Experimental and Simulation for the Effect of Partial Shading on Solar Panel Performance

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ABSTRACT

Partial shading is one of the problems that affects the power production and the efficiency of photovoltaic module. A series of experimental work have been done of partial shading of monocrystalline PV module; 50W, I_{sc}: 3.1A, V_{oc}: 22V with 36 cells in series is achieved. Non-linear power output responses of the module are observed by applying various cases of partial shading (vertical and horizontal shading of solar cells in the module). Shading a single cell (corner cell) has the greatest impact on output energy. Horizontal shading or vertical shading reduced the power from 41W to 18W at constant solar radiation 1000W/m^2 and steady state condition. Vertical blocking a column of cells (9 cells) in a module reduces the power from 41W to 18W (53% power reduction); while, blocking one or two cell in the row reduces the power from 41 W to 18W (53% power reduction). Shading three or four cells in the same row reduces the power from 41W to 1W or 0.006W (94% power reduction). A complete Matlab / Simulink model are achieved to simulate the effect of partial shading on power output of module. It is found that shading a single cell reduces the power from 50 W to 25 W (50%) using Matlab/Simulink model. Comparisons have been made between the I-V and P-V characteristic curves from the simulation with the practical (experimental) curves. The results showed that the percentage of error between the Simulink results and the corresponding experimental measurement are 22% without shading effect and, 32% with partial shading.

Key words: partial shading, bypass diode, matlab/simulik, pv module, photovoltaic system

التجربة والمحكاة لتأثير الظل الجزئي على أداء اللوح الشمسي

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الخلاصة

التظليل الجزئي هو احد المشاكل التي تؤثر على الطاقة المنتجة والكفاءة للوح الكهروضوئي .تم اجراء سلسلة من التجارب من الظل الجزئي على وحدة كهروضوئيه من نوع احادية البلورة 50 واط ،3.1 امبير،22 فولت تحتوي 36 خلية مربوطة على التوالي.الاستجابة الغير خطيه للطاقة الناتجة يمكن ملاحظتهاعند تطبيق حالات مختلفه للتظليل الجزئي(افقي ،عمودي).تظليل خليه واحده(خلية الزاوية) لها الاثر الكبير على الطاقة الخارجية.التظليل الافقي او العمودي يقلل الطاقة من 41 واط الى 18واط عند اشعاع ثابت ١٠٠٠وحالة مستقرة . تم

التحقق من ان حجب عمود من الخلايا(9خلايا)في الوحده الضوئية يقلل الطاقة من 41 واط الى 18واط (53%تخفيض استهلاك الطاقة) و حجب خلية او خليتين في الرف الواحد يقلل الطاقة من 41 واط الى 18 واط (53%تخفيض استهلاك الطاقة).) .تظليل ثلاث او اربع خلايا في نفس الرف يقلل الطاقة الى 1واط او 0.006 واط (94%تخفيض استهلاك الطاقة) .تم توضيح تاثير الظل الجزئي ببرنامج السميولنك ماتلاب.تم التحقيق ان تظليل خلية واحده يقلل من الطاقة من ال50واط الى 25واط (50% تخفيض استهلاك الطاقة).عملت مقارنة بين منحنيات (تيار- فولتية)و(طاقة- فولتية)الناتجه من برنانج الماتلاب مع المنحنيات الناتجة من التجارب العملية،وكما هو مبين من النتائج نسبة الخطأ المئوية بين النتائج العمليه والنظرية بدون تأثير الظل تصل الى 22%،ومع تاثير الظل الجزئي تصل الى 32%

الكلمات الرئيسية :الظل الجزئي ، الدايود الثنائي ، ماتلاب/ سميولنك، النظام الفوتوفولتائي

1.INTRODUCTION

Solar cell is a device that directly converts sunlight into electricity with no intervening heat engine through the process of photovoltaic. In 1839, French physicist Antoine Edmond Bequerel’s research was the beginning to develop of solar cell technology.

A number of parallel/series connected solar cell are used to construct a PV module. Series connected solar cells has a negative impact on PV module performance if all its cells are not equally illuminated (partially shaded).

Shading is one of the many factors that have a great effect on the performance of solar photovoltaic modules. Two possible sources that the shading arises from them in the natural environment; the first is some type of plant such as trees, while the second is a solid body like a socle or construction **Di Piazza and Vitale, 2010**. So even if a tiny part of the solar photovoltaic module is in shade, the performance of the full solar photovoltaic module will significantly decrease. Also, there are two factors have impact on the performance of PV modules in natural environmental; artificial like evaporation of pollution from different factories and natural like dust, temperature and clouds. Accumulation of a permanent pollution strip along the edge of the framed cell lead to reduction of energy production up to 10-20% of PV cell **Eloy Dı´az-Dorado, 2014**.

In recent years, the effect of partial shading on the PV array performance has been widely discussed and studied. the impact of partial shading is complicated because the testing field is costly, time consuming and depends strongly on the prevailing weather condition, **Ahmed et al., 2014.**

All the cells carry the same amount of current. In a series connected concentration of cells, Even though a few cells under shade produce less photon current but these cells are also obliged to carry the same current as the other fully lighted cells. The shaded cells may be in reverse biased state, acting as loads, absorbing power from fully lighted cells. Hot-spot problem can appear if the system is not well protected; the system can be irreversibly damaged, **Quaschning and Hanitsch, 1996**.

