

Performance of Partially Shaded Solar Photovoltaic Systems

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Abstract:

Renewable energy is the energy which is directly collected from natural sources such as sunlight, wind, waves and geothermal. This form of energy is becoming important for us as the conventional sources are usually limited, and can be utilized, for example, in the field of electricity generation, where solar irradiance plays an important role. Shadowing anyhow may result in a non-uniform irradiance on the PV modules affecting their performance. This study aims at evaluating the performance of conventional SPV systems under shadowing effects. Simulations are done on Simscape of MATLAB for this study.

Keywords: Partial shading effects, PV model, Solar Irradiance, Simulation/Simscape

1. Introduction

The sun is the heart of the solar system and is the only source of energies available or perceived on our earth. Thermonuclear fusion of Hydrogen at the surface of the sun is responsible for its high surface temperature of about 6,000°C. Sun emits short waves of electromagnetic light all around which passes thru earth's atmosphere in the form of the known light spectrum, including infrared, visible and ultraviolet radiations. Sunlight passes through the atmosphere and reaches the earth as daylight. The energy density of solar radiation at upper reach of atmosphere is 1368 w/m². The earth surface receives approximately 1367 watts per square meter equivalent energy from the solar irradiance. This energy reception of the earth surface depends upon the tilt of the incident sun rays with respect to the normal on the incipient earth surface. The earth has a bright light and radiant heat when the solar radiation is not blocked by clouds or atmospheric dust, and has diffused light otherwise. The photon of the sun and its direction changing every time affects the radiation on the earth surface.

A photovoltaic cell is a semiconductor device which converts light energy into electric current at a fixed voltage [Ekpenyong et al, 2013, 01; P. Sathyanarayana et al, 2015,1; Fialho L. et al, 2014, 296]. A silicon based solar photovoltaic cell produces an open circuit voltage of 0.5 to 0.6 volt [P. Sathyanarayana et al, 2015,1]. The photovoltaic process of PV panel depends on the basic operating condition [L. Fialho et al. 2014 296]. These basic operation of the SPV cell is based on three important factors i.e. generation of electron-hole pairs on absorbing the incident photons, separation of the charge carriers of opposite polarity and extraction of these carrier and their mobilization on to the external circuit [P Sathyanarayana et al, 2015,1]. Multiple solar cells integratively form a photovoltaic module, a glass layer on the face side, allowing light to pass through while protecting the semiconductor cells from physical damage. The solar cells are usually connected in series and parallel to control voltage and current conditions on the output nodes. Modules can be interconnected to form an array with desired loading capacity to produce maximum power point (MPP).

Normal operation assumes that the PV module is fully illuminated with sun rays as the solar systems are usually installed on terraces to let them fully open to sun. These systems also keep on working in cloudy weathers as the infrared radiations are always available. However, circumstances may cause a local problem due to which certain cells come under a quasi shade, or a shade continuing for a while. Examples for this type of shading may be feces of birds, stains due to water drops in a rain and sticky accumulation of dust, self shadowing due to the parts or instruments of the installation and dead leaves happen to fall on the panel and stuck there somehow [Mahammeda Idriss Hadj et al,2017,81]. This partial shading causes the cells lying underneath to become standstill. This may affect the battery of cells depending upon their connections. The cells are acting as a supplier of electric current at a fixed voltage, therefore the cells happen to lie under shade may stop working due to reverse bias [Fei Lu et al, 2013, 249] and be considered as pure resistor equivalent to the internal resistance of the cell. For the cells connected in series, a cell under shade will be ceasing offit's voltage and

current contribution to the series branch. As a result, gets heated [Saadsaoud M. et al, 2016, 415] and the branch will operate at a voltage reduced by a factor of “1”, and hence the overall series circuit. Bypass diodes across branches are used for the purpose of security of the cell arrays or panels from any physical damage. This helps to put the affected cell strings shorted out, through the bypass diodes turned ON.

