Industrial Engineering Journal
ISSN: 0970-2555
Volume : 51, Issue 03, March : 2022

ANALYSIS AND BRIEF STUDY ON SOLAR PV SYSTEM

[1*] **Dr. SATYAJIT MOHANTY**, [2 *] **Mrs.MITALI MOHAPATRA**
[1*] *Asst. Professor, Dept. Of Electrical Engineering, NIT BBSR,*
Asst. Professor DEPT. of Electrical Engineering, NIT BBSR,
[1], **satyajitmohanty@thenalanda.com,** ,
[1*] **mitalimohapatra@thenalanda.com,**

Abstract

Global anthropogenic activities that cause harmful greenhouse gases (GHG) to enter the atmosphere have increased the challenges of climate change. The increased awareness of the need to mitigate climate change has led to an intensive treatment of the harmful environmental effects of energy based on fossil fuels, which encourages the transition to renewable electricity production in addition to traditional electricity production methods. The demand for renewable energy is increasing every day due to rising energy prices and environmental changes. The current electricity grid is highly dependent on traditional fossil fuel-based power generation units. The transmission of electricity from these production units to the consumer through the electricity network of distribution lines causes significant electricity losses. In addition, several traditional fossil fuel-based power generation devices cause harmful effects, e.g. radiation produced by nuclear power plants, CO2 emissions. Therefore, electricity production must be reformed, moving away from fossil fuel-based plants to renewable energy sources.

Introduction

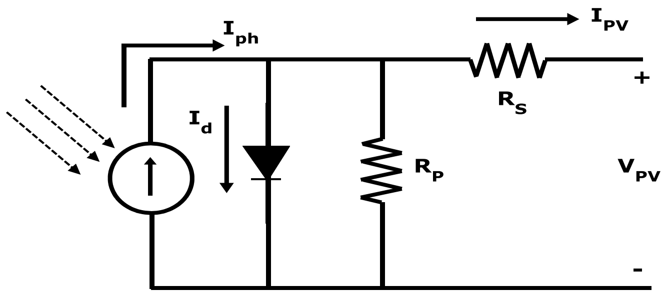
Solar energy provides flexibility ,it can be utilized for large installations or can be used for the small scale generation for house hold use. Once installed, a solar PV system requires very little upkeep, adjustment or maintenance.If we talk about the PV panels, they can be installed in the areas where solar irradiance is more, its installation is easy and don't take more time even. Unlike the other renewable energy resources like biomass, and wind energy and hydro power, solar energy has very less impact over the environment and less complicated installation. Research suggests that there are advantages of solar power over any of its competition.

The various factors affecting the solar PV performance is analysed in this paper are operating temperature, solar irradiance, dust, colour spectrum and shading. The analysis has been done on the basis of experimental results. In this study, the impact of different factors that influence on PV power generation has been reviewed comprehensively.

Modeling of Solar PV System

The solar PV devices basically can be represented in two different models.

- Single Diode Model
- Double Diode Model



One diode equivalent circuit model of solar PV cell

The characteristic equation for single diode circuit model is given by

$$I_d = I_S\left[\exp\left\{\alpha\left(V_{PV} + R_S i_{PV}\right)\right\} - 1\right] \tag{2.1}$$

Where,

I_d = Diode Current in amperes; I_s = Saturation Current in amperes; R_s = Series Resistance in ohms; R_p = Parallel Resistance in ohms; I_{pv} = Output current of PV cell in amperes; V_{pv} = Output voltage of the PV cell in volts; α = Constant.