Many researchers examined the effect of partial shading on PV technologies. **Gross et al., 1997** depending on heliodon analysis concluded that replacing the current central inverter by module inverters could decrease losses due to shading from 25 to 19.5% of the yearly energy product. **Tegtmeyer et al., 1997** found from experimental measurements that when partial inverter systems where shading happens from time to time, with central inverters extra losses are lower than 5% of the optimum. **Beuth, 1998** simulated two present PV systems with partial shading for various arrangements did not see big avail of the module inverter configuration. Depending on the cost for installations and inverters, and reliability considerations, advises the application of series or central inverters. **Belhaouas et al., 2013** studied the built PV module depended on two diode model by use matlab / Simulink under partial shading. Concluded when shaded one cell the power reduced 50%.

The objective of this work is to illustrate the effect of partial shading first by experimental measurements, and then theoretically by Matlab /Simulink.

2. MODELING OF PHOTOVOLTAIC SYSTEM

2.1 PV Cell Model

The single diode equivalent circuit of a photovoltaic cell in **Fig.1** consists of a current source, a diode, a series and a parallel resistance.

The open circuit voltage (V_{oc}) and the short circuit current (I_{sc}) obtained from the cell manufacturer's data sheet the PV current can be derived by Eq. (1) **,Yusof et al., 2004**.

$$I_{pv} = I_{ph} - I_o \tag{1}$$

In which $I_{pv}$is the output current and I_{ph}refers to the photo-generated current, I_o represents the diode current, the photo-generated current(I_{ph}) which is a function of incident solar irradiation and cell temperature. It can be calculated as Eq. (2), **Wang and Hsu, 2010**.

$$I_{ph}\,(G) = \left(I_{sc} \; + k_i \, T_{dif} \; \right) \frac{G_1}{G_r} \tag{2}$$

Where k_i is the temperature coefficient, T_{dif} is the deviation of the operating temperature from the reference temperature (T_{dif}= T− T_r), and G_r and G_1 are reference and operating irradiances, respectively. Also the reverse saturation current (I_{rs}) at a certain reference temperature can be calculated as follows, **Ekpenyong and Anyasi, 2013**.

$$I_{rs} = \frac{I_{sc}}{exp(\frac{qV_{oc}}{KAT_rN_s} - 1)} \tag{3}$$

The diode current saturated (I_s) changes with fluctuations in environmental conditions, so it can be calculated by the equation below. The parameter E_g refers to the band gap energy for the silicon semiconductor which should be between 1.1 and 1.2 eV, **Pandiarajan and Muthu, 2011**.

$$I_s = I_{rs} \left(\frac{T}{T_r}\right)^3 exp\left[\frac{qE_g}{AK}\left(\frac{1}{T_r} - \frac{1}{T}\right)\right] \tag{4}$$

Where K is the Boltzmann constant, q is constant known as the electron charge (q = 1.602 × 10−19 C), A is ideality factor depends on PV technology as I_o is the diode current that will be calculated by the Shockley Equation, **Pandiarajan and Muthu, 2011**.

$$I_o = I_s \left[exp\left(\frac{q(V_{pv}+I_{pv}R_s)}{AkT}\right) - 1 \right] \quad (5)$$

A photovoltaic module is the basic element of each photovoltaic system. It consists of many jointly connected PV cells. The equivalent module circuit equation for an (Ns) PV cells in series, leads to equation, **Wang and Hsu, 2010**.

$$I_{pv} = I_{ph} - I_s \left[exp\left(\frac{q(V_{pv}+I_{pv}R_s)}{AKTN_s}\right) - 1 \right] - \frac{(V_{pv}+I_{vp}R_s)}{R_p} \quad (6)$$

3. EXPERIMENTAL FACILITIES AND MATLAB – SIMULINK

3.1 Experimental setup

A study on the effect of partial shading has been done through a series of experimental measurements. **Fig.2** shows the PV system of single PV module. A single monocrystalline silicon solar module used in this experimental, which consists of 36 solar cells connected in series and placed on a mobile metallic holder, to get the desired radiation flux. The experimental work has been make at the department of energy engineering in March, April and May, 2015.**Table 1** shows the electrical characteristics of monocrysalline module under standard test conditions (STC); irradiance G = 1000 W/$m^2$and temperature = 25°C.The PV module is connected to the Prova 200 solar module analyzer shown in **Fig.3** which used for the measurements of output power, efficiency, fill factor, V_{max} and I_{max} of the solar module. Solar power meter (TES1333R) shown in **Fig.4** that measures irradiation in W/m^2. The temperature of the module was measured using digital thermometer (TPM-10) attached firmly to the back of the module shows in **Fig.5**. The entire device and the solar module, which is supplied by the manufacture (Pasco, TES Electrical Electronic Corp), are calibrated on line. A software program is supplied by the manufactory company for calibrated the solar module and prova 200 and solar power meter. For resolution accuracy of the measuring device (prova 200, solar power meter, digital thermometer), **Table 2** demonstrates the properties of measurement apparatus range, resolution and accuracy.