In order to enhance power out efficiency, the cell strings may be of shorter sizes and hence the number of bypass diodes increases. This will cost an increase in power loss due to the reverse biasing of the by-pass diodes [Teo.J.C et al, 2017, 226]. A reverse connected diode does ensure a constant current or reverse saturation current. The reverse saturation current of a diode is heavily temperature dependant and is reported to double for every 10°C temperature rise [Jacob Millman et al, 2007]. In order to reduce power loss due to shadow on SPV panel a shunt diode is applied. Several studies had been done on shading which affects the characteristics of SPV system [4]. These effects can be seen by the analysis done by modeling of the Solar PV Panel under shading condition and its simulation done on Matlab Simulink.

Since the cells connected in series and parallel circuits, the performance of solar panel is reduced even if small part of the panel somehow comes under a shade[Teo.J.C et al, 2018, 2 off 22]. Another important parameter of partial shading is overheating. Partially shaded part of the solar panel generates less amount of energy as compared to the un-shaded part of the panel. Hence power regenerated in shaded and unshaded parts of panel varies. The shaded and un-shaded part of the panel is shown in figure 1(a, b) . Figure 1(a) shows the shaded area due to bird’s feces and figure 1(b) shows the shaded part of panel due to building. Figure 1 and figure 2, these images are taken from the roof top of Integral University, having solar panel, manufactured from Vikram Solar, model ELDORE VSP.70.AAA.03.04. It is made of polycrystalline material having 72 cells and can generate 310-330 watt power (single panel). The I-V characteristic is affected by shading effects on SPV panel



Figure 1a: Shading due to Bird’s Feces



Figure 1b: Shading due to Building



Figure 2: SPV Panels on Roof Top of Integral University

There are techniques by which the shading effects of the solar panels can be reduced. One simple and quite elegant technique is to use bypass diodes. Here in this work, this aspect is studied in some detail.

1.1 Bypass Diode:

By pass diode are applied to prevent the damages occurring due to reverse bias on partial shading of SPV panels. These diodes are connected in parallel to SPV panels in reverse direction to solar cell. Under normal condition the solar cell operates in forward bias condition and these bypass diode will work as reverse bias hence act as open circuit [Seyedmahmoudian et al, 2013, 133. If this solar cell operates in reverse bias condition then the bypass diode will conduct in forward bias condition, allowing the current to flow through the load.

2. Modeling of Solar PV Panel under Partial Shading Condition

Modeling of Solar PV Panel under Shading Condition is done using Matlab Simscape. Simscape helps to create model of physical system using simulink and test system-level performance. Figure 3 shows the model of SPV system under shading condition.

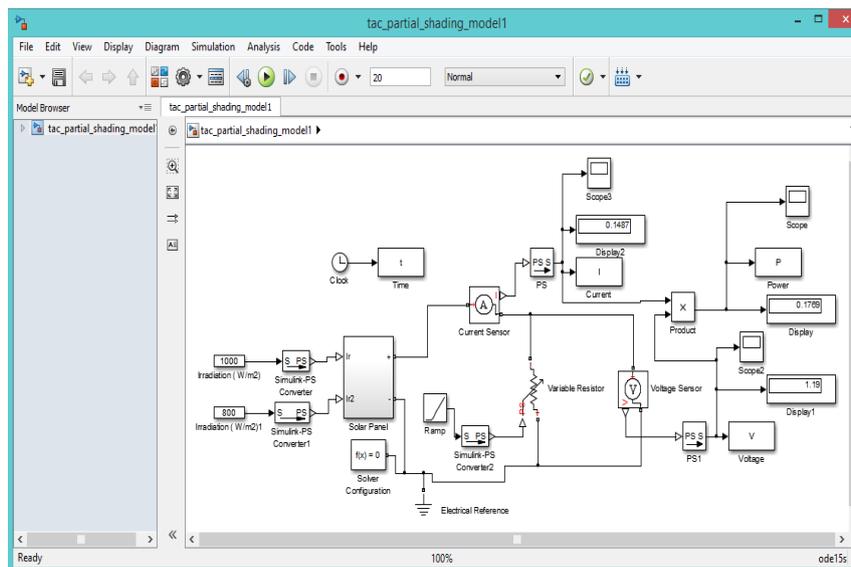


Figure3: SPV Model under Shading Condition

2.1 Simulation of SPV Module with Shaded and Un-shaded PV Cells

To understand the performance of SPV system under shading and un-shading of PV cell simulation is done in both the condition at the irradiance of 1000 w/m^2 and 800 w/m^2 and the variation in their characteristic clears the picture. The subsystem model of shaded and un-shaded photovoltaic cell with bypass diode is shown in figure 4.

