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Study of Partial Shading Effects on Photovoltaic Arrays with Two-Diode Model

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***Abstract*— The purpose of this paper is to propose a MATLAB/Simulink simulator for PV cell/module/array based on the Two-diode model of a PV cell. This model is known to have better accuracy at low irradiance levels which allows for more accurate prediction of PV systems performance. To reduce computational time, the input parameters are reduced as the values of Rs and Rp are estimated by an efficient iteration method. Furthermore, all of the inputs to the simulators are information available on a standard PV module datasheet. The paper present first brief introduction to the behavior and functioning of a PV device and write the basic equation of the two-diode model, without the intention of providing an in-depth analysis of the photovoltaic phenomena and the semiconductor physics. The introduction on PV devices is followed by the modeling and simulation of PV cell/PV module/PV array, which is the main subject of this paper. A MATLAB Simulink based simulation study of PV cell/PV module/PV array is carried out and presented .The simulation model makes use of the two-diode model basic circuit equations of PV solar cell, taking the effect of sunlight irradiance and cell temperature into consideration on the output current I-V characteristic and output power P-V characteristic . The simulation results, compared with points taken directly from the data sheet and curves published by the manufacturers, show excellent correspondence to the model. The partial shading is one of the major problems that exist in the photovoltaic farm installations. This is due to the presence of multi peaks in the power curves characteristics.**

***Keywords*— *Double* diode, cells/modules/arrays, modeling, two-diode, shading, bypass diode, partial shading.**

I. INTRODUCTION

The human activities contribute to the global warming of the planet. As a result, every country strives to reduce carbon emissions. The entire world is facing the problem not only the depletion of fossil fuels, but also of its rising prices which cause the worldwide economic instability. Numbers of efforts are being undertaken by the Governments around the world to explore alternative energy sources and to achieve pollution reduction.
Recently, the use of photovoltaic power (solar power) as a source of energy has become increasingly important. Energy generated from clean, efficient, and environment friendly has become one of the major challenges for engineers and scientists. Among all renewable energy sources, photovoltaic power systems attract more attention while greenhouse emissions are reduced. Regarding the endless aspect of solar energy, it is worth saying that solar energy is a unique solution for energy crisis. However, despite all the aforementioned advantages of solar power systems, they do not present desirable efficiency.
Solar electric or photovoltaic technology is one of the biggest renewable energy resources to generate electrical power and the fastest growing power generation in the world. The environmental effects such as temperature, irradiation, special characteristics of sunlight, dirt, shadow, and so on affect the performance of the photovoltaic (PV) system. Changes in insulation on panels due to fast climate changes such as cloudy weather and increase in ambient temperature can reduce the PV cell output power.
In this paper, a simple but efficient and optimized photovoltaic system by using power electronics devices is presented here. It provides theoretical studies of photovoltaic (PV) and its modeling techniques. [1]

II. PHOTOVOLTAIC SYSTEM

A photovoltaic (PV) system directly converts sunlight into electricity. The basic device of a PV system is the photovoltaic (PV) cell. The photovoltaic module is the result of associating a group of PV cells in series and parallel and it represents the conversion unit in this generation system. An array is the result of associating a group of photovoltaic modules in series and parallel. The obtained energy depends on solar radiation, the temperature of the cell and the voltage produced in the photovoltaic module. The voltage and current available at the terminals of a PV device may directly feed small loads. More sophisticated applications require electronic converters to process the electricity from the PV device.

The photovoltaic effect is a physical phenomenon of converting the energy carried by optical electromagnetic radiation into electrical energy. It was discovered by E. Becquerel in 1839, when he found that some specific

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materials will generate an electric current when they are exposed to light. The solar light is composed of packets of energy, called photons, which is the basic unit of light and other electromagnetic radiation. It contains various amount of energy corresponding to the different wavelengths of light. The energy can be expressed by the equation:

$$E = h\,\nu \qquad (1)$$

Where h is Planck's constant and ν is the photon's frequency. The photon energy of that light decreases when the wavelength of light increases. When certain materials, such as semiconductors, are exposed to light, the photons within a certain energy band can be absorbed. Other photons may pass through the material or be reflected without being absorbed. Different semiconductors have different optical absorption coefficients. When a photon is strike on the PN junction of solar panel, the energy of the photon will be transferred to an electron of the material under illumination. If this energy is greater than the electron binding energy, the electron will be ejected from its ground energy state, and an electron-hole pair will be created. The solar cells are made on basis of this effect and converting solar energy to electricity. Figure 1 shows how silicon based PV cell works. PV cells are made of various semiconductor materials, most commonly silicon. A typical PV cell is formed with a PN junction and two electrical contact layers (front contact and rear contact). Light allows passing through the front Contact and being absorbed in the semiconductor. When the PV cell is exposed under light, some photons are reflected or pass through the cell without being absorbed. Except those the others are absorbed and hole-electron pairs are then formed. The electric field produced by the p-n junction separates the holes and electrons. A potential difference results due to this and a current flow (electricity) if the PV cell is connected to a load. [2,3]

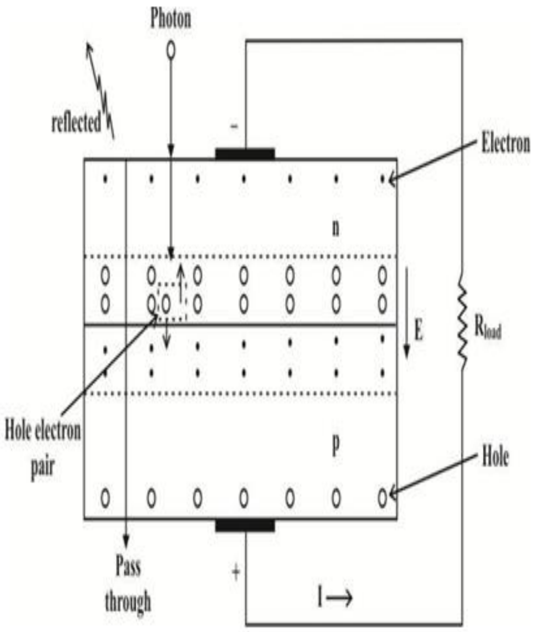

Figure 1: Structure and working mechanism of a PV cell.

A. Basic configuration

A photovoltaic cell/module is mathematically modeled using single diode equivalent circuit or a double diode equivalent circuit. The various parameters which influence the characteristic of a cell are classified as environmental parameter like irradiance and temperature, internal parameter like ideality constant, Boltzmann constant energy band-gap and charge of electron, electrical parameter like open circuit voltage, short circuit current, series resistance, and shunt resistance .