3.2 Matlab Simulink

A single solar module simulation is based on the single diode model equations were implemented in Matlab/Simulink. This simulation allows modifying the environmental data and the electrical parameters characteristic of the implemented photovoltaic module such as irradiance (G), temperature(T), short circuit current (I_{sc}), open circuit voltage (V_{oc}), etc. The simulation model of the PV system shown in **Fig.6** is divided into two groups, each one of them connected to bypass diode. The first group contains number of solar cells without shade at radiation flux 1000W/m^2.The second group contains number of shaded cells at radiation flux 500W/m^2.

4. RESULTS AND DISCUSSION

4.1 Experimental Results

The effect of partial shading is shown in **Figs.7** and **8** the I-V and P-V characteristic curve respectively at G=1000W/m^2 and T=45^{o}C. I_{sc} is equal to 2.8A ,V_{oc} is close to 21.4V ,the I_{max} is equal

2.4A ,V_{max} equal 16.5V.The blue curve represent the case without shade , the red and green curves represent the case when one or two cell is shaded in horizontal way, noticing that shading has a strong influence on the I-V and the P-V characteristics curve of the module and the maximum power decreases for approximately 50% power reduction. The Purple and light blue curves represent the case when three or four cells are shaded in horizontal way, so that the maximum power decreases for approximately (96%power reduction). **Fig.9** shows the power drop with number of cells. The power decreases whenever the number of shaded cells increases.

The I-V and P-V characteristic curves of partial shading in vertical way illustrated in **Figs.10** and **11** .The blue curve (without shade). The red and green curves represent when one and two cell is shaded respectively (power decreases for approximately50%).The Purple and light blue curves represent the case when three and four cells are shaded respectively (power decreases for approximately 96%). **Fig.12** shows the power drop with number of cells. The power decreases to half when one or two column is shaded .and continue decreasing when shading three or four columns.

The power drop with number of shaded cells at different radiation flux 500,800,100 in horizontal and vertical case shown in **Figs.13** and **14**. Notice that whenever the radiation flux decreases the power is decrease. When the radiation flux value of 500W/m^{2}the power became 20 W less than what it was when the radiation flux (800, 1000), which is 36W, 41W respectively. When 1,2 cells is shaded the power reduces to half and when 3,4 cells are shaded the power reduce more than half in horizontal case, when shading 1,2,3,4 cells in vertical case the power reduce to half. Notice the impact of shading when shading (1, 2, 3, 4) cells, in vertical state .it's different from the shading (1, 2, 3, 4) cells in horizontal state.

4.2 Partial Shading Simulation

The simulation result of the I-V characteristic curve is shown in **Fig.15**. The short circuit current is very closed to 3.1A and the V_{oc} is very close to 22V. The simulation result of the P-V characteristic curve is shown in **Fig.16**. The maximum power is 50 W which is the expected value. V_{max} is very close to 17.5 V and I_{max} is very close to 2.9 A. In **Fig.17** shows the simulated I-V characteristic curve for irradiance (G = 1000 W/m^2) on Group 1 and shading on Group 2 (G = 500 W/m^2) with two bypass diodes connected. The V_{max} equals 8.6 V, as the two groups are not equally illuminated the power shown in **Fig.18** contributed by each group is different and the maximum power is less than 50 W. **Table 3** introduces a comparison between the maximum power obtained in this work and a sample of other previous work such as **Basim et al., 2013** and **Quaschning** and **Hanitsch ,1996**.Those works studied the partial shading effect on the performance of PV modules.

5. CONCLUSIONS

This paper presented the procedure for creation the mathematical model of photovoltaic module under partial shaded condition in the different current Simulink libraries and choose the appropriate one. The results are found to be in close agreement with the Laboratory results. Experimental results showed that single cell shading reduces the total power of the solar module to 50%, and the horizontal shading more influential than the vertical shading .In horizontal shading blocking one or two cells in the row reduce the power 41 W to 18W (53% power reduction).Shading three or four cells in the same row reduces the power to 1W or 0.006W (94% power reduction) and also, in vertical shading blocking a column of cells (9 cells) in a module has reduce the power from 41W to 18W (53% power reduction).The decrease in power of the photovoltaic module is not proportional to the shaded area. Also showed when decrease solar radiation the Isc and Voc reduce. As it is shown by the results that the percentage of error between the theoretical and practical in case without shade reach to 22.0%, and with partial shading reach to 32%.

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NOMENCLATURE

A = diode ideality factor, dimensionless.

E_g = band gap energy (EV= electron volt)

G_1 = operating irradiances (W/m^2)

G_r = reference irradiances (W/m^2)

I_o = diode current (Amp)

I_{Ph} = solar-generated current (Amp)

I_{pv} = output current (Amp)

I_{rs} = reverse saturation current (Amp)

I_s = diode current saturated (Amp)

Isc = short circuit current, (Amp)

K = boltzmann constant 1.3805*10-23(Joule/k)

K_i = temperature coefficient

N_s = number of solar cells connected in series.