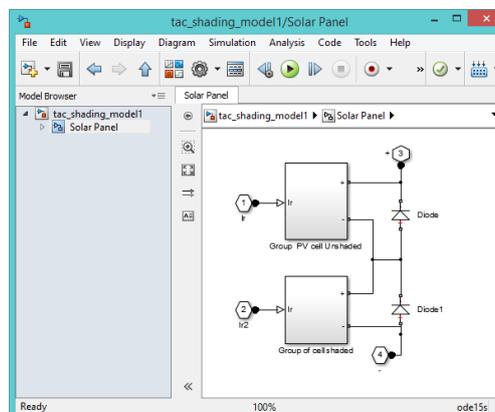


Figure 4: Subsystem of solar panel with groups of PV cell shaded and un-shaded

60 cells are connected in series (6 groups of 10 cells each). Bypass diode is connected across cells in a group. The characteristic curve of the SPV module under STC condition (1000 W/m², spectrum AM1.5 and 25°C), the output current and power with respect to voltage is shown in figure 7 and 8 respectively. If 6th row of the cell is shaded or the circuit get disconnected as shown in 6th group of cell the current passed through the cell in serpentine arrangements through a bypass diode D3 as shown in figure5.

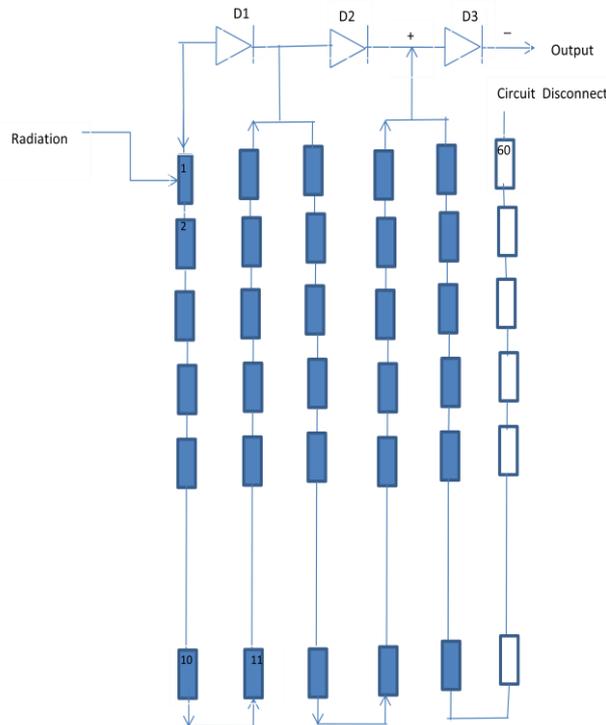


Figure 5: PV Module with Solar cells connected in series, serpentine arrangement.

2.12 Characteristics of SPV Module with un-shaded PV cells

The un-shaded photovoltaic cell is shown in figure 6.

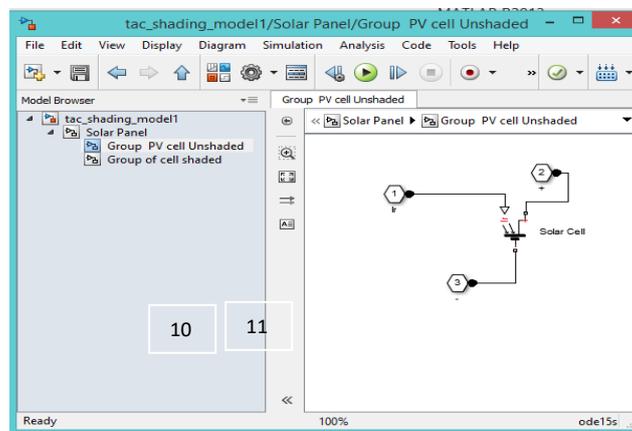


Figure 6: Un-shaded PV cell from subsystem solar panel

The output of current is given by the relationship [Lee. Hoe-Gil et al, 2018, 10]