Based on current-voltage relationship of a solar cell , a mathematical model of single diode PV cell is developed .The representation of an ideal PV cell is represented by a current source and an anti parallel diode connected to it.

In order to study the photovoltaic system in distributed generation network, a modeling and circuit model of the PV array is necessary. A photovoltaic device is a nonlinear device and the parameters depend essentially on sunlight and temperature. The photovoltaic cell converts the sunlight into electricity. The photovoltaic array consists of parallel and series of photovoltaic modules. The cell is grouped together to form the panels or modules. The voltage and current produced at the terminals of a PV can feed a DC load or connect to an inverter to produce AC current. The model of photovoltaic array is obtained from the photovoltaic cells and depends on how the cells are connected.

The basic equation from the theory of semiconductor to describe mathematically the I-V characteristic of the ideal photovoltaic cell. It is a semiconductors diode with p-n junction. The material used is monocrystalline and polycrystalline silicon cells. Figure 2 is the model of single diode photovoltaic cell with the internal resistance and diode. A real photovoltaic device must include the effects of series and parallel resistance of the PV.

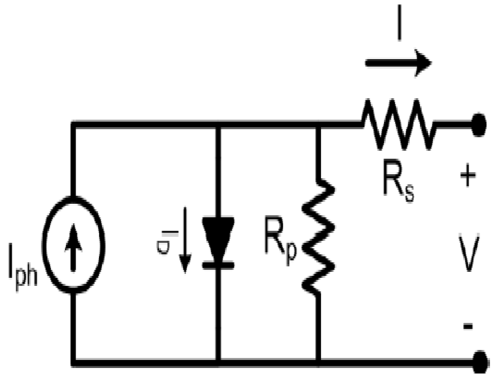

Figure 2: Single diode equivalent circuit of a solar cell

The equivalent circuit model of a PV cell is needed in order to simulate its real behavior. One of the models proposed in literature is the two-diode model [4]. Using the physics of p-n junctions, a cell can be modeled as a DC current source in parallel with two diodes that represent currents escaping due to diffusion and charge recombination mechanisms. The consideration of the recombination loss leads to a more precise model known as

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two-diode model shown in figure 1 [5]. Two resistances, Rs and Rp, are included to model the contact resistances and the internal PV cell resistance respectively [6,7]. The values of these two resistances can be obtained from measurements or by using curve fitting methods based on the I-V characteristic of the cell. The curve fitting techniques is used here to approximate the values of Rs and Rp. Assuming that the current passing in diode D2 due to charge recombination is small enough to be neglected, a simplified PV cell model can be reached as shown in fig. 2 known as single-diode model [8].

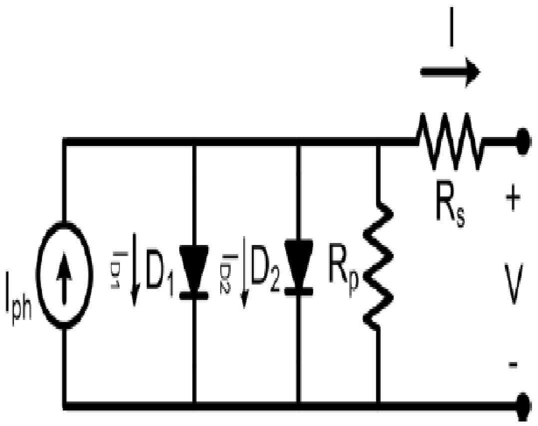


Figure 3: double diode equivalent circuit of a solar cell

B. Mathematical Modeling of PV Cell

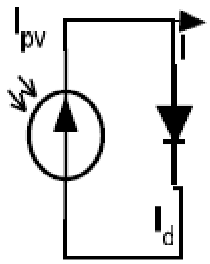
Solar energy has a major role in renewable energy resources. Solar Cell as a basement of solar system has attracted lots of research. To conduct a study about solar energy system, an authenticated model is required. Diode base PV models are widely used by researchers. These models are classified based on the number of diodes used in them. Single and two-diode models are well studied. Single-diode models may have two, three or four elements.

In this study, these solar cell models are examined and the simulation results are compared to each other. All PV models are re-designed in the MATLAB/Simulink software and they examined by certain test conditions and parameters. This paper provides comparative studies of these models and it tries to compare the simulation results with manufacturer's data sheet to investigate model validity and accuracy. The results show a four- element single-diode model is accurate and has moderate complexity in contrast to the two-diode model with higher complexity and accuracy. [9]

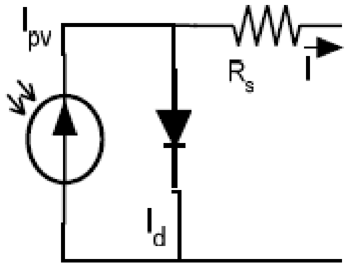
Similar to two-port networks, open circuit voltage (Voc) and short circuit current (Isc) are used to establish circuit model of solar cell. Voltage at maximum power point (Vmpp), Current at maximum power point (Impp) and maximum power peak of PV
module (Pmm) are important to shape the models. These data are given by manufacturer in STC (temperature is Tn=25^{o}c and sun irradiation is Gn=1000W/m2) and can be found in PV manufacturer's datasheet. The first step to modeling is finding the mathematical relationships. An ordinary engineering model of PV cell will be studied in this paper without getting involved into details that need semiconductor physics and light phenomena. A lumped circuit model will be used in this study. [10]

i. Single-diode PV Model

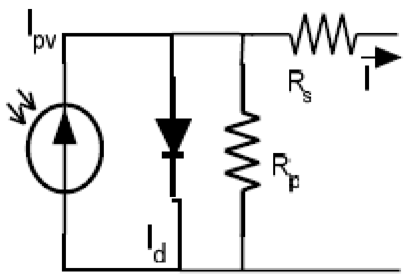
Single-diode models, presented by Townsend in1989, are depicted in Fig.1.In this model, one diode is used to modeling.