R_p = parallel resistance (Ω)

R_s = series resistance (Ω)

T = operating temperature (K)

T_{dif} = deviation of the operating temperature from the reference temperature (K)

V_{oc} = open circuit voltage, V.

Table 1. Electrical characteristics parameters of the PV module at 25°C and 1000 W/m^2.

Rated power	50 W
Voltage at maximum power (V_{max})	17.5V
Current at maximum power (I_{max})	2.9A
Open circuit voltage (V_{oc})	22V
Short circuit current (I_{sc})	3.1A
Total number of cells in series	36
Module weight	5.6Kg
Module type	(50)17M800×541
Temperature coefficient k_i	0.0017

Table 2. Measurement apparatus range, resolution and accuracy.

	Measuring range	Resolution	Accuracy
Solar module analyzer PROVA 200A			
DC voltage measurements	0-60 V	0.001-0.01 V	±1% ±(1% of Voc±0.09 V)
DC current measurements	0-6 A	0.1-1 A	±1% ±(1% of Isc±0.9 mA)
Solar power meter TES1333R			
Solar radiation measurements	0-2000 W/m^2	0.1 W/m^2	±10 W/m^2 or ±5%. higher temperature induced error of ±0.38 W/m2/°C from 25°C
Digital thermometer TPM-10			
Temperature measurement	-50~70 °C	0.1 °C	±1 °C

Table 3. Maximum power degradation comparison with some previous studies.

	Power without partial shade (W)		Power with partial shade (W)		P^*_{loss}%
	Experimental	Simulink	Experimental	Simulink	
Present Results	41	50	18.93	25	0.53
Basim et al., 2013	110	108	49	48	0.55
Quaschning and Hanitsch ,1996	20	30	6.3	10.3	0.68

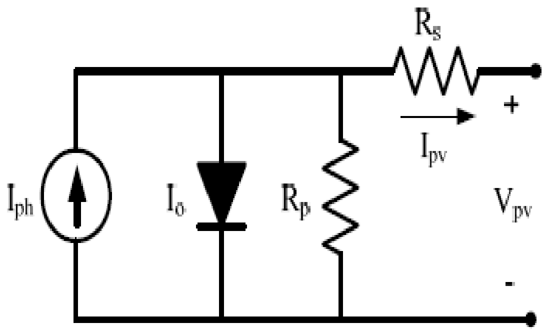


Figure 1. Equivalent circuit of PV.

Figure 2. Experimental system.

Figure 3. Solar analyzer prova.

Figure 4. Solar power meter.

Figure 5. Digital thermometer.

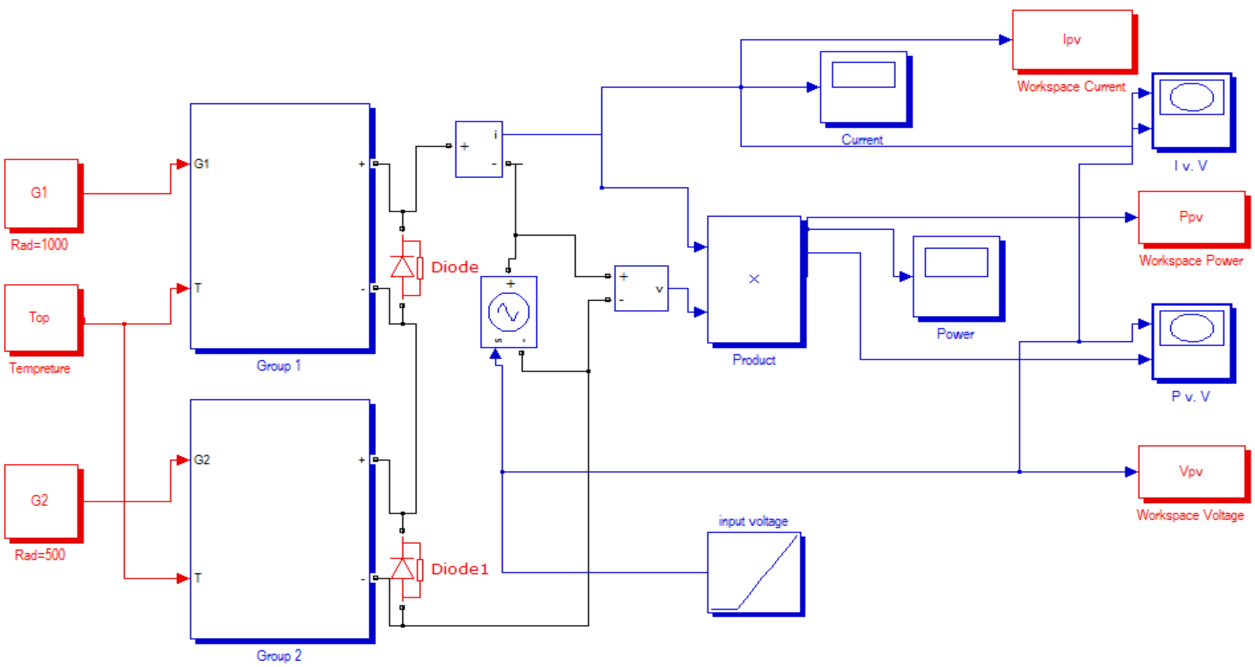


Figure 6. Simulink model for partial shading of single PV module.