$$I = I_{ph} - I_o \left(e^{\left(\frac{v_d}{\alpha v_t}\right)} - 1 \right)$$

Where $V_t = \frac{kT}{q} = 20\text{mV}$ at room temperature

V_d = Forward bias voltage of diode

I_{ph} = Current generated due to irradiation,

I_o = The dark saturation current of diode

V_t = Thermal voltage of diode

Figure 7: I-V Characteristic of Un-shaded PV cell (Uniform irradiance)

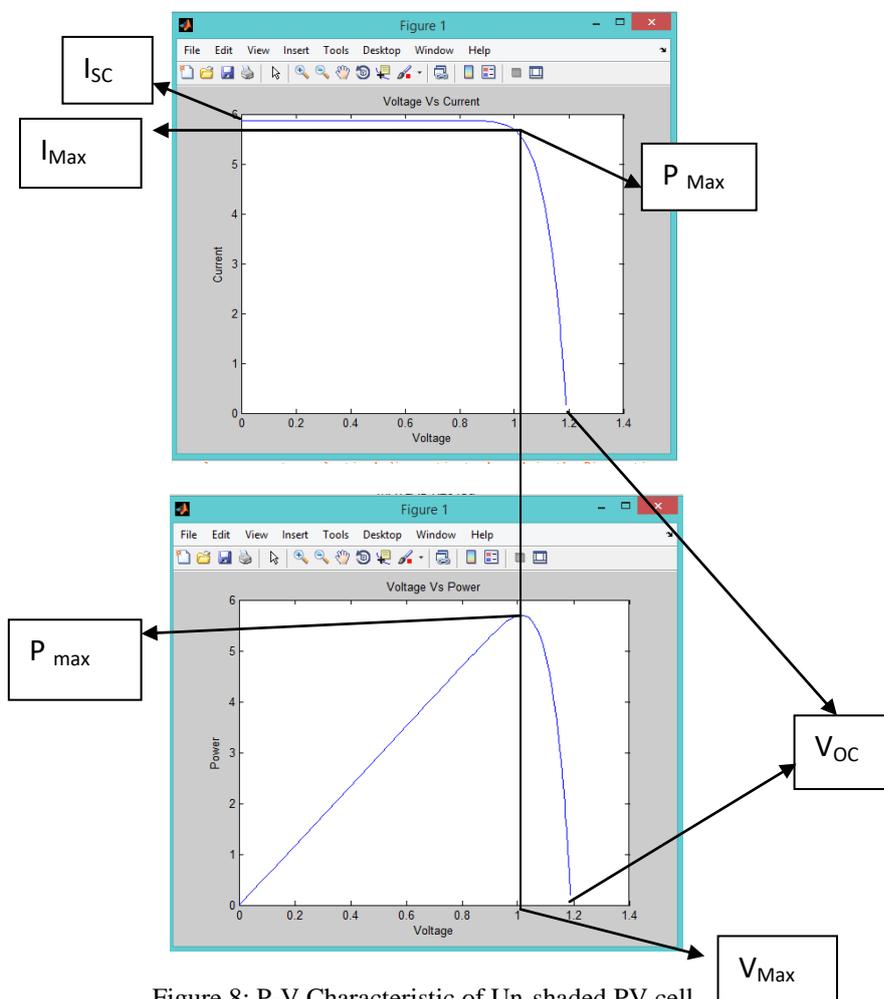


Figure 8: P-V Characteristic of Un-shaded PV cell (Uniform irradiance)

The DC power at the output is the product of current and voltage as shown in figure 8. The current is maximum when there is no resistance. This maximum current is known as short circuit current (I_{sc}). The voltage is zero when there is shorting. The maximum voltage occurs when the circuit is open. This voltage is known as open circuit voltage (V_{oc}). Under this condition resistance is infinite and no current flows through the load [Tarek Selmi et al, 2014, 100].