And α is given by,

$$\alpha = \frac{q}{AkT_C} \tag{2.2}$$

Where,

K = Boltzmann constant (1.3807×10^{-23} JK^{-1})
q = Electron charge (1.607×10^{-19} C)
T = Nominal Temperature (298.15 K)
A = Ideality factor (Ranges between 1 to 5)

Applying KCL in the equivalent circuit of the PV cell we get,

$$I_{pv} = I_{ph} - I_d - I_{sh} \tag{2.3}$$

Putting the value of I_{ph} , I_d , I_{sh} in equation (2.3) we get ,

$$I_{PV} = I_{ph} - I_S\left[\exp\left\{\alpha\left(V_{PV} + R_S i_{PV}\right)\right\} - 1\right] - \frac{V_{PV} + R_S I_{PV}}{R_p} \tag{2.4}$$

Where,

I_{pv} = Output Current of the PV cell in amperes; I_{ph} = Photon Current in amperes

The photo current depends upon the solar irradiance expressed as

$$I_{ph} = I_{SC} + k_i\,[T_C - T_{Ref}\,]\frac{G_a}{1000} \tag{2.5}$$

Where,

G_a = Solar irradiance (W/m^2); I_{sc} = Short circuit current (amperes); K_i = short-circuiting current coefficient of cell ; T_{ref} is temperature of the cell at STC condition.

The saturation current of the cell is temperature dependent this can be expressed in the equation given below.

$$I_S = I_{RS} - I_S\left[\frac{T_C}{T_{Ref}}\right] - \exp\left[\frac{qE_g}{AK}\left(\frac{1}{T_{ref}} - \frac{1}{T_{ref}}\right)\right] \tag{2.6}$$

Where,
E_g = energy band-gap of the semiconductor utilized as a part of the cell; I_{RS} = Reverse saturation current of the cell at the reference temperature and solar irradiation.

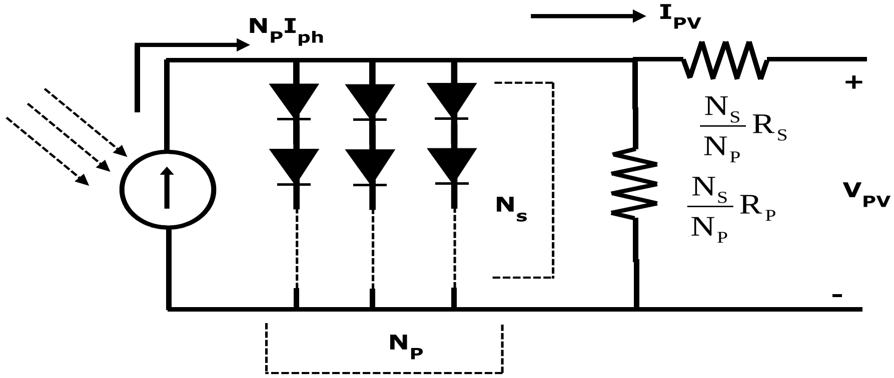


Figure 2.1 PV array equivalent circuit

An individual silicon solar cell has a voltage of just under 0.6V under 25 °C and AM1.5 illumination. A bulk silicon PV module consists of multiple individual solar cells connected, nearly always in series, to increase the power and voltage above that from a single solar cell. To get the required value of voltage and power these modules are connected in parallel fashion as shown in the figure 2.2. which resembles the circuit diagram of the PV group.

Where,
N_s = Number of the modules connected in series in each string of N_p.
N_p = Number of the strings connected parallel in an array.
For such a configuration of an array, the array current is expressed as,

$$I_{PV(array)} = N_P I_{ph} - N_P I_S [e^{[\alpha\left(\frac{V_{PV}}{N_S}+\frac{R_S i_{PV}}{N_P}\right)]} - 1] - \frac{N_P}{R_P}(\frac{V_{PV}}{N_S} + \frac{R_S I_{PV}}{N_P}) \quad (2.7)$$

The effect of change in irradiance level or temperature over the output of the PV is of fluctuating nature and is given by the following equation.

$$I_{SC}(T_1) = \left(\frac{G}{G_{norm}}\right) I_{SC}(T_{1,nom}) \quad (2.8)$$

Where,
I_{SC} = Current at temperature T_1; $T_{1,\ nom}$ = Temperature of cell at normal condition; G_{nom} = Irradiance from the sun at normal condition.

PV Cell Efficiency

$$\eta = \frac{FF \times V_{OC} \times I_{SC}}{\text{Solar power input}} = \frac{P_{out}}{P_{in}} \quad (2.9)$$

or

$$\eta = \frac{I_{sc-max} V_{oc-max}}{A_c(\text{Irradiance level})} \quad (3.0)$$

Where,

P_{in} = Input power (Watt); P_{out} = Output power (Watt); FF = Fill Factor and A_c = Module's effective area (m^2).