(a)



(b)



(c)

Fig. 4 Single-diode lumped circuit model a) two-element model, b) three-element model c) four-element model

Fig. 4(a) is PV lossless model (Ideal model without resistance), Fig. 4(b) has three elements with thermal loss (series resistance Rs) and Fig. 4(c) has four-elements circuit model with leakage current to ground (shunt resistance Rp). So the single-diode model is classified as:

1. Two-element (Rs=0 & Rp=∞) or three-parameter
2. Three-element (Rp=∞) or four-parameter
3. Four-element or five-parameter

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The equations that give the behavior of the PV are:

$$I=I_{ph}-I_d-I_p \quad (2)$$

Iph is the photocurrent, Id is the diode current which is proportional to the saturation current and is given by the equation

$$I_d = I_0[e^{\left(\frac{V}{A.NS.VT}\right)}-1] \quad (3)$$

Where V is the voltage imposed on the diode.
The expression of V_T is given by

$$V_T = \frac{K.T_C}{q} \quad (4)$$

I_{pv}: current generated by the incident light
I_0: reverse saturation
q: electron charge (1.602 10-19 C)
k: Boltzmann constant
T: the temperature of the p-n junction
V_t: the thermal voltage of the array
R_s: the resistance series
R_p: the resistance parallel.

The problem of modeling a PV array is to calculate the resistance series R_s and resistance parallel R_p.R_s and R_p are determined iteratively, based on the manufacture datasheet.

I_0 is the reverse saturation or leakage current of the diode can be expressed as written below.

$$I_0 = I_{sc}\left[exp\left(\frac{-V_{oc,ref}}{a}\right)\right] \quad (5)$$

The photocurrent depends on both irradiance and temperature:

$$I_{ph} = \frac{G}{G_{ref}}\left(I_{ph,ref}+\mu_{sc}.\Delta T\right) \quad (6)$$

Hence the final equation that give the behavior of the PV is:

$$I=I_{ph}-I_0\left[\exp\left(\frac{q(V+IR_s)}{\propto kT}\right)\right]-\frac{V+IR_s}{R_p} \quad (7)$$

G: Irradiance (W/m^2), G_{ref} : Irradiance at STC = 1000 W/m^2, $\Delta T = T_c - T_{c,ref}$ (Kelvin), $T_{c,ref}$: Cell temperature at STC = 25 + 273 = 298 K, $_{\mu\ SC}$: Coefficient temperature of short circuit current (A/K), provided by the manufacturer, $I_{ph,ref}$: Photocurrent (A) at STC.

The model is obtained with the parameters of the I-V equation given by manufacturer datasheet such as open-circuit voltage V_{oc}; short-circuit current I_{sc}, maximum output power P_{max}, voltage and current at the maximum power point (V_{mpp}, I_{mpp}). The method used "the mathematical model of I-V curve without need to guess or estimate any other parameters except the diode constant. The relation between I_{pv} and I_{sc} replaces the assumption that I_{pv} is equal to I_{sc}. The model in gives a good correlation of PV characteristic and I-V curve. [11]

The equations allow calculating the five parameters. The equations are based from the equal circuit of the single-diode for PV cells. The other equations are derived from open circuit point, maximum power point and the short circuit point of the PV. The model obtained represents the stipulations put forth through the datasheet for the product. The method proposed a new method depends on the temperature of the dark saturation current.

ii. Two-diode PV Model
The two-diode model (Fig.2) has one extra diode. It is also called seven-parameter model. This model is more accurate than the single diode model especially in low irradiance level [10-11]. The voltage –current relation is depicted in (6). Here Io1 and Io2 are diodes reverse saturation current. Unfortunately, reverse saturation current, resistances and ideality factors are unavailable in PV panel data sheet, so some recursive and incremental methods are needed to calculate these parameters. Some papers suppose α1 and α2, 1 and 2, respectively.

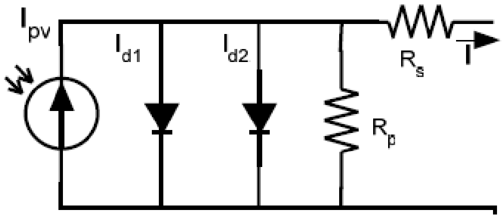

Fig. 5 Two-diode or five-element PV model

The basic equations of the two-diode model of the PV cell are given below:

$$I=I_{ph}-I_{d1}-I_{d2}-I_p \quad (8)$$

$$I_{D1} = I_{01}[\exp\left(\frac{q*V}{\propto_1*k*T}\right)-1] \quad (9)$$

$$I_{D2} = I_{02}\left[\exp\left(\frac{q*V}{\propto_2*k*T}\right)-1\right] \quad (10)$$

Therefore the final terminal current equation is:

$$I=I_{ph}-I_{01}\left[\exp\left(\frac{q(V+IR_s)}{\propto_1 k_1 T}\right)\right]-I_{01}\left[\exp\left(\frac{q(V+IR_s)}{\propto_1 k_1 T}\right)\right]-\frac{V+IR_s}{R_p}$$
(11)

To simplify the model, in this work, both of the reverse saturation currents, *I01* and *I02* are set to be equal:

$$I_{01} = I_{02} = \frac{I_{SC,n}+K_1\Delta T}{\exp\left(\frac{V_{OC,n}+K_V\Delta T}{V_t*\frac{(\propto_1+\propto_2)}{p}}\right)-1} \quad (12)$$

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Where $V_{OC,n}$ is open circuit voltage, $I_{SC,n}$ is the short circuit current, $V_{t,n}$ is the thermal voltage and G_n is the irradiance, T_n is the temperature, all at standard test conditions, K_V is the open circuit voltage temperature coefficient , K_I is the short circuit temperature coefficient [12].

The diode ideality factors α1and α2 represent the diffusion and recombination currents. In accordance with Shockley's diffusion theory, α1must be unity [9], [10]. The value of α2 is flexible. Based on the simulation results, it was found that if α2 ≥ 1.2, the best match between the proposed model and the practical I-V curve is obtained. Since (α1+ α2)/p =1 and α1=1, it follows that the variable p can be chosen to be ≥2.2. With these considerations' equation (13) becomes equation (14) [13].

$$I_{01} = I_{02} = \frac{I_{SC,n}+K_1\Delta T}{\exp\left(\frac{V_{OC,n}+K_V\Delta T}{V_t}\right)-1} \quad (13)$$

Cells connected in parallel increase the current and cells connected in series provide greater output voltages. If the module is composed of N_P parallel connections of cells the photovoltaic and saturation currents may be expressed as:

$$I_{PH,module}=I_{PH} * N_p,\ I_{0,module}=I_0 * N_p. \quad (14)$$

In equation (11) R_s is the equivalent series resistance (unknown) and R_p is the equivalent parallel resistance (unknown), so they have to be calculated by iteration. Equation (11) originates the I-V curve seen in fig. 3, where three remarkable points are highlighted and will be taken for comparison between simulation results and experimental values given in data sheet, these points are:

a) open- circuit voltage (*Voc*, 0).
b) short circuit current (0, *Isc*).
c) maximum power point (*Vmp*, *Imp*).

