Analysis of Simulation of PV array with Partial Shading effect

Ms. Kruthi Jayaram
Assistant Professor
Dept. of Electrical & Electronics Engineering, BNMIT
Bangalore, India
kruthijayaram@bnmit.in, kruthijay@gmail.com

Abstract—Solar electricity or Photovoltaics (PV) is the world's fastest increasing energy technology. This field of electricity generation is expected to grow day by day. Even the production of PV modules in increasing at a higher rate. The electricity generation using PV can be either stand-alone or grid connected system. Grid connected systems work on higher capacities therefore; their functioning of the system needs to be accurately good enough. If there is uneven supply of sun,'s energy or if there is a fault in the PV modules the generated output will automatically change. Only solar cells cannot supply power to the field, it requires module or array to power the entire field. These modules are made up of many cells connected in series. The PV modules depend upon various factors like irradiance, temperature, configuration of the array, shading of the array etc. This paper concentrates on the effect of shading on PV modules/array. If a cell receives no sunlight due to shading, no output power will be produced. Due to shading of the PV cells multiple maximum peaks arises and that analysis is what is captured and explained in this paper using MATLAB/Simulink software. Based on the formation of the array, the maximum power output as well as the factors rating changes accordingly depending upon the location. In this paper, an illustration of partial shading concept is provided consequently.

Keywords—Solar energy, Solar cell-module-array configuration, Photovoltaic system, partial shading

1. INTRODUCTION

Conventional or non-renewable energy sources are the ones that we have been using from decades for our day-to-day energy consumption. It can be utilized for domestic, commercial and industrial consumers. These energy resources are based on fossil fuels like coal, diesel, oil, natural gas etc. Currently, major energy production takes place with the help of conventional energy sources only. However, some day it will become extinct because extreme consumption of these fossil fuels can lead to adverse phenomenon. When the combustion of fossil fuels takes place, since fossil fuels are mainly made up of carbon it releases CO_2 gases into the atmosphere. The greenhouse effect of the above-mentioned problem increases the global temperature of the earth day by day. The other gases like methane, nitrous oxide are also greenhouse gases and their concentration is increasing because of human activities. If the temperature increases due to this greenhouse effect, it will result in erratic weather patterns, floods, droughts etc.[1]
All the above-mentioned problems related to fossil fuel based energy generation can be reduced largely by two possibilities:

- Improving the quality of fossil fuels used
- Alternative sources of clean energy

Therefore, looking into one of the suitable energy resources, which is sustainable, clean and non-extinct in nature the best choice, is renewable energy sources. Amongst the various non-conventional energy sources that are available in nature like solar, wind, geothermal, biomass, tidal, ocean thermal and etc, solar energy is the first & best choice for electricity production as it is abundantly available at any given choice of location, it is equitable and quantifiable.
It's an interesting fact to know that renewable sources of energy was never a point of discussion to any scientists or policy makers. The search for alternative sources of energy came into grip in 1970s following the oil crisis where the prize of fossil fuels raised drastically.

Solar Energy

Amongst the various renewable energy sources, solar energy has the humongous potential and if only a trivial of this energy source if utilized, it can replace major electricity production in any parts of the world. Energy comes to the earth from the sun. It is estimated that the solar power that touched the atmosphere is 1017 watts; the solar power that touched the surface of the earth is 1016 watts. Roughly, the total power request required for overall civilization is equal to 1013 watts. We can analyze from the above statements that sun gives 1000 times more power to us. Thus, if we use even 5percent of this energy it will be 50times what the world will require for the consumption as shown in Fig1[2]