Factors Affecting the Performance of the Solar cell

Temperature

The cell temperature play a very a crucial role in the reduction of solar PV cell performance and efficiency. This phenomenon occurs because as the temperature of the PV cell increases, the open circuit voltage of the pV module decreases due to the shrinking of the band gap of the intrinsic semiconductors. The p-n junction voltage temperature dependency can be seen in the diode factor q/kT. Solar cells therefore have a negative temperature coefficient of V_{OC} (β). Furthermore, a lower output power results gives the same photo current because the charge carriers are liberated at a lower potential. Figure 2.3 shows the I-V characteristics at the constant illumination when the temperature changes. Normal operating cell temperature (NOCT) of PV cell depends on the temperature T_m and the ambient temperature T_{amb}. NOCT can be found from the following equation.

$$T_m = T_{amb} + (NOCT - 20)\frac{G_a}{800}$$

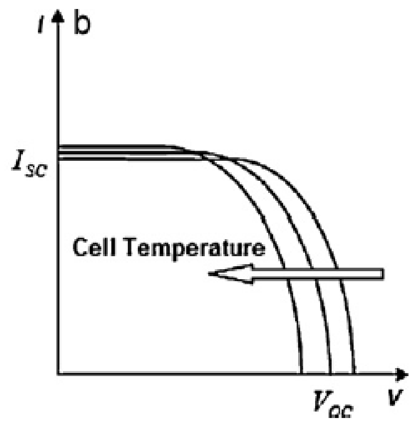


Figure 2.1 Effect of increased temperature on PV module

Dust

when dust particles gets stored over PV cells there is an interference of attenuating and scattering component of incident light. The particles gets attached to the surface of cell due to gravity, electrostatic and mechanical force. The short circuited current reduce to 20 percent of its initial value due to 28 g/m2 , Carbon aggregation with cement deposited to 73 g/m2 , 126 g/m2 for 50 µm limestone, 169 g/m2 for 60 µm and 252 g/m2 for 80 µm limestone. The arrangement of dust material in-fact affects the PV performance it may be noticed particularly.

Dust deposition is not that much affects to open circuit voltage but the short circuit current is influenced, it is affected 30–40% in the open air atmosphere furthermore, 4–5% in the indoor atmosphere.

This dust impact mainly relies on the latitude and longitude of the mechanism of the system. Efficiency differed from 0% to 26% when dust accumulation thickness improved from 0 to 22 g/m2 [34] Due to

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 51, Issue 03, March : 2022

dust accumulation, the efficiency is depend upon the irradiance and Clearness index (kt) is related to the diffusion component. i.e.

$$kt = \frac{\overline{G}}{\overline{G_o}} \tag{3.3}$$

$$\frac{\overline{G_d}}{\overline{G}} = \begin{cases} 1.0 - 0.09kt & kt \le 0.22 \\ 0.9511 - 0.1604kt + 4.388kt^2 - 16.63kt^3 + 12.336kt^4 & 0.22 \le kt \le 0.8 \\ 0.165 & kt > 0.8 \end{cases} \tag{3.4}$$

A_i measures the atmospheric transmittance of beam radiation. The circumsolar diffusion radiation is

$$A_i = \frac{\overline{G_b}}{\overline{G_o}} \tag{3.5}$$

Under clear condition, A_i will be high and under no beam condition it is zero. The global solar radiation incident on the PV panel is

$$\overline{G_t} = \left(\overline{G_b} + \overline{G_d}A_i\right)R_b + \overline{G_d}(1 - A_i)\frac{(1 - \cos\beta)}{2}\left[1 + f\,\sin^3\left(\frac{\beta}{2}\right)\right] + \overline{G}\rho g\left(1 - \frac{\cos\beta}{2}\right) \tag{3.6}$$

Where,

$\overline{G}$ = Local horizontal radiation (kW/m^2); $\overline{G_o}$ = Extra-terrestrial horizontal radiation (kW/m^2); $\overline{G_d}$ = Diffusion radiation (kW/m^2); $\overline{G_b}$ = Beam radiation (kW/m^2); $\overline{G_t}$ = Total radiation (kW/m^2); A_i = Anisotropy index; f = Horizon brightening; ρg = Ground reflectance; β = Slope of surface.