The efficiency of solar cell is given by the ratio maximum power output to the input solar radiation [Sathyanarayana, 2015, 5(1A), 1-4, Pachpande S.G et al, 2012, 47] thus

$$\eta = \frac{V_{mp} \times I_{mp}}{(I \times A)}$$

Where,

- V_{mp} = maximum voltage at peak power
- I_{mp} = maximum current at peak power
- I = solar radiation per square meter
- A = area on which solar radiation falls

2.2 Characteristics of SPV Module with Shaded PV Cells

The shaded photovoltaic cell of the subsystem solar panel is shown in figure 9. The partial shading was done by modeling two PV modules connected in series and a bypass diode in parallel to it as shown in figure 10

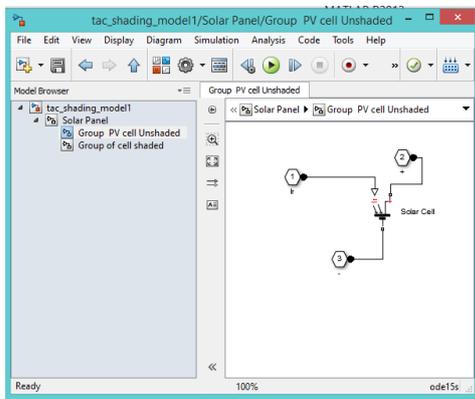


Figure 9: Shaded PV cell from subsystem solar panel

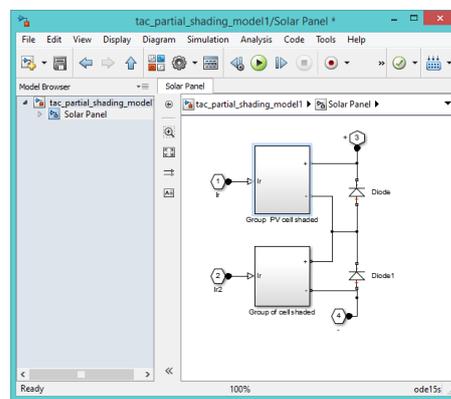


Figure 10: Two modules in series with bypass diode in parallel

The partial shading is given by irradiance 1000 W/m² and 800 W/m² at 25° C temperature. During partial shading the solar cells produces low current as compared to un-shaded solar cell. The low irradiance solar cell becomes reverse bias hence dissipating more power than the high irradiance solar cells. Thus low irradiance solar cell gets overheated causing damage or junction break in the cells.

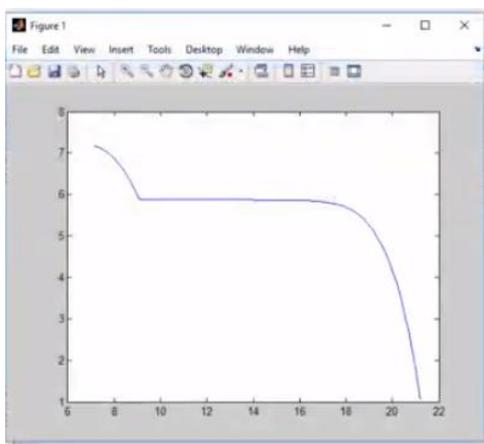


Figure 11: I-V Characteristic of Shaded PV cell

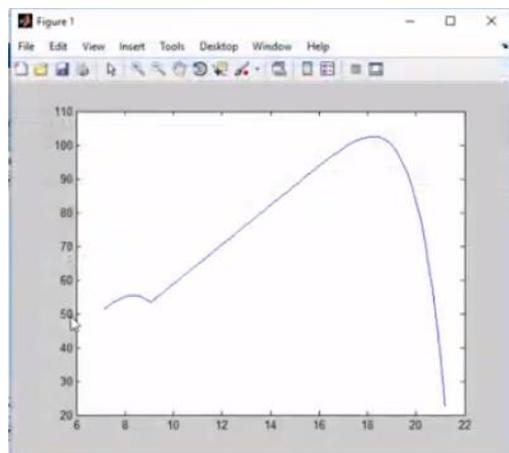


Figure 12: P-V Characteristic of Shaded PV cell

(Non uniform irradiance)

Hence, the characteristics of solar cell changes with irradiation. This change can be seen in the graph shown in figure 11 and 12 respectively. Due to these reasons the performance of current and power in shaded panel is poor in comparison with un-shaded panel as shown above.

