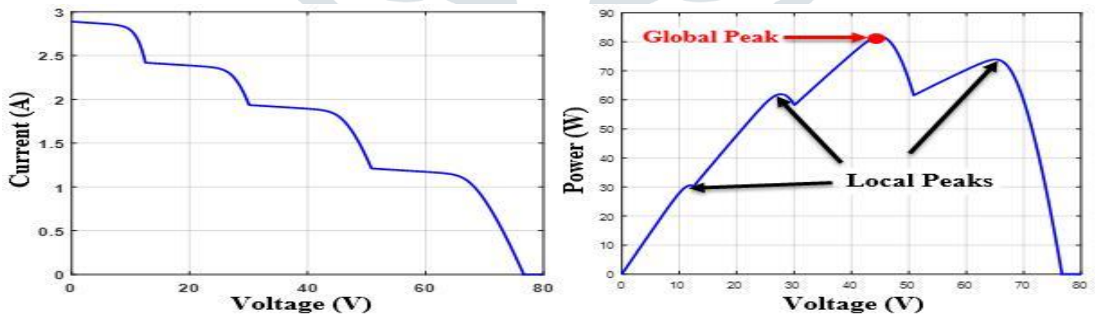


Figure. 8 I-V and P-V characteristics of four modules connected in series With different irradiance

As we can see from figure. 8 if bypass diode connected in parallel with PV module than it introduces a multiple peaks in output characteristics. In case of low irradiance level the PV module which having a less irradiance level it act as load on the other module on the array configuration and produces a reverse voltage across it. If bypass diode connected in parallel with the PV module than it in case of lower irradiance level the generated current flows from pass from bypass diode and contributing for a generation. In figure. 8 shows the effect of bypass diode. By using bypass diode the output power of the PV system increases but the multiple peaks are observed in the output characteristics in that one is global peak and rest of are locals peaks.

## III. CONCLUSION

In this paper the modeling of the solar cell carried out and it extended to PV module and PV array. The PV module is constructed by connecting number of cells in series and PV array is constructed by connecting PV modules in series and parallel. the theory of partial shading is discussed as well as the impact of shading on the PV modules also discussed. To prevent the hot spot phenomenon the bypass diode connected to a PV module. By using bypass diode we can improve the total power output of the system but bypass diode introduces a multiple peaks in PV output characteristic. The results are established to be in adjacent agreement with theoretical expectation.

## IV. REFERENCES

[1] M.C. Glass, Improved solar array power point model with SPICE realization, in: Proc. 31st Intersoc. Energy Convers. Eng. Conf. (IECEC), vol. 1, 1996, pp.286–291.
[2] Y.T. Tan, D.S. Kirschen, N. Jenkins, A model of PV generation suitable for stability analysis, IEEE Trans. Energy Convers.19 (4) (2004) 748–755.
[3] A. Kajihara, A.T. Harakawa, Model of photovoltaic cell circuits under partial shading, in: Proc. IEEE Int. Conf. Ind. Technol. (ICIT), 2005, pp. 866–870.
[4] N.D. Benavides, P.L. Chapman, Modeling the effect of voltage ripple on the power output of photovoltaic modules, IEEE Trans. Ind. Electron. 55 (7) (2008) 2638–2643.
[5] W. Xiao, W.G. Dunford, A. Capel, A novel modeling method for photovoltaic cells, in: Proc. IEEE 35th Annu. Power Electron. Spec. Conf. (PESC), vol. 3, 2004, pp. 1950–1956.
[6] G. Walker, Evaluating MPPT converter topologies using a matlab PV model, J. Elect. Electron. Eng., Aust. 21 (1) (2001) 45 55.
[7] F. González-Longatt, Model of Photovoltaic Module in MatlabTM, II CIBELEC, 2005.
[8] N. Celik, N. Acikgoz, Modelling and experimental verification of the operating current of mono-crystalline photovoltaic modules using four- and fiveparameter models, Appl. Energy 84 (1) (2007) 1–15.
[9] Y.C. Kuo, T.-J. Liang, J.-F. Chen, Novel maximum-power-point tracking controller for photovoltaic energy conversion system, IEEE Trans. Ind. Electron. 48 (3) (2001) 594–601.
[10] Y. Yusof, S.H. Sayuti, M. Abdul Latif, M.Z.C. Wanik, Modeling and simulation of maximum power point tracker for photovoltaic system, in: Proc. Nat. Power Energy Conf. (PEC), 2004, pp. 88–93.
[11] C. Carrero, J. Amador, S. Arnaltes, A single procedure for helping PV designers to select silicon PV module and evaluate the loss resistances, Renew. Energy 32 (15) (2007) 2579–2589.
[12] N. Mendalek ,K. Al-Haddad"Photovoltaic system modeling and simulation," IEEE International Conference on Industrial Technology (ICIT), 2017
[13] Hiren Patel, Vivek Agarwal "MATLAB-Based Modelling to Study the Effects of Partial Shading on PV Array Characteristics," IEEE Transactions on energy conversion, vol. 23, no. 1, MARCH 2008
[14] Kshitijaa Ranjan ; Narendra Kumar "Modeling and simulation of Perturb and Observe algorithm on solar PV system using different converters in MATLAB/SIMULINK" Power Electronics, Intelligent Control and Energy Systems (ICPEICES),IEEE International Conference on 4-6 July 2016.
[15] M.A.Elgendy, B. Zahawi, D.J. Atkinson, "Evaluation of perturb and observe MPPT algorithm implementation techniques", Power Electronics, Machines and Drives (PEMD 2012), 6th IET International Conference, IEEE Publication, March 2012, pp.1-6.