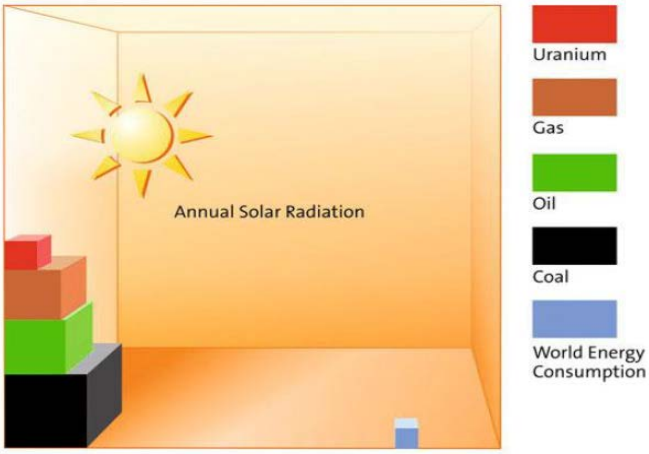

Fig1: The picture depicts the amount of solar radiation the earth receives which is 1000 times better to meet the energy demand

Sun's energy: Advantages-

- renewable energy source is undying
- Clean energy source, no harm to the environment
- This source of energy is humongous (power estimated from the sun intercepted by the earth is found to be $1.8*10^{11}$ MW)
- Solar energy is free, roots no pollution

Sun's energy: Conversion challenges-

- Cost of energy
- Intermittent in nature
- Dependent on location
- Capital cost is huge

Direct and Diffuse radiation

Solar radiation entering at the atmosphere of the earth has a peak irradiance of 1367W/m^2 (Solar Constant). When it reaches the surface of the earth, the peak irradiance is 1000W/m^2.

Light is replicated from the earth in three ways majorly:

- Radiations are reflected back into the space
- Radiations are reflected off into the clouds
- The earth's surface itself reflects sunlight

Solar Radiation that enters into the earth's atmosphere differs in the nature and amount of radiation at the atmospheric level.

Direct Radiation or Beam Radiation: Solar radiation that reaches directly to the earth's surface as shown in Fig2
Diffuse Radiation: Solar radiation which gets absorbed by clouds and gases and then reaches the earth surface as shown in Fig2

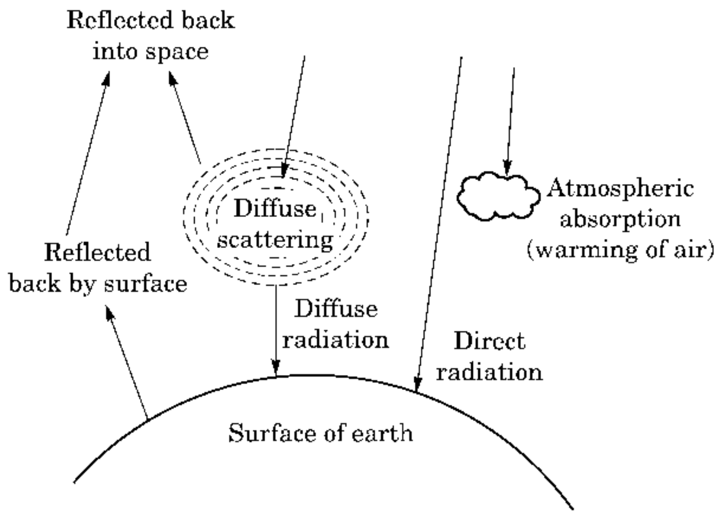

Fig2: Direct, diffuse and total radiation

Direct + Diffuse radiation = Total radiation received at any point on the earth's surface. This is also termed as Irradiance/Insolation.
Insolation differs extensively according to various location. While designing any system, considering the characteristics of the solar radiation data is an important criterion.

Solar Cell & Characteristics

The conversion from solar energy into electrical energy takes place in a solar cell whose principle is termed as photovoltaic effect. PV effect is observed in various type of materials, but it is best suited for semiconductors. Solar cells forms the fundamental contribution in solar electricity generation.[3]
Cells → Modules → Array

Solar cells are described by four parameters:

- Short Circuit Current – I_{SC}
- Open circuit Voltage – V_{OC}
- Fill factor - FF
- Efficiency - ŋ