The following equation gives the percentage efficiency.

$$\eta_{reduction} = \frac{\eta_{clean} - \eta_{dusty}}{\eta_{clean}} \times 100\% \tag{3.7}$$

Shading

Shading of cell, illumination non uniformity, damaged cell causes the significant drop of energy in PV framework. Out of which incomplete shading is a major issue. Due to partial shading a lot of harm causes to cell i.e. solar cell may get reversed biased. So it acts as an external load which consumes power from other cells. The overall generation reduced which ultimately causes the hot spot phenomenon. The shaded cell(s) could be half of a single cell or a row of cells half shaded horizontally or vertically as shown in figure 2.4.

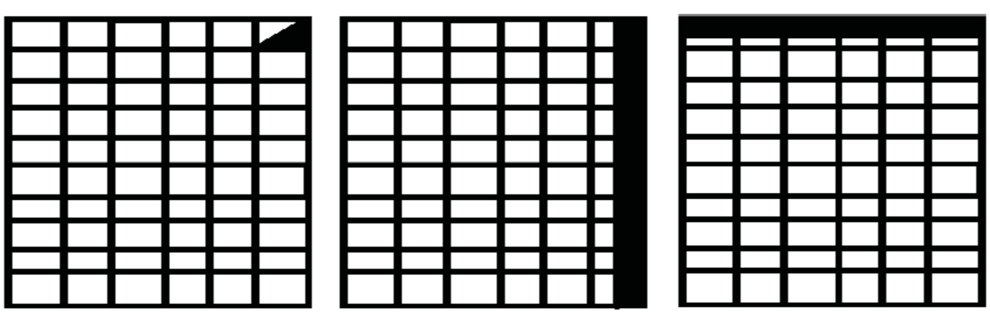


Figure 2.1 Different types of partial-cell shading that reduce module power

Different types of shading causes different types of problems as described earlier in the above statement of soft and hard shading. In both the case there is reduction in energy density. The overall efficiency may get reduced.Each of the cases of shading causes different types of symptoms on a PV module. Due to soft shading voltage of PV modules remains same and current magnitude gets altered. But due to hard shading the effect depend upon the area covered on the cells of PV modules. The uncovered cell will receive the solar irradiance and current will flow as in healthy condition but some current will flow into shaded cells causing hotspots. But as discussed above this problem can be solved by a bypass or antiparallel diode. Sometimes hard shading causes total shutdown of the PV module [35-38].

Irradiance

To observe the affect of variation of solar irradiance it must be taken care how the open circuit voltage and short circuit current is varying so as to predict the efficiency of the solar PV module.

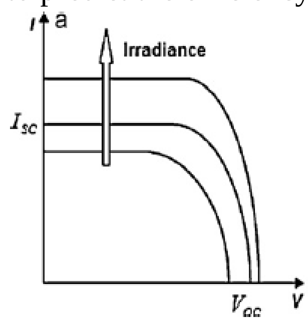


Figure 2.1 Effect of increased irradiance

The open circuit voltage of the solar cell increases logarithmic and the short circuit increases linearly with raise in the solar irradiation. The efficiency of the solar PV module can be calculated by the following expression.

$$\eta = \frac{P_{max}}{G_a \times A_c} \qquad (3.8)$$

Where,

G_a = Solar irradiance (W/m^2) under STC; A_c = Surface area of PV panel (m^2).

Colour Spectrum

The sun light is electromagnetic waves. It consists of multi ranges of wavelength from around 400 nanometers (nm) to around 800 nm. Daylight is consists of higher amount of high vital violet end of the spectrum. Red photons consists of lowest vitality, blue photon has normal vitality. Green has the middle kind. The vitality of the photons is mainly distinguished by their individual frequency with the formula E= hf, here E- energy of photon, f - frequency (hertz) and h - Planck's constant. And h=6.663*10^ -34 Js. The increase in apparent wavelength of light affects significantly the performance of photovoltaic module. Solar cell is respondent to some specific value of wavelength but not all of them.The different colour filter are used to cover the photovoltaic solar module and change in panel current and voltage output in order to do measurement and record. A portion of the six coloured filters of various transmittance are, Red, yellow, orange, white, green, blue, violet. [39].