Result

3. Comparative Analysis of Performance of SPV panel

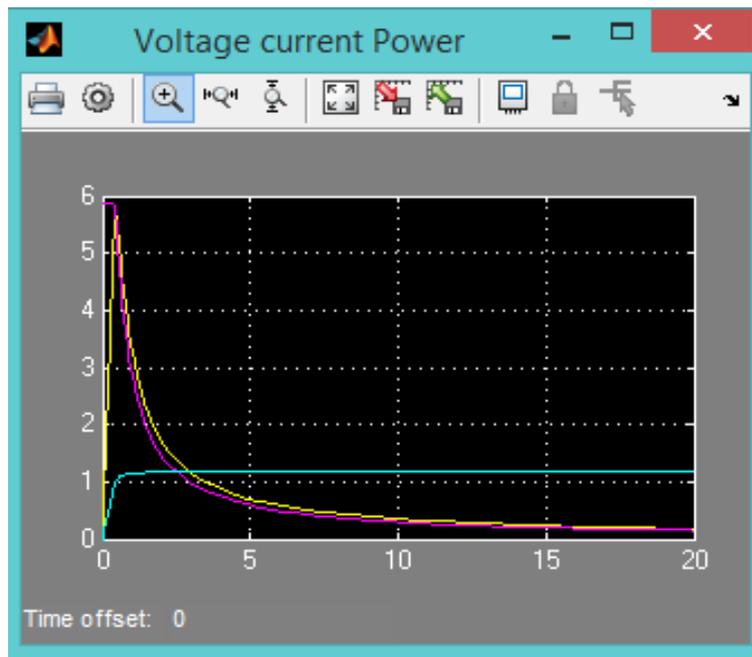


Figure 13: Current Voltage and Power w.r.t time for un-shaded PV cells

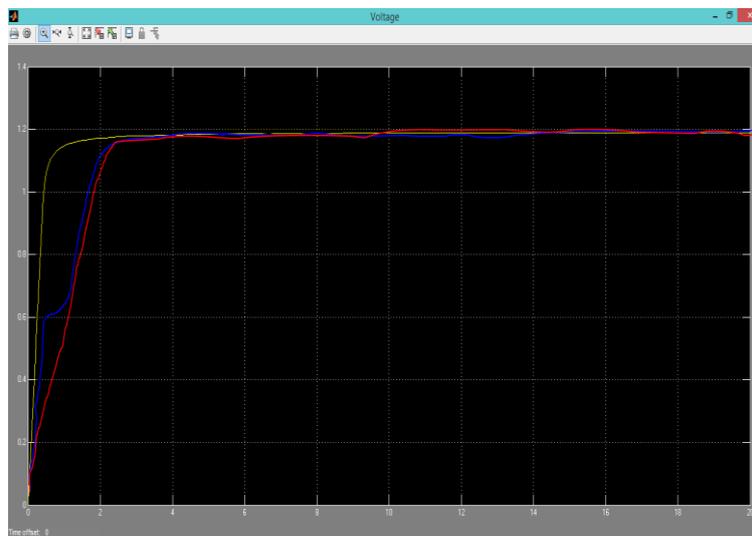


Figure 14: Comparison of voltage with normal irradiance (yellow), Blue partial shading

(with bypass diode), Red partial shading (without bypass diode)