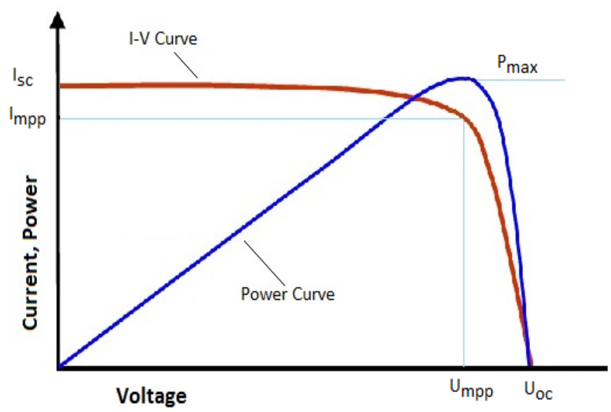

Fig3: I-V & P-V Characteristics of solar cell

When any PV module is connected to a part of measurement, I-V & P-V characteristics obtained is as shown in Fig 3. The amount of electrical power delivered by the PV module at various voltages is shown.
P_{max} represents the maximum power provided/obtained by the photovoltaic module. The term P_{max} is very important in power generation concept as this is what determines the efficiency of the given system.

Factors affecting solar cell performance

Perfromnace of photovoltaic cell/module/array is affected by various factors which inturn affects the characteristics of the cell. The significant factors are mentioned here:

- Irradiance
- Temperature
- Shading

Irradiance: The amount of solar radiation hitting the cell will determine the power output of the given system.

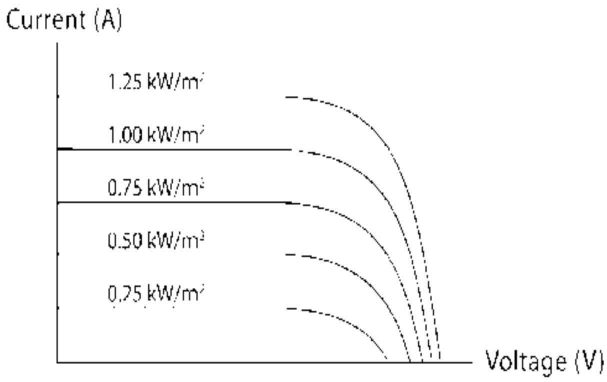

Fig4: As the irradiance in kW/m² increases, the power output also increases

Temperature: This is one of the important factor that affects the PV array performance because irradiance hitting the solar panels will also heat up the panels. It is very common to say that the temperature of the module can reach upto 70ºC during sunny days.
Note that, as temperature increases, V_{OC} decreases quickly and I_{SC} starts to increase slowly. Since, Power = Voltage * Current, the power output will also reduce automatically.

Cell temperature = ambient temperature + 25ºC ------ (1)

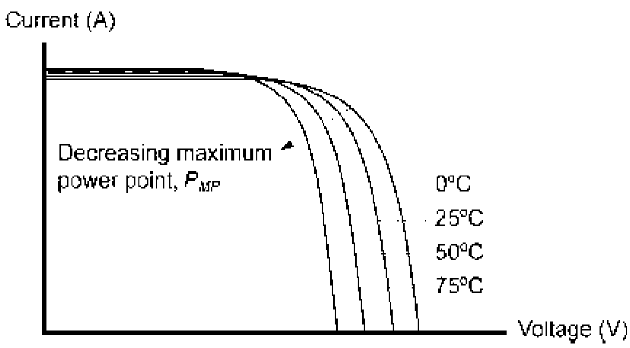

Fig5: As voltage decreases, power decreases

From Fig5. we can conclude that since power reduce with reduction in voltage for hot temperatures the output of PV array needs to be calculated considering the temperature effects. Therefore, cell temperature is determined according to the equation 1 mentioned above.

Shading: For any electricity to be produced by the PV cell it requires sunlight. Ex: if we 9*4 matrix and even if one cell does not receive sunlight, it will reduce/no overall output of the PV array. [4],[5]

Fig6: Shading observed on a panel

As observed in the fig6, even a small amount of shading on the panels can reduce the output power. We are aware that, cell are connected in series which forms a module. Module can be connected in series and panel to form an array. When cells are connected in series current through every cell remains to be the same. Therefore, under shading of even one cell the overall current output reduces. This shading if continues for longer duration can lead to irreversible damage.