a) Open-circuit voltage: this point is obtained when the terminals of the module are disconnected. The module presents a voltage called (V_{OC}) expressed analytically using equation (15).

$$V_{OC} = \frac{\propto * k * T}{q} \ln\frac{I_{PV}}{I_O}\ ;\ I_{PV} > I_0 \quad (15)$$

b) Short-circuit current**:** the terminals of the module are connected with an ideal conductor, through which flows a current called (I_{SC}). In this situation**,** the voltage between module terminals is zero.

$$I_{sc} = I_{ph} = k * G \quad (16)$$

where *K* is a constant and *G* is the irradiance (W/m²).
c) P_{MPP} where the voltage versus current product is maximum which means maximum power. V_{MP} is related to V_{OC} through the relation (17):

$$V_{MP} \approx 0.8 * V_{OC} \quad (17)$$

And I_{MP} is related to I_{SC} through the relation (18) :

$$I_{MP} \approx 0.9 * I_{SC} \quad (18)$$

The best conditions, are the "standard test conditions " happen at Irradiance equal to 1000W/m², cells temperature equals to 25°C, and spectral distribution (Air Mass) AM is equal to 1.5.

Rs and Rp are calculated iteratively. The goal is to find, applying equation (20), the values of Rs and Rp that makes the mathematical Power-Voltage curve peak coincide with the experimental peak power at the (*Vmp*, *Imp*) point by iteratively increasing the value of Rs while simultaneously calculating the value of Rp with equation (21). The initial conditions for Rs and Rp are shown in equation (21). The value of Rs and Rp are reached when the iteration stopped for $P_{max,m}$ calculated is equal to $P_{max,e}$ experimental from data sheet .

$$P_{max,m} = V_{MP}\left\{I_{ph} - I_{01}\left[\exp\left(\frac{q*(V_{MP}+I_{MP}R_S)}{\propto_1 k_1 T}\right)\right] - I_{01}\left[\exp\left(\frac{q(V_{MP}+I_{MP}R_S)}{\propto_1 k_1 T}\right)\right] - \frac{V_{MP}+I_{MP}R_S}{R_p}\right\} = P_{max,e} \quad (19)$$

$$R_p = \frac{V_{MP}(V_{MP} + I_{MP} * R_S)}{V_{MP} * I_{MP} - V_{MP} * I_0\left[\frac{q * (V_{MP} + I_{MP}R_S)}{N_s * \propto * k * T}\right] + V_{MP} * I_0 - P_{max,e}} \quad (20)$$

$$R_S = \frac{R_p * I_{PH}}{I_{sc}} - R_p \quad (21)$$

C. The Characteristics Of A PV Cell

A PV cell, when subjected to certain levels of light intensity, gives an output in the form of voltage V (V), current I (A), and power P (W). The values of V, I and P display the performance and help in determining the characteristics of a PV cell where I-V is current - voltage and P-V is power-voltage. The PV cell gives non-linear characteristics which need to be studied and analysed while keeping in mind the factors that affect them. Figure 4 shows the characteristics of a standard PV cell. Here **Isc** is the short-circuit current, VOC is the open-circuit voltage, MPP is the maximum power point, Imp and **Vmp** are the current and voltage at MPP respectively. [14]

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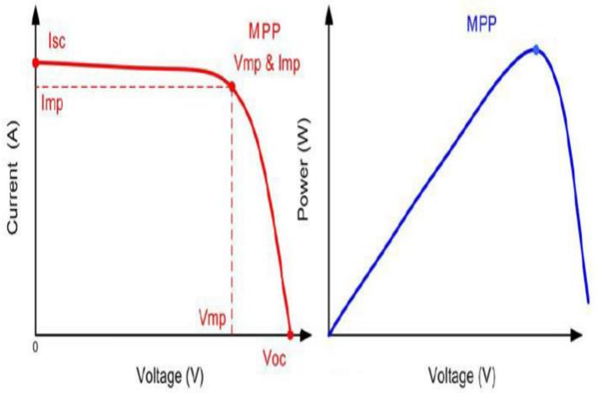

Fig 6 P-V and I-V characteristics of a PV module under STC conditions.

D. CHARACTERISTICS WITH DIFFERENT IN TEMPERATURE:

The PV cell performance depends on factors such as the cell material, atmospheric and cell temperature, intensity of the sunlight, inclination angle towards the sun and the irradiation mismatch of the cells. The most important factors that affect the PV cell are: insolation and temperature, where the greater the insolation, the greater will be the output (I & V) but on the other hand, the higher the temperature of the cell, the lower the output voltage (V) will be. Winter weather and high altitude can also result in low insolation values and as with any other electronic device, the solar cells operate better when kept cool. Another important point to consider is that, at VOC the value of ISC is equal to zero and similarly at the point of ISC the value of VOC is equal to zero.

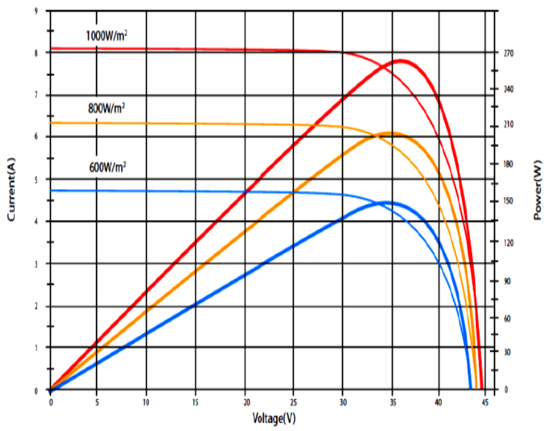

Fig 7 I-V characteristics of a PV module under variable conditions.