Table I. Different colours or light and there corresponding wavelengths

Colour	Wavelength (nm)

Red	622 – 780
Orange	597 – 622
Yellow	577 – 597
Green	492 – 577
Indigo	420 – 450
Blue	455 – 492
Violet	390 – 455

Wind Velocity

If the velocity of air increases then the cell temperature also drops and result will improve. With the increase in wind speed more will be the heat removed from the solar cell surface. Similarly, higher the velocity of air lowers will be the relative humidity of the atmosphere of the surroundings. It is in turn leads to a better efficient production. But wind can lift dust along with scatters. Which results in shading and degraded performance of the PV cells [32][40].

Snow

Sometimes snow storm causes the solar cell to be covered with cloud. This may cause the solar cells to lose their efficiency. After the snow fall the solar panels may work much efficiently with the reflection of the sun light which lies on the ground.

The cooling of panels that is caused due to the snow fall has good effect with the energy production. Solar cell works well in cool conditions than that of very hot and warm conditions. So temperatures more than 30 degrees cause the panels to stop and the efficiency will decrease.

Humidity

Impact of humidity on dust accumulation shows a negative relation between them when natural removing agents like rain and wind are excluded. Tidy gathering begins to increment after steady diminishing of relative dampness. Dust aggregation is likewise influenced by the dampness and surface wetness that can improve or weaken the adhesive force bonding the particles to the surface. Relative humidity can be considered as the auxiliary impact due to their part in long term collection. The impact of dust increases in humid weather because they make together cement layer which make the cleaning process difficult task. So humidity causes degradation in solar PV efficiency [27][32][40].

Experimental Result

To examine how the different factors are affecting the performance of the PV panels, an artificial environment is created in the lab by using the different things such as in the place of sun light we have used lights, we have used dust particle to show the affect of dust over the PV cell etc, the whole setup for determining the I -V characteristic is shown in the figure.2.9.

Figure 2.1 System setup to determine I-V characteristic at different irradiation level