Hot spot heating: The phenomenon of hot spot heating will occur when any cell in the module is shaded and its output power reduces. Here, the current flowing through other cells will start flowing through that one shaded cell causing it to heat up very fast. This will lead to cell damage, which we call as cracking and can lead to breakage of glass covering.

Shading cannot be avoided because it is a natural phenomenon. However, it can be overcome by adding a diode in parallel to the cell. As inserting, a diode in parallel to the cell can provide a path for the current flow. It is like providing an alternate path to the current. This will help in avoiding complete damage to the cell. This type of diode is referred to as “Bypass diode”.
Per module manufacturers try to install, two or three bypass diodes.

2. SOLAR ARRAY CONFIGURATION

Solar cell: Every cell has unique and individual characteristics. While designing array characteristics even if one cell is not functioning correctly the overall output of the system automatically reduces.

Connecting PV cells to create a module: photovoltaic cells having similar characteristics are connected together in series to form a photovoltaic module. When cells are connected in series note that current remains the same and voltage gets added up. Therefore, current output of one module is equal to current output of each cell. Due to shading effect or etc., even if one cell is underperforming it will reduce the overall output performance of the system. The characteristics of the cell automatically changes.

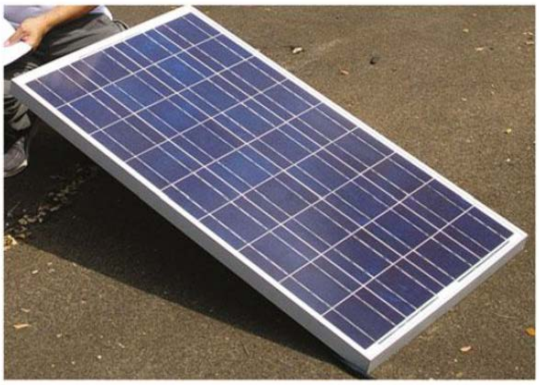

Fig7: PV Module: (9*4) grid = 36 cells

As shown in fig7. PV module is obtained by connecting many cells in series. Generation of power obtained from a single cell is insufficient for domestic applications like home lighting, water pumping etc. We need to connect many of them to get a desired output.
Creating an Array: To make an array modules are connected in series and then in parallel. Modules connected in series or parallel is referred to as "string".
Fig.8 shows the overall configuration of solar array.

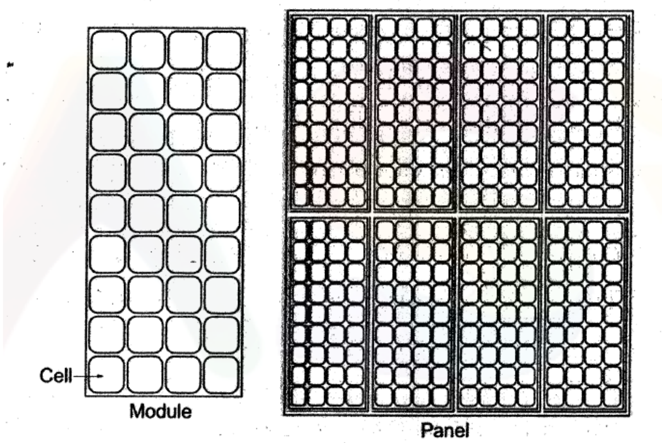

Fig8: PV Module and Array

3. MISMATCH IN CELL OR MODULE

Matching of many cells interconnected together to form a module is very important for the performance of the system. Matching in the sense its factors like V_{oc}, I_{sc}, V_m and I_m for all the cells connected must be the alike. Any mismatch in these parameters will give rise to losses. Peak power of the group is always less than the sum of individual peak power of the cells. [6]