II. PARTIAL SHADING CONDITIONS

It is a well-documented fact that the output power capacity will be reduced by a partial shading of a photovoltaic array; however, the reduction in energy production cannot be determined in a direct method, as it is frequently not proportional to the shaded area. Some of the previous studies supposed that the decrease in power production is proportional to the shaded area and reduction in solar irradiance as well. In actuality, this concept is valid for just a single cell. The power reduction at the array level is predominantly far away from linearity with the shaded portion . Numerous factors can influence the performance of a photovoltaic (PV) system. One of the most significant factors is shading. Shading indicates a shadow on the PV modules on the outer surface that will decrease the system energy yield. As a consequence, the three fundamental PV module characteristics of power, voltage, and current will be affected. With changing irradiation during the day, the array output varies in a wide range. This variation of array output is expected. However, uniform lighting concentration in a panel is not roughly satisfied due to unexpected shading effects caused by dust, clouds, trees, buildings, atmosphere fluctuation, an existence of clouds, and daily sun angle changes causing shading on cells or side of modules. Shade impact depends on module type, fill factor, bypass diode placement gravity of shade, and string configuration. Power loss happens from the shade as well as current mismatch within a PV string and voltage mismatch between parallel strings .PV solar panels are very sensitive to shading. In PV systems, it is virtually impossible to utterly avoid shading. Looking at the electrical characteristics of PV solar panels, partial shading effect results in a distortion of the overall I-V and P-V curves of the PV solar panels. As a result, the I-V and P-V characteristics of the solar panels become more complex with existing multiple maximum power points (MPP) under the non-uniform irradiance conditions. The total output power of a PV module will be reduced by a shadow falling on it from two mechanisms, which are reducing the energy input and increasing energy losses. Even though only one cell is shaded in the PV module, around 30% power loss will happen. The power losses will increase proportionally to the number of shaded cells. A partial shading problem results in a deformity of the overall I-V curve, and this impact can be illustrated by the mismatch between the individual modules' I-V curves. [15]

A. Effect of Shading

Shading can have a huge impact on the performance of solar photovoltaic panels. It is obvious that the best solution is to avoid shading altogether, though this isn't possible in practice due to factors like cloud, rain etc. but what many people don't realize is that even if a small section of the solar photovoltaic panel is in shade, the performance of the whole solar photovoltaic panel will significantly reduce. This is because solar photovoltaic panels actually consist of a number of solar photovoltaic cells that are wired together into a series circuit. This means that when the power output of a single cell is significantly reduced, the power output for the whole system in series is reduced to the level of current passing through the weakest cell. Therefore, a small amount of shading can significantly reduce the performance of your entire solar photovoltaic panels system. One of the main causes of losses in energy generation within photovoltaic systems is the partial shading on photovoltaic (PV modules).

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These PV modules are composed of photovoltaic cells (PV cells) serial or parallel connected, with diodes included in different configurations. The curve of a PV cell varies depending on the radiation received and its temperature. Furthermore, the modules have diodes that allow the current flows through an alternative path, when enough cells are shaded or damaged. There are two typical configurations of bypass diodes: overlapped (Fig. 8a) and no-overlapped (Fig. 8b). It should be noted that the analysis in modules with overlapped diodes is a more complex one, because there may be different paths for current flow. This paper examines the individual behavior of a PV module and a photovoltaic array of PV modules (PV array) connected to an inverter with shadows in both cases. The impact of partial shading on PV system has been studied at great length in the past. Some past studies assume that the decrease in power production is proportional to the shaded area and reduction in solar irradiance, thus introducing the concept of shading factor. While this concept is true for a single cell, the decrease in power at the module or array level is often far from linearity with the shaded portion.

Other past studies tend to be rather complicated and difficult to follow by someone with limited knowledge on electronic/solid-state physics. The specific objective of this work is to clarify the impact of shading on a solar panel performance in relatively simple terms that can be followed by a power engineer or PV system designer without difficulty. First, the circuit model of a PV cell and its I-V curve are reviewed. This is followed by the impact of partial shading on the I-V and P-V curves of a circuit containing two cells with and without bypass diodes and more.

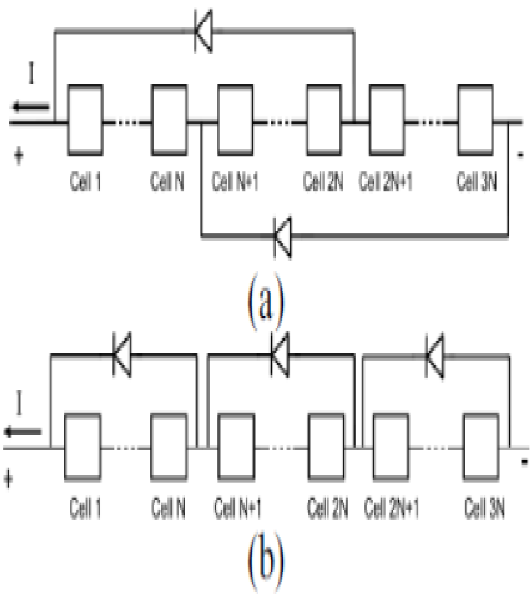

Fig.8 Bypass diodes (a) overlapped (b) no-overlapped

B. PV Array Properties under the Impact of Partial Shade

The significant improvement of our study is to cover the diverse behavior of PV power characteristics under both ordinary and mismatching weather conditions without diving in the physical and internal analysis of semiconductors characteristics of solar cells. The hot-spot is a physical phenomenon appears when one of panel string is shaded; it can then act as an electric load. The shaded photovoltaic cells absorb an important quantity of electrical energy generated by other photovoltaic cells receiving high irradiation and converting it to heat. Further, the addition of a bypass diode between specific numbers of cells in the series circuit is given as a good solution in this case. In the case of the shaded cells, the anti parallel connection of bypass diodes with each chain of cells lets the current flows through the bypass diode in a single direction. [16]

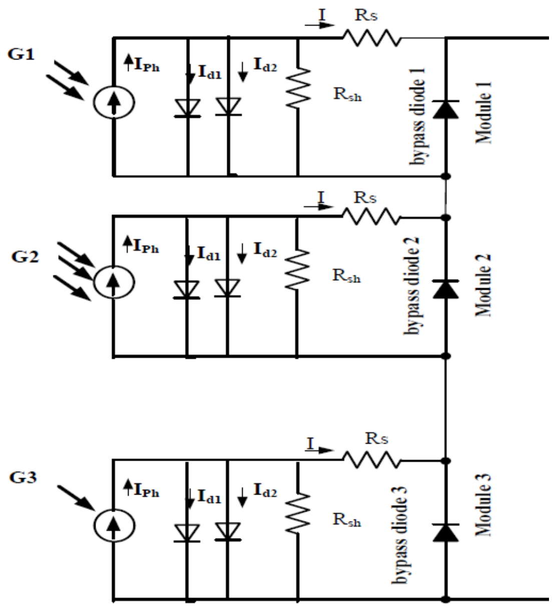

Fig.9. Simulation of 3 serial PV panels under partial shading conditions with bypass diodes

In the present paper, the string of photovoltaic panels connected with non-uniform irradiation has been measured and "Figure 9", shows the series connection of modules with three bypasses diodes where MATLAB / Simulink is employed for the simulation. Figure 10, shows the I-V and P-V responses under uniform conditions and under shaded conditions, where 3 peaks are created, with GP is the global maximum peak and are local maximum peaks.