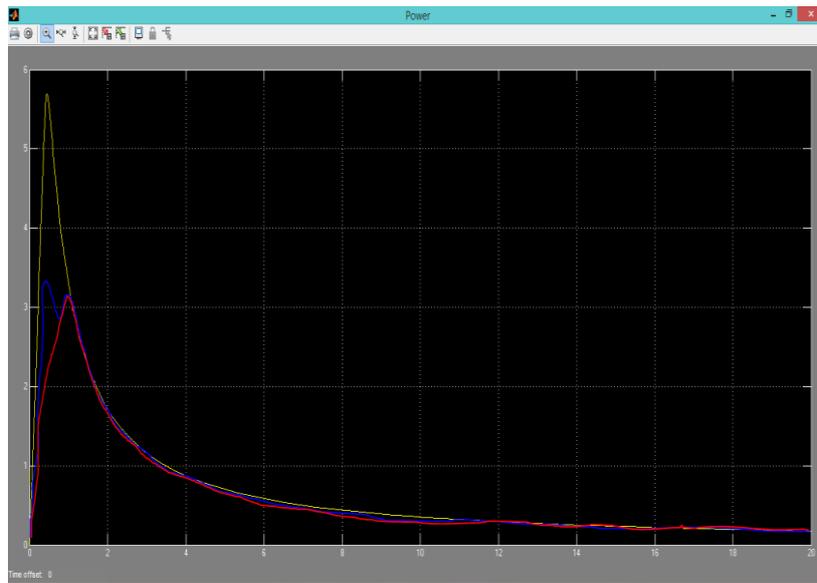


Figure 15: Comparison of power in uniform irradiance (yellow), Blue partial shading (with bypass diode) and Red partial shading (without bypass diode)

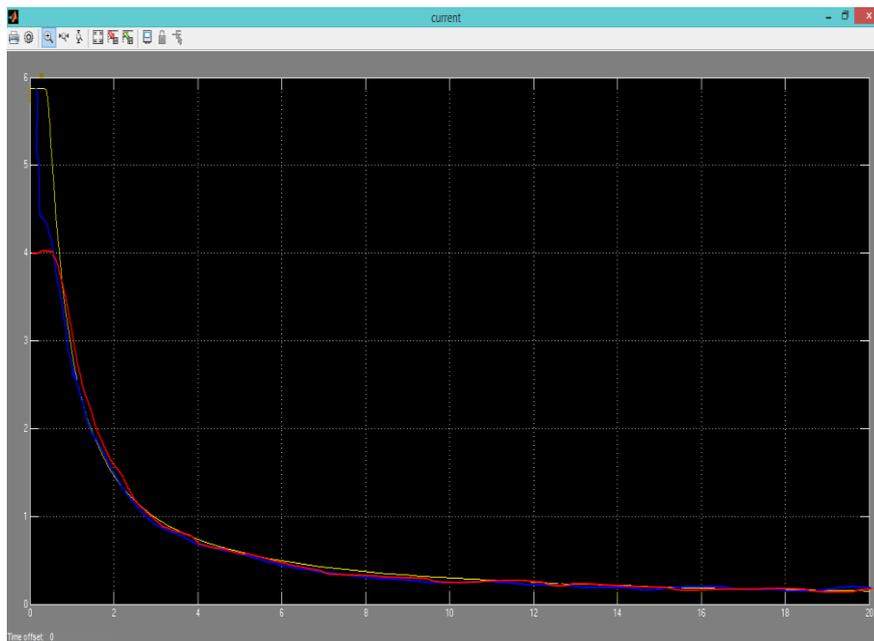


Figure 16: Comparison of Current in uniform irradiance (yellow), Blue partial Shading (with bypass diode) and Red partial shading (without bypass diode)

Conclusion

The performance of SPV cell is affected by partial shading. The electrical characteristic of SPV module is analyzed and shown in graph. There is a difference in I-V and P-V characteristic in case of partial shading. The PV modules are connected in series and bypass diodes in parallel reduces the

power under shading condition as shown in figure 15. Thus, the degradation of maximum power is clearly visible from the graph. We conclude that with partial shading, SPV module generates low power at the load and thus the power degrades.

Acknowledge

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