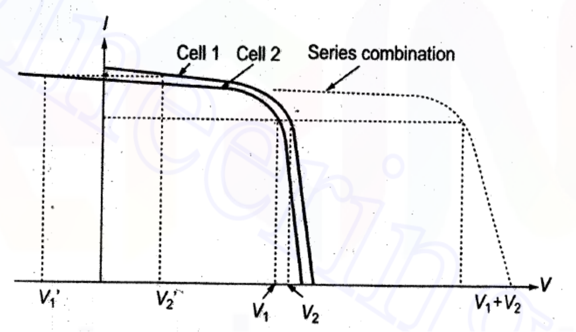

Fig9: Composite characteristics of two cells connected in series

Let us consider cells to be connected in series. WKT, when cells are in series the current drawn by every cell remains to be the same whereas the voltage is added up across the output voltage as shown by the composite characteristics in Fig9. At one specific point, one cell may be operating at peak power referred to as global peak and others might not be. Therefore, peak power of the group of the cells is always less than the power of individual cells. It is simple to say that one cell will be producing power and the other will be wasting the power. In order to reduce cell mismatching cells are manufactured from the same batch of material.

Effect of shadowing: Partial shadowing leads to serious significances causing hotspots, which will eventually damage the module.
Under these conditions, we can examine the operation of the module in two ways:
a. Partial shadowing of a cell in a series string of cells when open circuited
b. Complete shadowing of one cell in a series string of cells when short circuited

Partial shadowing of a cell: The effect of partial shadowing of cells is as shown in fig.10.

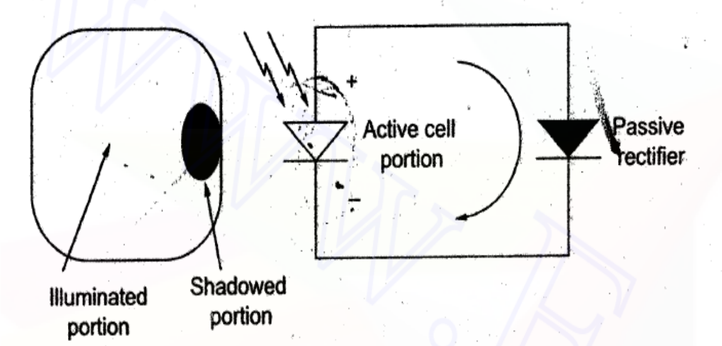

Fig10: Partial shading effect

From fig10. we can infer that in a cell one portion is partially shaded the other portion is illuminated. It is evident from the practical operation of the cell that the portion that is shadowed will not generate any power whereas the illuminated portion does. The illuminated portion will generate voltage, which will forward bias the rectifier. If the shadowed portion persists, circulating current will continue to flow and results in extreme heating of the shadowed portion. This phenomenon is referred to as “Hot spot effect”. [1]-[7]
Bypass diode: let us consider ‘n+1’ no of cells connected in series with one cell completely shadowed as shown in fig11.

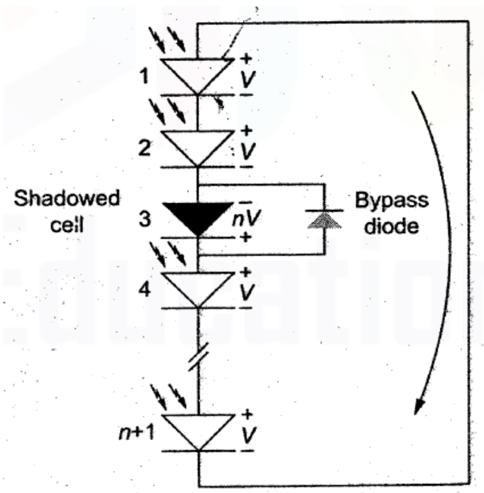

Fig11: shadowed cell in parallel with a bypass diode

Voltage across each cell will add up and appear across the shadowed cell as reverse bias voltage nV volts across shadowed cell. In case PIV (Peak Inverse Voltage) of the cell is more than nV volts there will not be circulating current flowing through the cell. In case if the PIV is less than nV volts then circulating current will flow which will damage the cell severely. To avoid this partial shading effect we connect a bypass diode in parallel with the cell that is affected. The function of bypass diode is to allow another path for the current movement. During normal condition, the bypass diode has no part in the system. However, providing bypass diode for every cell can lead to some losses therefore it is practiced internationally to connect a bypass diode for every 18 solar cells. For every 36 cells, two bypass diodes will be used.