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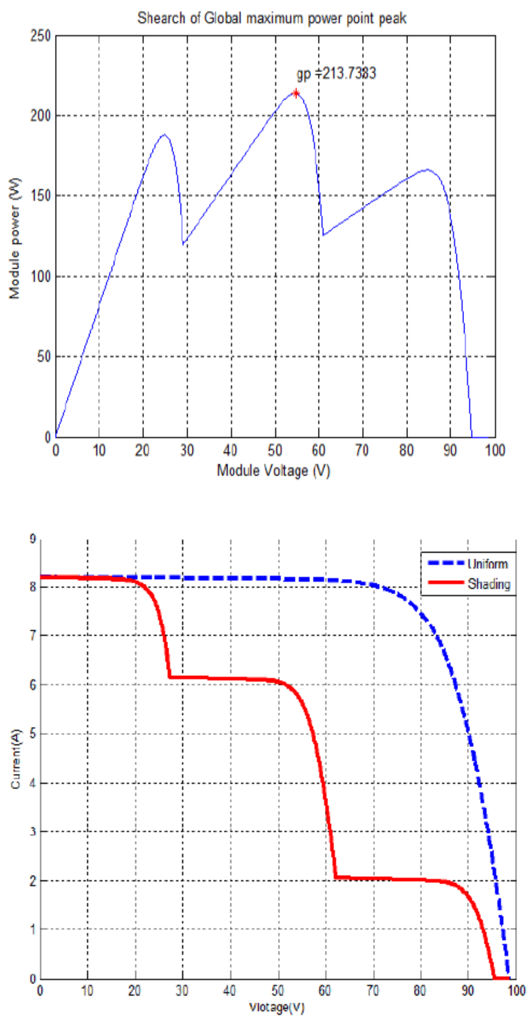

Fig.10. The resulting simulation of power-voltage and current-voltage curves.

The multiple peaks established in the characteristic curves I-- V and P-V in partially shaded conditions are caused by bypass diodes as given in "Figure 5”.

III. MATLAB SIMULINK MODEL

A model is constructed in MATLAB Simulink to create a standalone PV generated system. The samples of the various waveforms are taken for further analysis. The Simulink model is given by figure 11.

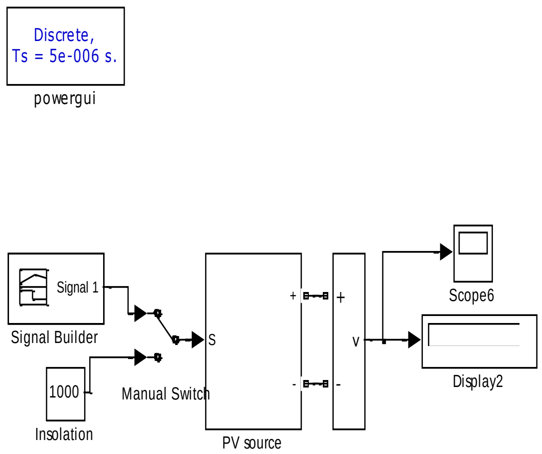

Figure 11 Simulink model of the solar generating system

The simulation of photovoltaic module is done in the mat lab Simulink environment. Here all the equation required for mathematical modeling of photovoltaic module as explained in previous chapter is simulated step by step using mat lab software. The Simulink model of mathematical equation of the test photovoltaic system is shown in the figure 12.A model is constructed in MATLAB Simulink to create a PV generated system. The samples of the various waveforms are taken for further analysis.