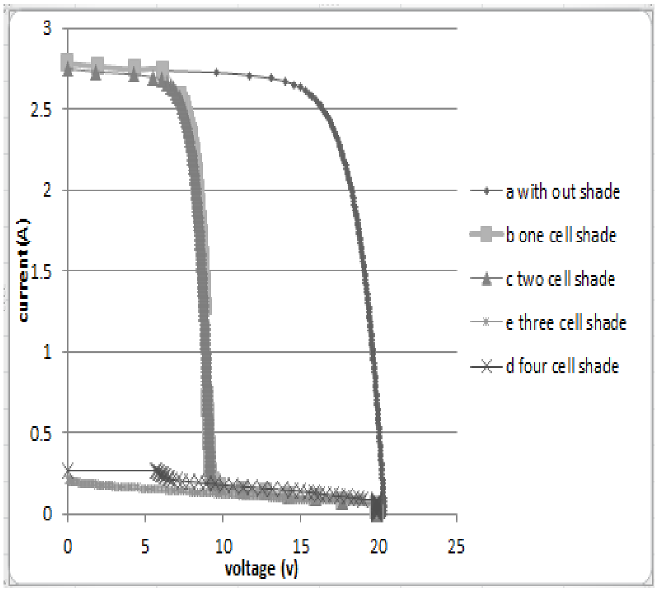


Figure 7. I-V curve with partial shade.

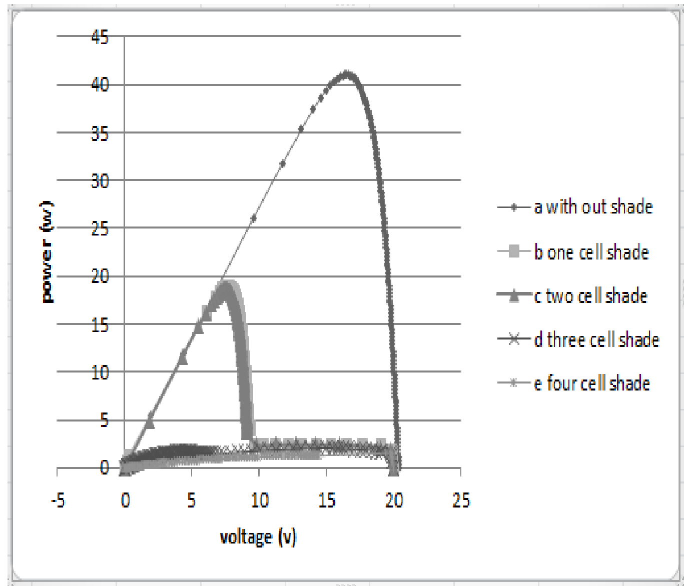


Figure 8. P-V curve with partial shade.

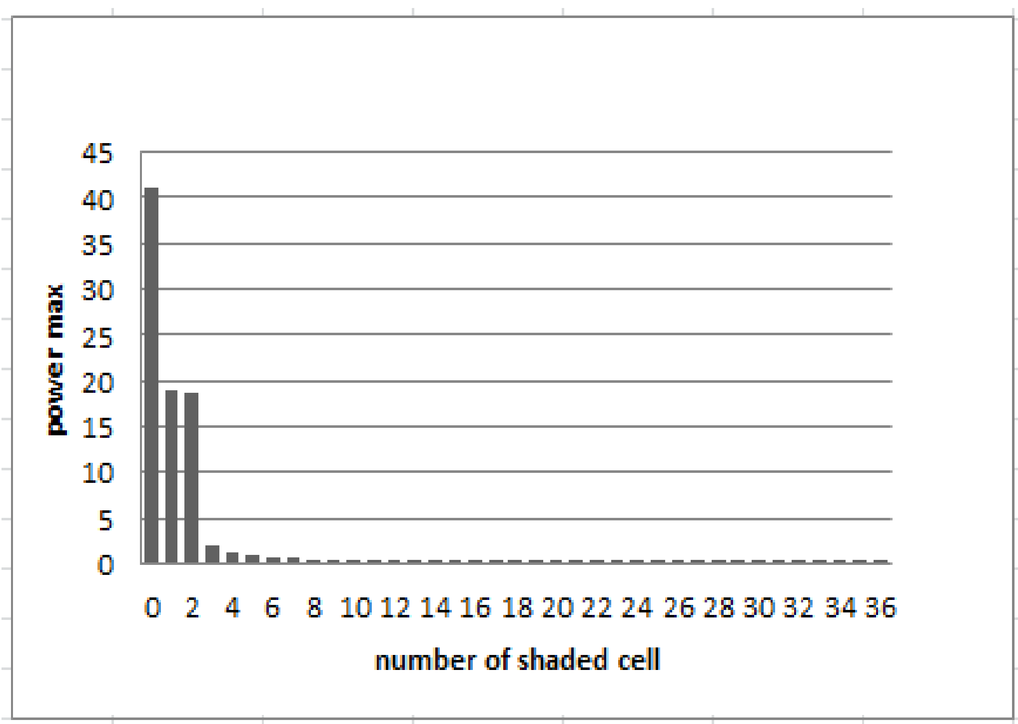
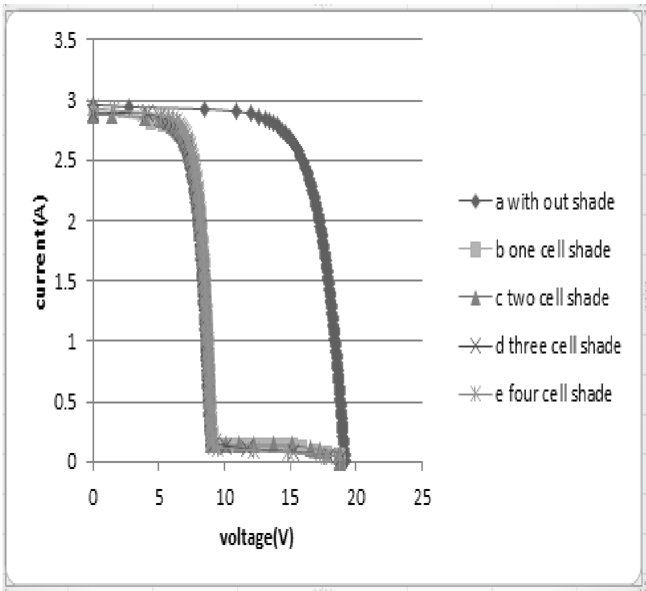