PV & IV Characteristics: The PV Characteristics generally or in ideal condition will have only one peak value as shown in Fig12.

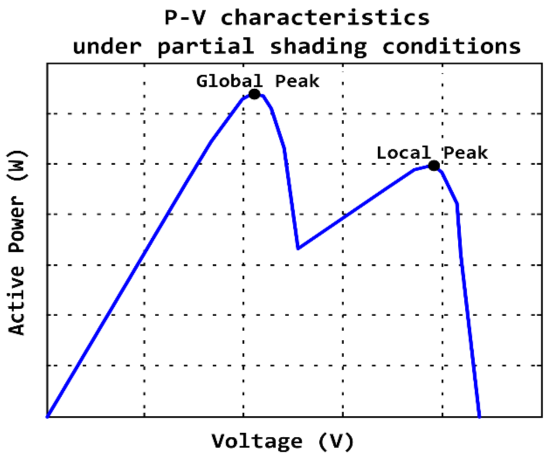

Fig12: PV characteristics of a solar cell representing global and local peak

When there is partial shading effect it will display more than one peak due to bypass diodes connected in the circuit. The change is characteristics is as shown in the fig12. the one obtained during ideal or normal operating condition is global peak, the peaks obtained during partial shading condition is local peaks. [8]

The effect on IV characteristics by blocking the solar cells will basically result in reduce power output which is produced by the solar cells.

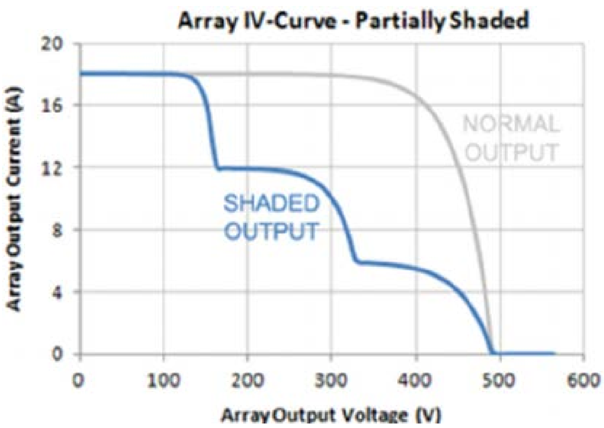

Fig13: IV characteristics of a solar cell with partial shading effect

As shown in fig13. When the cell is shaded the output current of the array automatically reduces for the same output of array voltage. If current reduces then power automatically reduces.