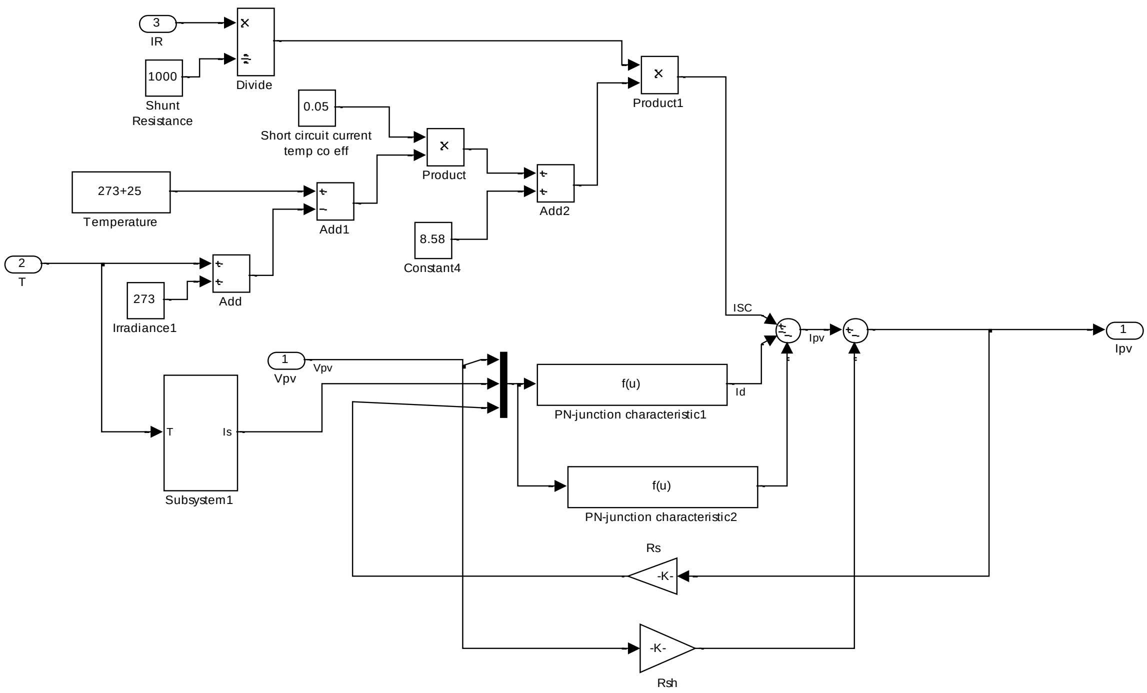

Figure 12 Detailed model of PV system

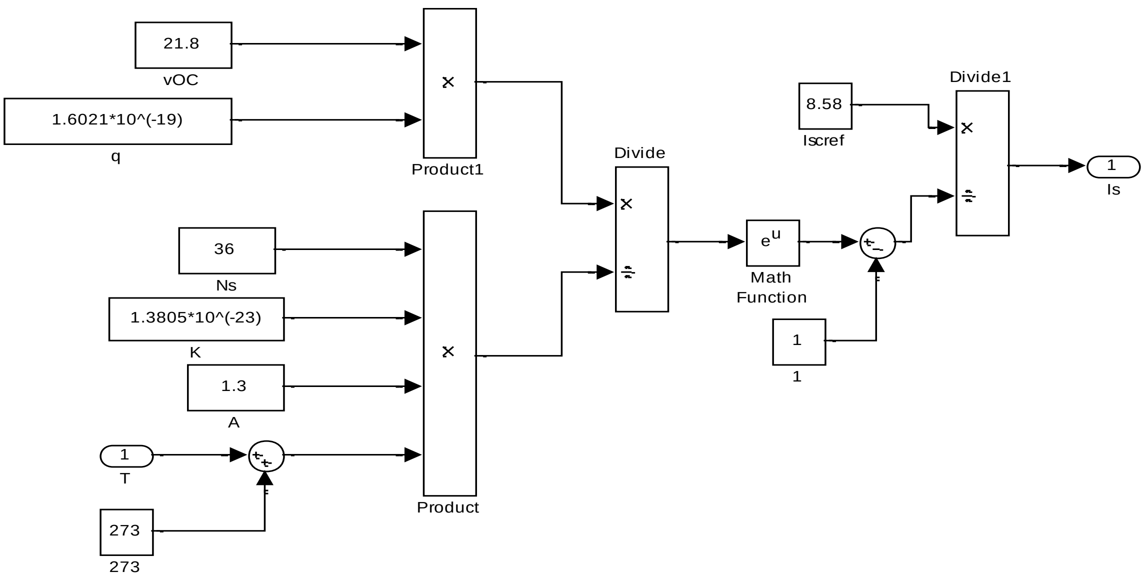

Fig. 13 Simulink model for calculation of saturation current

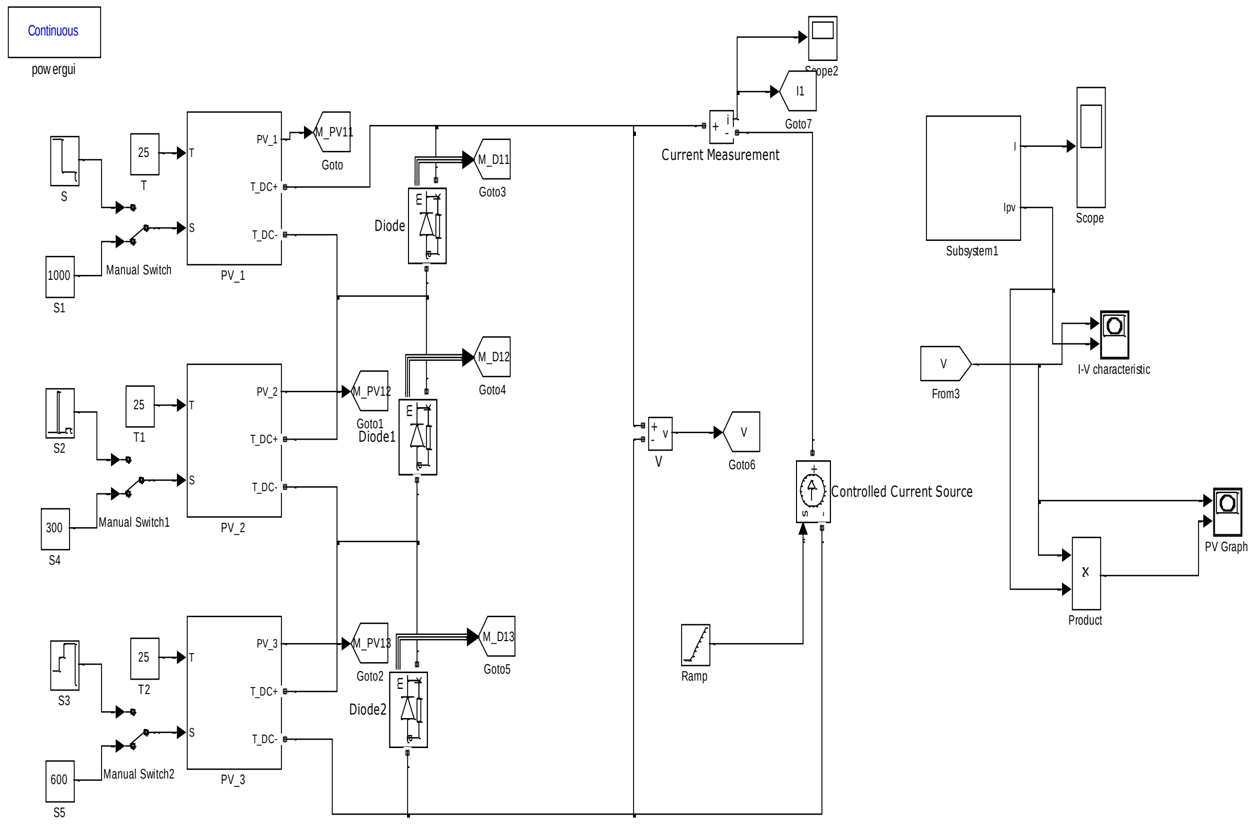

Fig.14. Simulation of 3 serial PV panels under partial shading conditions with bypass diodes using MATLAB Simulink

The simulation of photovoltaic module for studding the partial shading effect is done in the mat lab Simulink environment. The Simulink model of three serial PV panels under partial shading conditions with bypass diodes of the test photovoltaic system is shown in the figure 14.A model is constructed in MATLAB Simulink to create a PV generated system. The samples of the various waveforms are taken for further analysis.

IV.RESULT

With a constant and variable input, the test system is modeled. For constant input the PV generating system is providing a constant output voltage during steady state. As the input conditions were constant for this particular simulation the output is constant. But for variable input condition as the input condition is not constant but is a varying nature the output is

also varying. The output result of PV generating system with both constant speed and variable speed input is shown in figure. The P-V and I-V characteristics of the test system are shown in figure 15 and 16 for a constant and variable input the test system.