Temperature

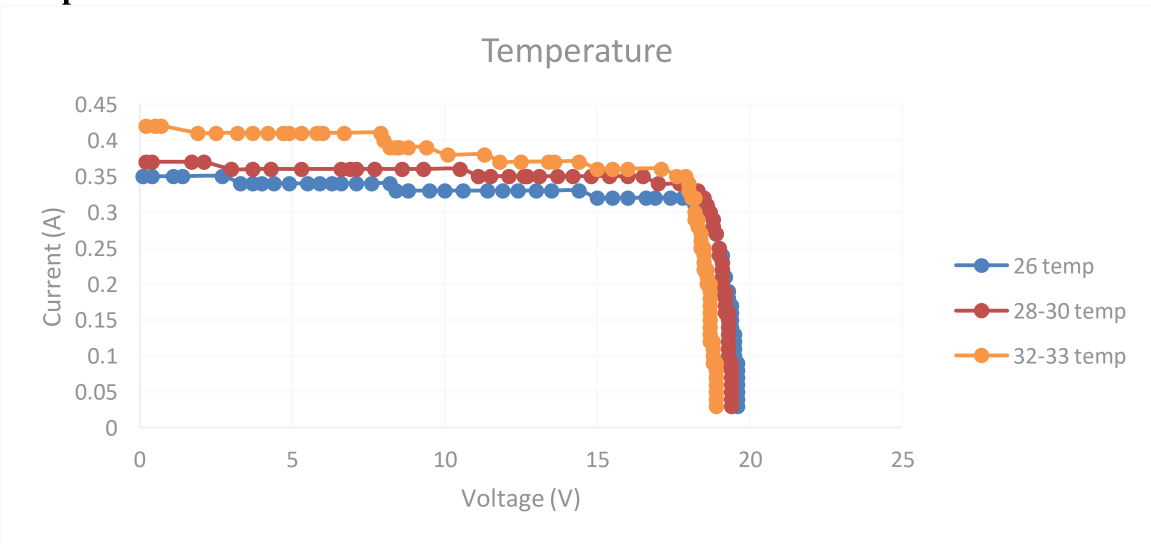


Figure 2.1 I-V characteristic of the pv cell due to the temperature variation

From the above graph we can see that as the temperature is increasing the short circuit current I_{SC} is as the temperature of the PV cell is increased but the open circuit voltage V_{OC} is deceasing simultaneously which decreases the overall cell efficiency. Hence we can conclude that the increase in temperature of the PV cell is not in term of it performance.

Dust

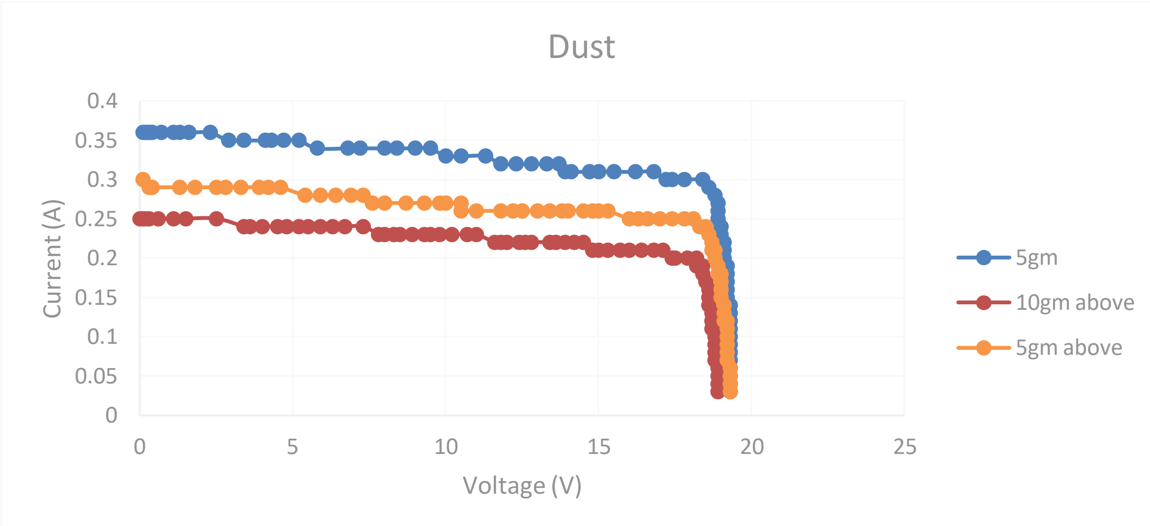


Figure 2.2 I-V characteristic of the pv cell due to the dust particles

From the above graph it can be observed that the as thickness of the dust particle is increasing the short circuit current is decreasing directly and also the open circuit voltage is falling simultaneously, resulting in decrease in the output power of the PV cell. The composition of the dust, density, and size of the particle has main affect over th PV cell performance.