Figure 9. Power drop with number of shaded cells.



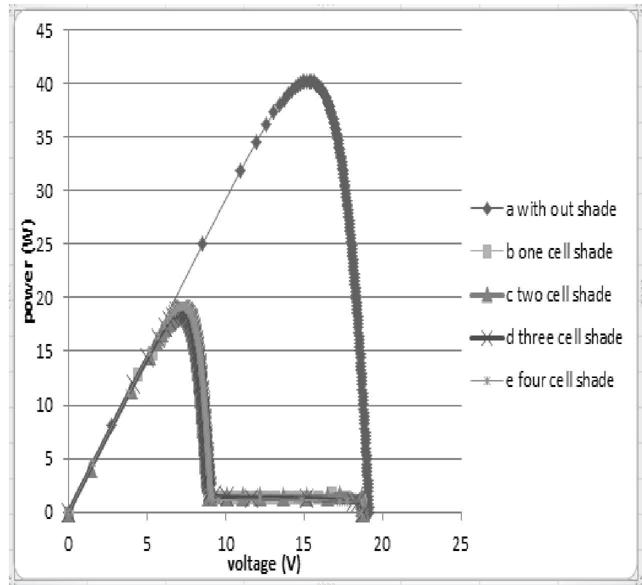


Figure 10. I-V curve of PV module.

Figure 11.P-V curve of PV module.

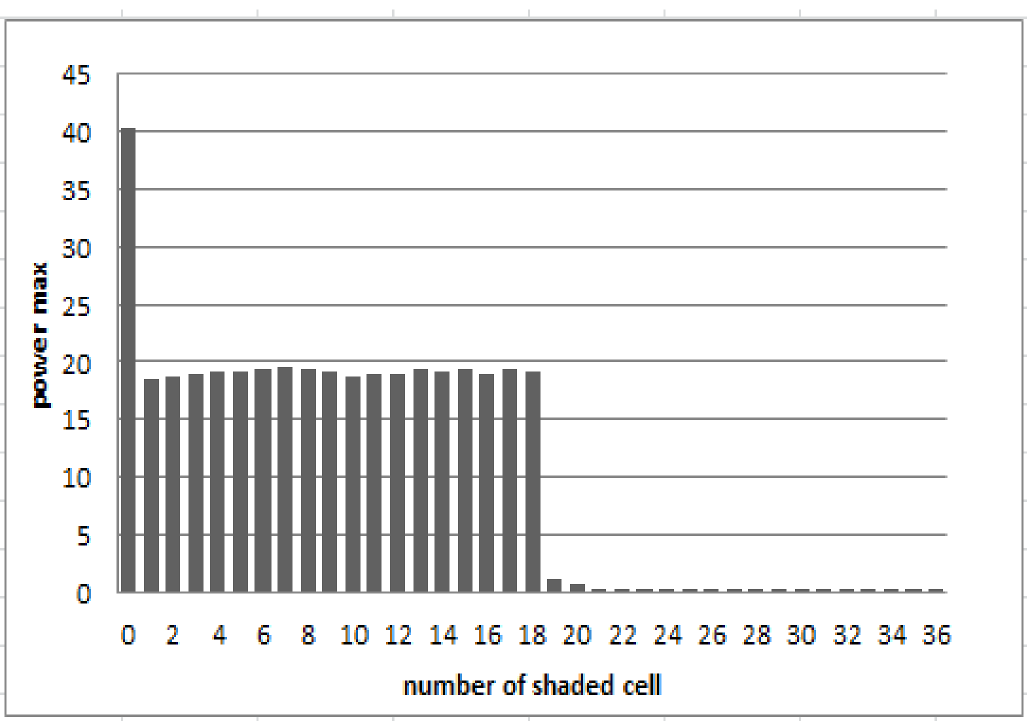


Figure 12. Power drop with number of shaded cells.