4. SIMULATION of effect of partial shading on PV array

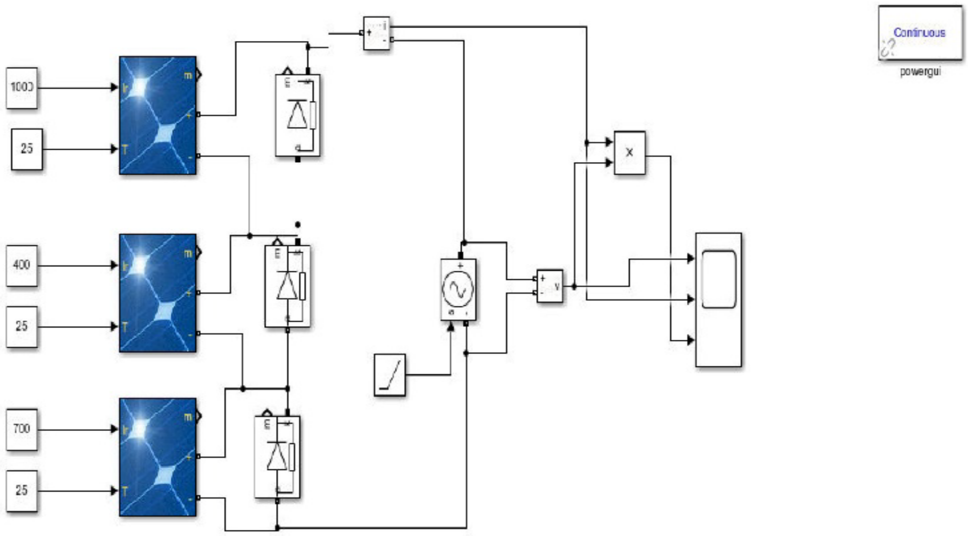

Fig14: Simulation of the paper

Fig14. Shows the simulation of the design of partial shading effect on PV panel. Three panels in series is connected with bypass diode in parallel with it. When the panel is shaded current flow will be blocked to that cell and the current from remaining cells will start flowing through that shaded cell to overcome this will use bypass diodes. If no bypass diode is used the panel will get heated up. Panel under partial shading condition will give rise to multiple peaks on PV and IV characteristics. [9]-[10]
To show this above condition in MATLAB simulation we will first keep constant irradiance and temperature for all three panels and observe the PV and IV characteristics. Then the irradiance value will be changed for each panel to observe the partial shading effect of the panel. To vary the load voltage I have used controlled voltage source with ramp input. In this simulation, PV array has parallel strings =1 and series strings = 1. Voc = 36.9Volts and Isc = 7.54A.

The circuit simulated in MATLAB software has two factors that will affect the characteristics externally. One factor is the irradiance and the other factor is ambient temperature. These two factors will be used as input parameters to check the outputs. Note that all the parameters are kept at standard temperature conditions initially.

Results and discussions:

To analyze the effect of changes in the PV and IV characteristics first standard test conditions on the panel is simulated with Irradiance = 1000W/m^2 and ambient temperature = 25ºC for all three PV array. This condition is without shading effect. The results thus obtained is as shown in Fig15.

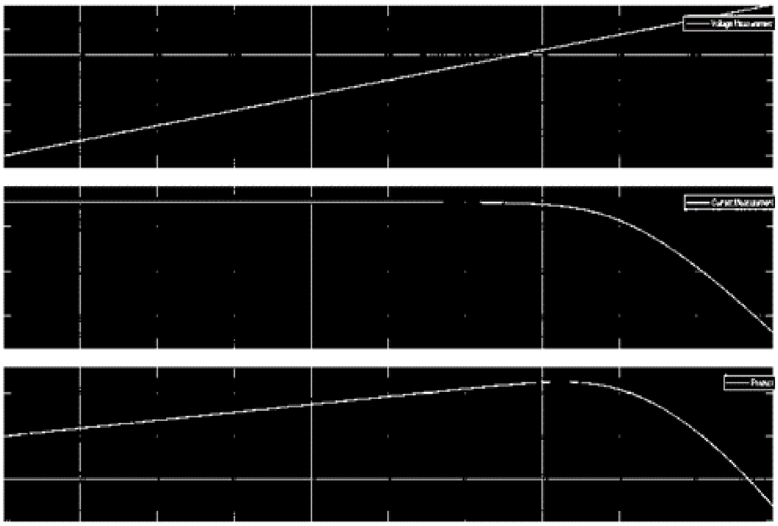

Fig15: Solar PV and IV characteristics based on STC

As the simulation lets us to modify the data according to the input factors like irradiance, temperature, Isc, Voc etc, the next case shown in Fig16 is with partial shading effect by changing the irradiance value in the input which automatically changes the IV and PV characteristics.