Irradiance

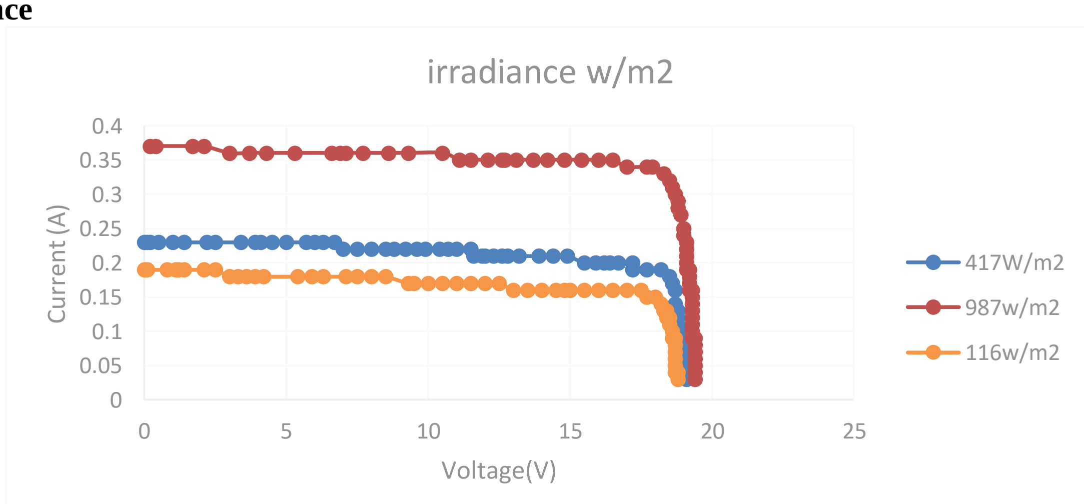


Figure 2.3 I-V characteristic of the pv cell due to the variation in Irradiance

The Graph in the figure 2.12 show the affect of variation of the irradiation on the PV cell performance.Which conclude that the with the rise in solar irradiance the short circuit current and the open circuit voltage increase linearly and logarithmically and vice verse. Here the for the different solar irradiation the maximum power point of the module P_{mpp} is analysised for different irradiance level.

Shading of Module connected in Parallel

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 51, Issue 03, March : 2022

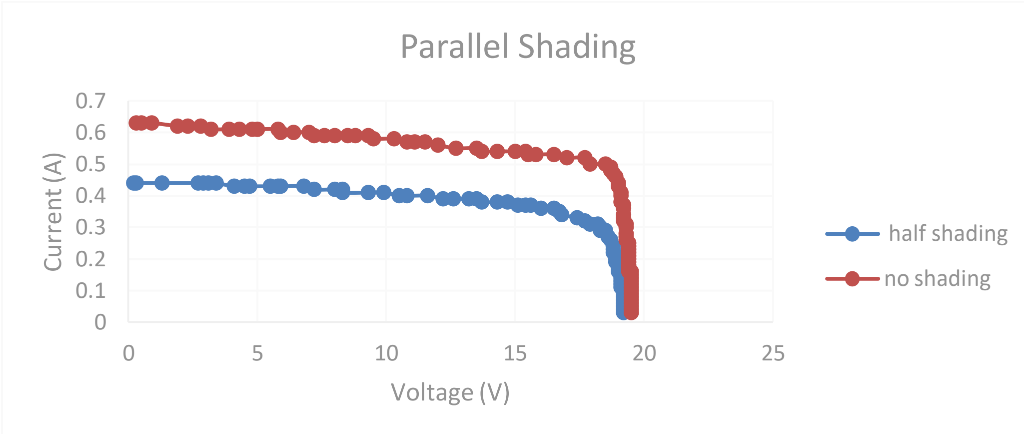


Figure 2.4 I-V characteristic of the pv cell due to shading in parallel variation