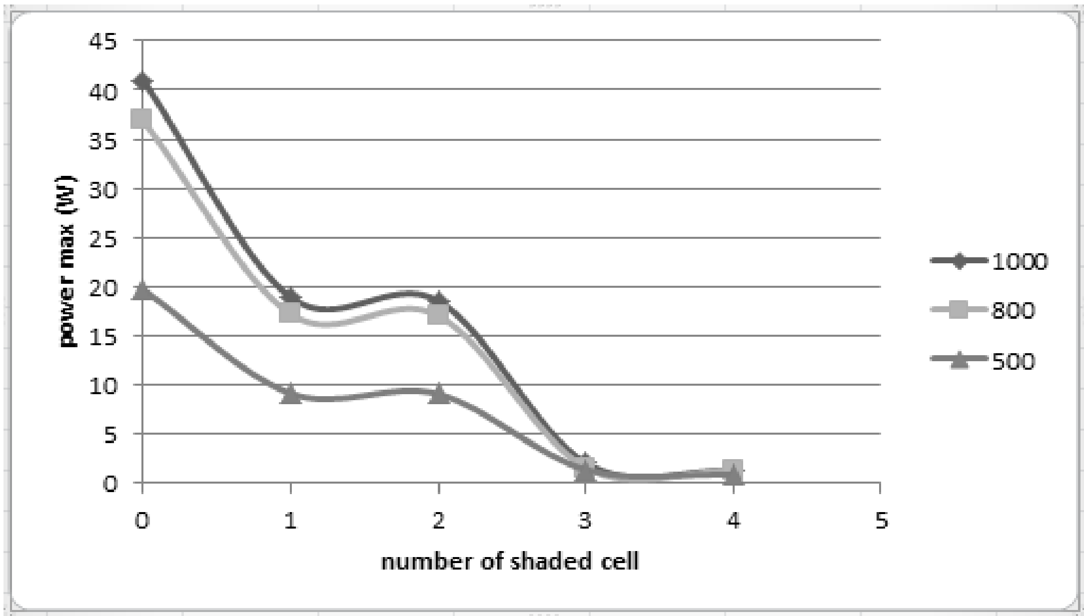


Figure 13. Power drop with number of shaded cells in horizontal shade at different radiation (500, 800, 1000) W/m^2.

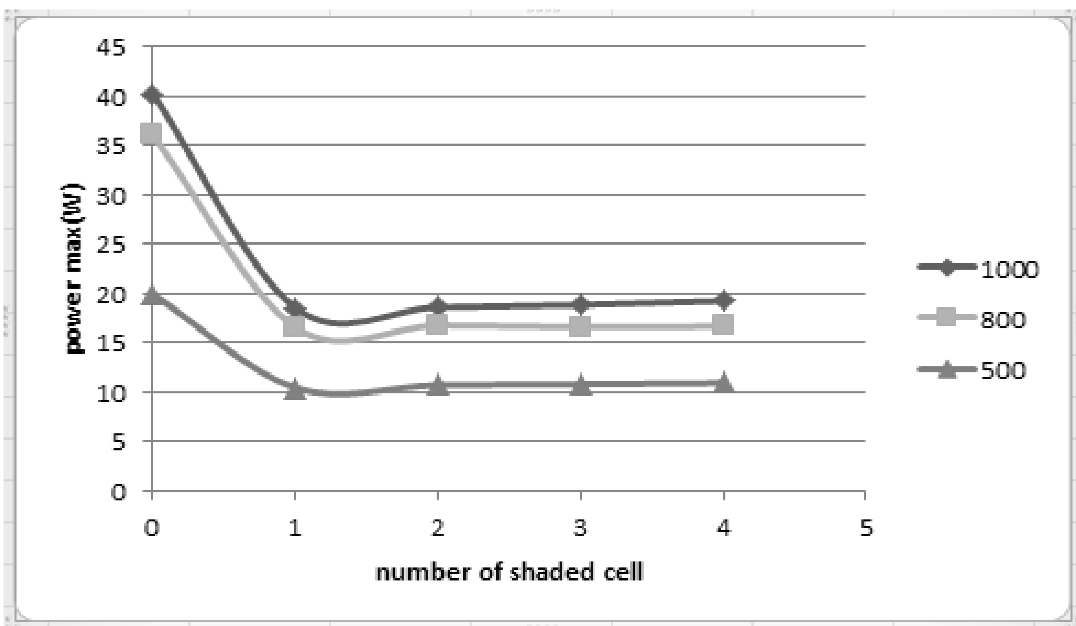


Figure 14. Power drop with number of shaded cells in vertical shade at different radiation (500, 800, 1000) W/m^2.