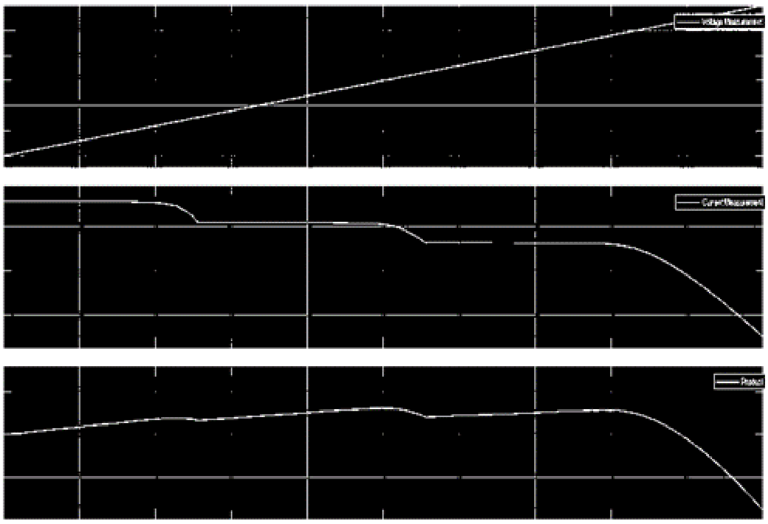

Fig16: Solar PV and IV characteristics under shading effect

From fig16. we can observe that where there is higher irradiance at that point we can observe global peak as the irradiance value changes for different panels to show the partial shading effect we are using irradiance as the input parameter, we can observe multiple peaks along with global peak. This indicates greater voltage peak lessens as the shaded module irradiance lessens.

5. CONCLUSION

Analysis of photovoltaic systems under different conditions is conceptually put forth initially in the paper. The conditions vary based on various meteorological parameters like Irradiance, temperature etc. one of the prominent effect we come across in PV panel operation is partial shading effect. PV systems are extremely vulnerable to partial shading. Whenever there happens partial shading the maximum power of a PV system decreases radically. However, all these changes happen based on the configuration and location of the PV system. MATLAB/Simulink software is used to develop and show the behavior of the system under normal and partial shaded condition. To overcome heating of the panels due to shading bypass diodes are attached in parallel with cell and the same has been simulated. The results conclude that because of partial shading the value of output power produced by solar panel can reduce from normal operation.

Acknowledgment

I express my sincere gratitude towards my college BNM Institute of Technology for constantly supporting and motivating us to take up research activities

References

[1] Andhika Giyantara, “Analysis of Partial Shading effect on solar panel power output”, Journal of physics, Conferenceseries,doi:10.1088/17426596/1726/1/012022

[2] Rupendra kumar P, Om Prakash mahela, Abhishek sharma, jianbo bai, yogesh k Chauhan, baseem khan, “Impact of partial shading on various pv array configurations and different modelling approaches: a comprehensive review”, IEEE Access, October 14, 2020, DigitalObjectIdentifier 10.1109/ACCESS.2020.3028473

[3] J C Teo, Rodney H G Tan, V H Mok, Vigna K Ramachandramurthy, Chiakwang tan, “Impact of partial shading on the PV characteristics and the maximum power of a photovoltaic string”, 17 july 2018, Energies 2018, 11, 1860; doi:10.3390/en11071860

[4] Basim A. Alsayid, Samer Y. Alsadi, Ja’far S. Jallad, Muhammad H. Dradi, “Partial Shading of PV System Simulation with
Experimental Results”, Smart Grid and Renewable Energy, 2013, 4, 429-435, http://dx.doi.org/10.4236/sgre.2013.46049 Published Online September 2013

[5] Niti agarwal, birinchi bora, supriya rai, avinashi kapoor, mridula gupta, “Performance Enhancement by Novel Hybrid PV Array Without and With Bypass Diode Under Partial Shaded Conditions: An Experimental Study”, INTERNATIONAL JOURNAL of RENEWABLE ENERGY RESEARCH N. Agrawal et al., Vol.11, No.4, December, 2021

[6] Anas Al Tarabsheh, Muhammad Akmal, Mohammed Ghazal, “Improving the Efficiency of Partially Shaded Photovoltaic Modules without Bypass Diodes”, Electronics 2021, 10, 1046. https://doi.org/10.3390/electronics10091046

[7] Amardeep Chaudhary, Shriya Gupta, Dhriti Pande, Fazal Mahfooz, “Effect of Partial Shading on Characteristics of PV panel using Sim s cape”, Amardeep Chaudhary et al. Int. Journal of Engineering Research and Applications