Shading of Module connected in Series

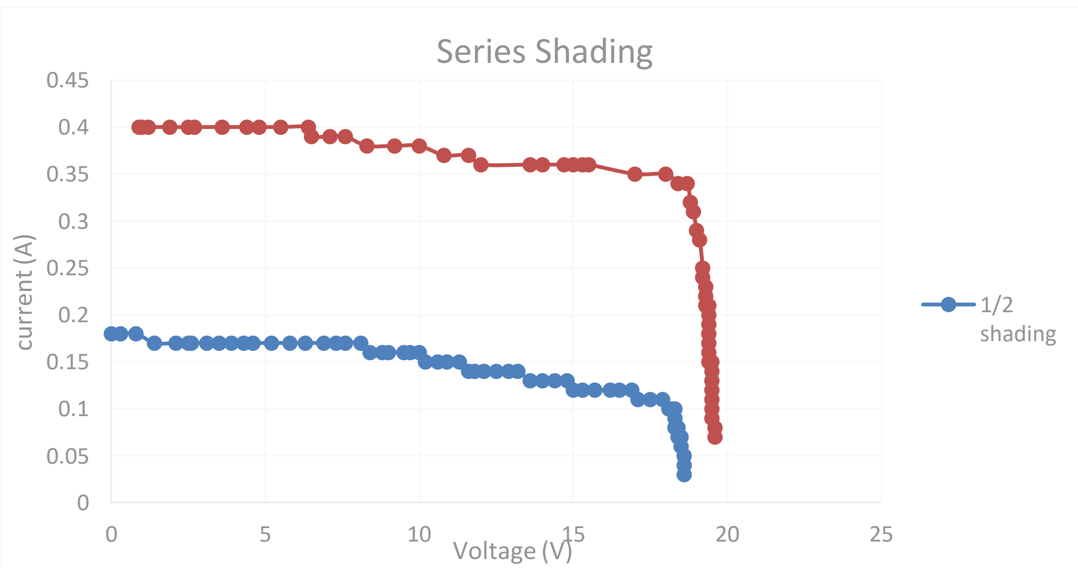


Figure 2.5 I-V characteristic of the pv cell due to shading in series variation

In both the cases the affect of the shading on the series and parallel connected modules shown is shown in the figure 2.13 and 2.14,it can be observed that the power output is degraded due to the presence of dust over the PV solar panel. As the shadowed area is relatively small, causes circulating current in large amount results in over heating of shadowed portion which may damage the module. Therefore to overcome such situations Bypass diode can be used to improve the efficiency of PV system in case of shading.

Colour Spectrum

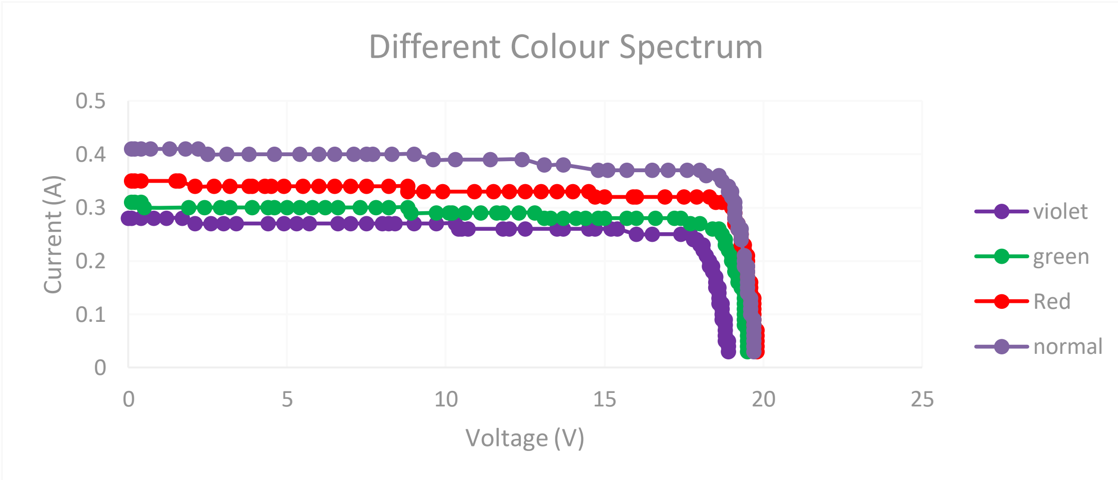


Figure 2.6 I-V characteristic of the pv cell due to colour spectrum variation

In the figure 2.15 the I-V characteristics for different colour is shown, it can be absorbed that for the violet colour we get the maximum output and for the blue colour we get the least output as the violet colour wavelength is more than that of the blue colour.

Conclusion

From the above results, we can conclude that factors such as temperature, dust, radiation, shade, color spectrum, etc. have a significant impact on solar cells. The capacity of the PV cell directly depends on these factors, and the variation of these factors directly or indirectly affects the capacity of the PV modules, becoming variable in nature. This variable nature of solar cell production causes harmonic distortions in the connected grid service. The variation of solar radiation in the morning, noon and evening causes a significant increase in the values of current harmonic distortion (THD), which is inversely proportional to the active power of the photovoltaic system. Therefore, it is always recommended to reduce the THD value to maximize the effective power of the PV system. To minimize the THD value, it is mostly recommended to use the current-controlled technology of grid-side converters, and this thesis also aims to minimize. THD and improves the active power of the photovoltaic system.