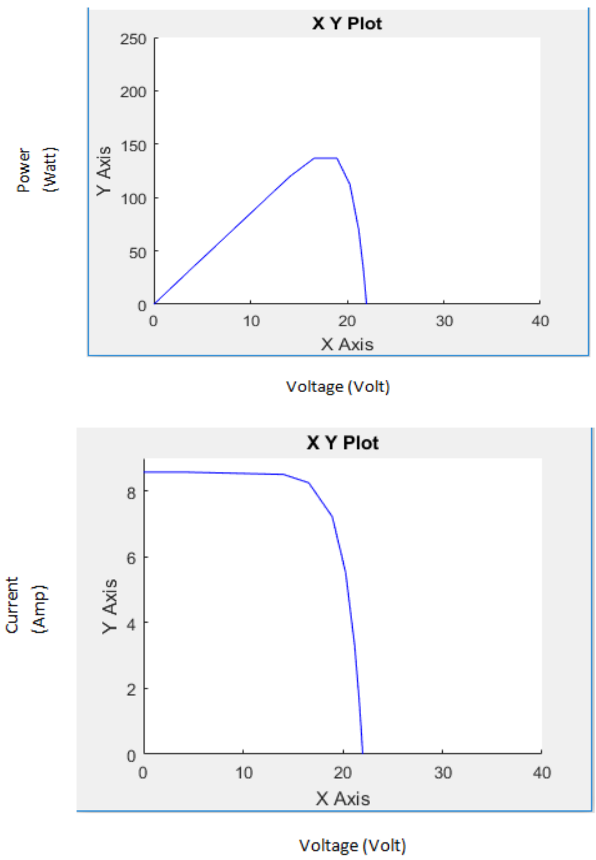

Figure 15 I-V and P-V characteristics of test system with Constant input

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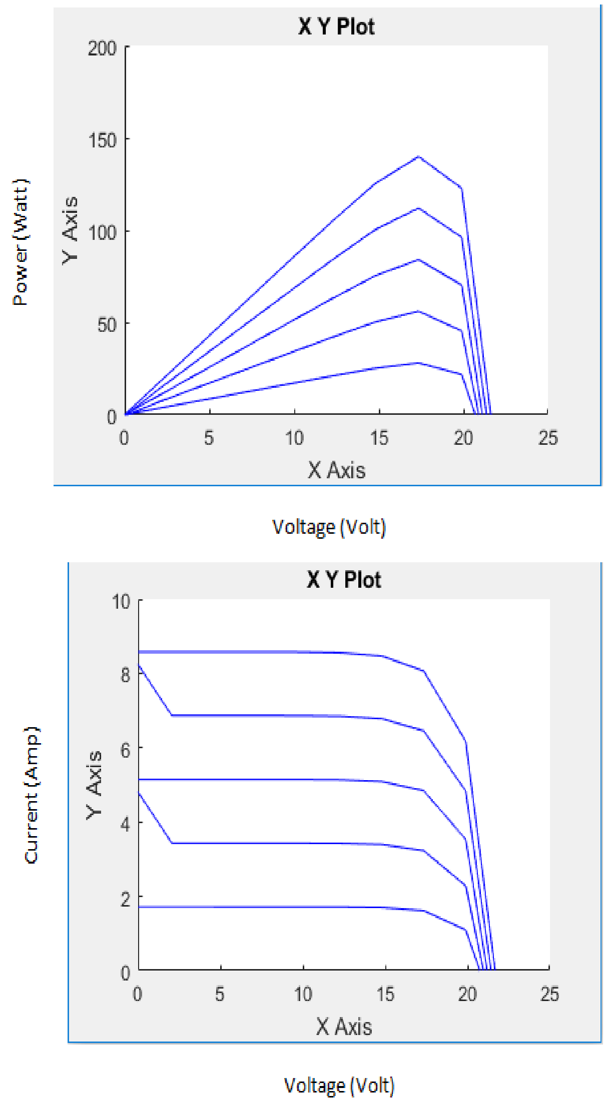
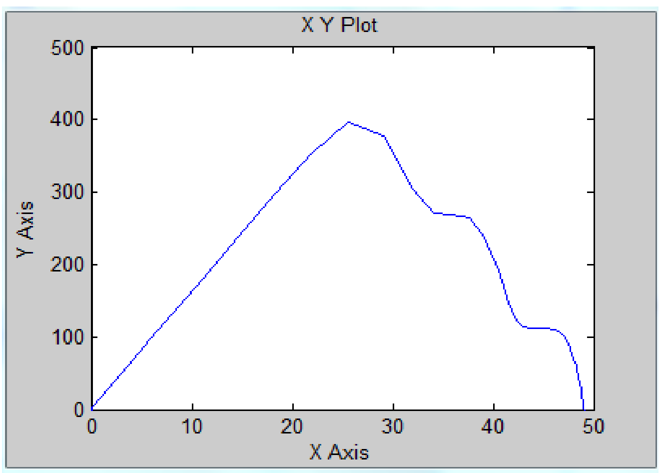


Figure 16 I-V and P-V characteristics of test system with Variable input

In the present paper, the string of photovoltaic panels connected with non-uniform irradiation has been measured, which shows the I-V and P-V responses under uniform conditions and under shaded conditions, where 3 peaks are created .



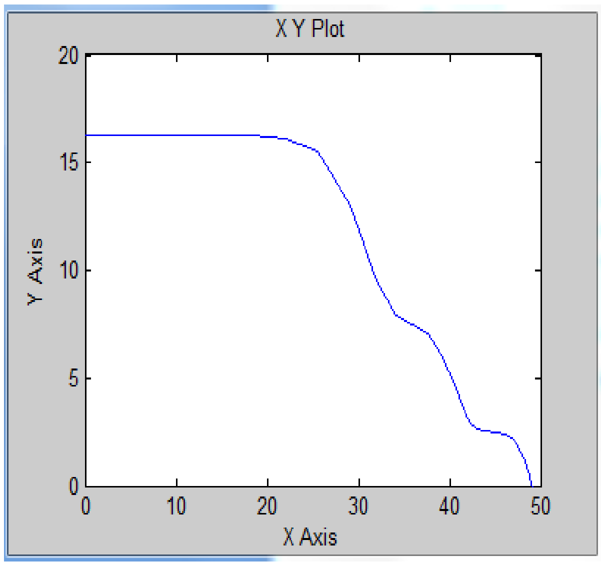


Figure 17 I-V and P-V characteristics of test system with Variable input

The P-V and I-V characteristics of the three serial PV panels under partial shading conditions with bypass diodes are shown in figure 17.

V. CONCLUSION

A typical solar module consists of series connection of solar cells to get practically utilizable voltage. A number of such modules are connected together in series and parallel to get the requisite power. From the results and inferences from this project, it is concluded that there is a substantial power loss due to non-uniform illumination of a series string. The power generated by highly illuminated cells is wasted as a heat in the poorly illuminated cells. So, care should be taken to see that all the cells connected in series receive the same illumination under different patterns of shading. Such a care will give a better protection to the array and at the same time the total energy output will also be higher.

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