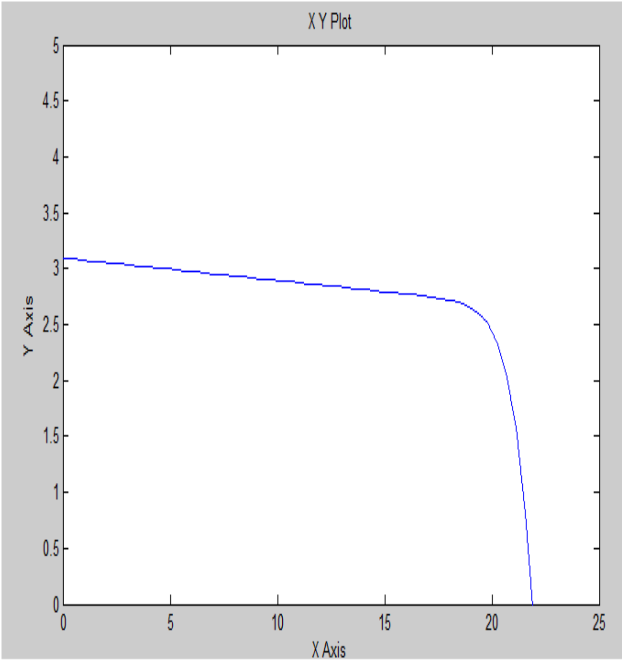


Figure15. Simulink I-V curve without shade.

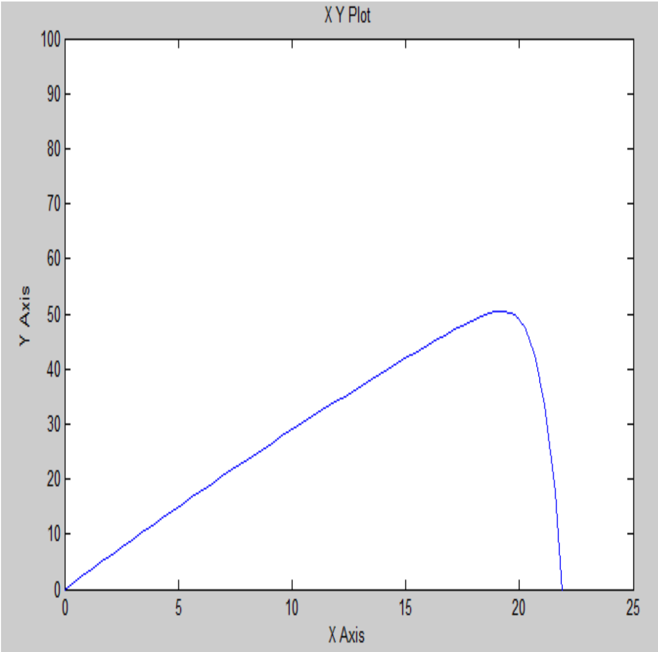


Figure 16. Simulink P-V curve without shade.

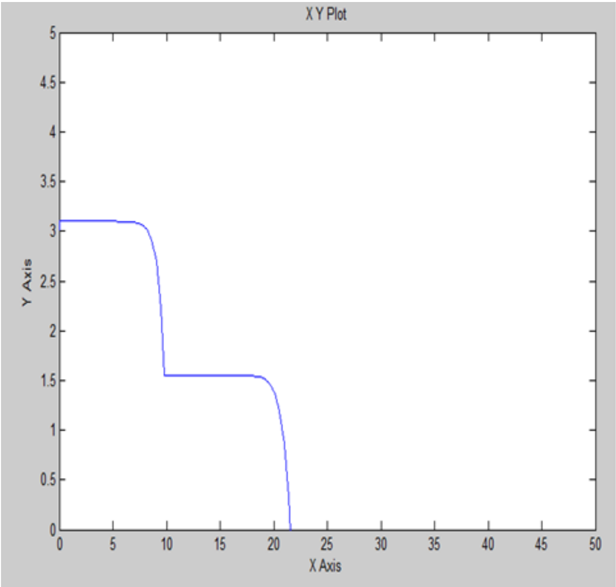


Figure17. Simulink I-V curve with shade.

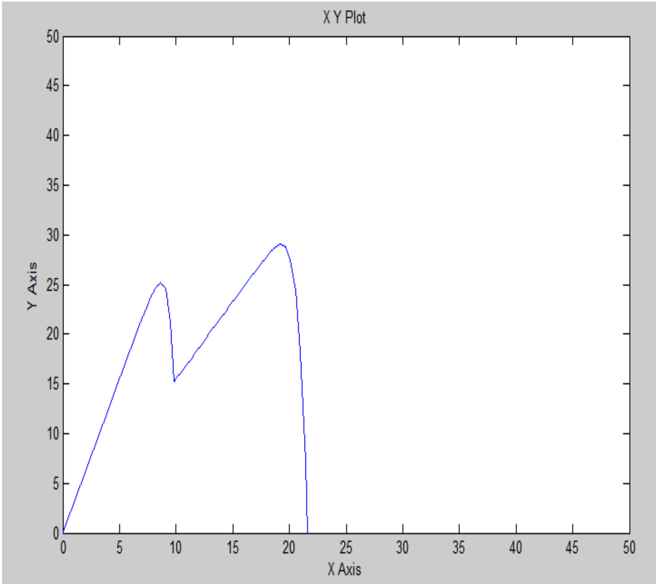


Figure18. Simulink P-V curve with shade.