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ANALYSIS OF SHADING IMPACT FACTOR ON PHOTOVOLTAIC MODULES

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Abstract:

Photovoltaic (PV) modules are very sensitive to shading effect. Unlike a solar thermal panel which can tolerate some shading, many brands of PV modules cannot even be operated by shadow of leave which resulted in high reduction of its output power. The effect of shading on solar PV models will be evaluated by using a simulation model for simulating both the I-V and P-V characteristics curves for PV panels. Different percentages of shading are taken into consideration of this paper which is: 25%, 50%, 75%, 100%, and without shading. The irradiation and temperature are constant during test. The results are extracted using the Matlab software. A typical Kyocera-54W and Solara-130W solar modules are used in the simulation part. The output power of models is widely decreased as the shading percentage increased. The Shade Impact Factor (SIF) is proportional to area of panels, so the systems built with big panels were more affected by shading effect.

تحليل تأثير عامل الظل على الألواح الكهروضوئية

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الكلمات المفتاحية: الظل، الكهروضوئية، نقطة اعظم قدرة، سولارا، كيوسيرا، تأثير عامل الظل

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المستخلص:

الألواح الكهروضوئية حساسة جدا لتأثيرات الظل على خلاف الألواح الشمسية الحرارية والتي يُمْكِنُ أَنْ تَتحمّلَ بعض الظل. فقد لا تستطيع العديد مِنْ أصنافِ الخلايا الكهروضوئية العمل في الظل الناتج من أوراق الأشجار أو غيره، اذ تقل المقدرة الناتجة بدرجة كبيرة. لذا قيمت تأثير الظلال على أداء الألواح الكهروضوئية باستخدام نموذج المحاكاةِ لتَقليد كلا من منحنيات المقدرة-الفولتية والتيار-الفولتية لنسب ظل مئوية مختلفة وهي: 25 %، 50%، 75%، 100%، ومن ثم بدون تَظليل. اذ كانت شدة الإشعاع ودرجةَ الحرارة ثابتين أثناء الاختبار. استخلصت التجارب باستخدام برنامج الماتلاب الهندسي مع منظومة Kyocera-54W ووحدات Solara-130W. فلقد كانت قلت الناتجة من النماذج على نحو واسع كلما تزداد نسبة التَظليل المئوية، كما إنّ عاملَ تأثيرِ الظِلِّ يتناسب مع مساحة اللوح، حيث إن الأنظمة المبنية بألواح كبيرة المساحة تتأثر أكثر بالظل عن الأنظمة ذات الألواح الصغيرة المساحة.

INTRODUCTION:

When a small section of a photovoltaic panel is shaded by the branch of a tree or other sources of shading, then a significant drop in power output from the panel will result. This is because a PV solar panel is made up of a string of individual solar cells connected in series with one another. The current output from the whole panel is limited to that passing through the weakest link cell. If one cell (out of for example 36 in a panel) is completely shaded, the power output from the panel will fall to zero. If one cell is 50% shaded, then the power output from the whole panel will fall by about 50%, so a very significant drop for such a small area of shading can happen. This paper reviews and analyzes the behavior of a photovoltaic device (cell or module) under partial shading conditions (García, et.al., 2011). To do this, the implementing a simulation model in an open tool (MATLAB) that takes into account the electrical and thermal equations of the photovoltaic device was did. The knowledge of the behavior of PV device under partial shading conditions is a main topic to optimize its operation. Simulations carried out taking into account the weather conditions (irradiance, ambient temperature and wind speed) as well as suitable time to analyze both transient and steady state. Partial shading of photovoltaic modules is a widespread phenomenon in all kinds of Photovoltaic (PV) systems. In many cases the PV arrays get shadowed, completely or partially, by the passing clouds, neighboring buildings and towers, trees or the shadow of one solar array on the other, etc. This further leads to nonlinearities in characteristics (Abdulazeez , et.al. 2011). In this study, the simulation and experimental results of uniform and partial shading of PV modules are presented. Different shading pattern have been investigated on series and parallel connected photovoltaic module to find a configuration that is comparatively less susceptible to electrical mismatches due shadow problems. Partial shading in photovoltaic arrays renders conventional maximum power point tracking (MPPT) techniques ineffective (Bidram , et.al., 2012). The reduced efficiency of shaded PV arrays is a significant obstacle in the rapid growth of the solar power systems. Thus, addressing the output power mismatch and partial shading effects is of paramount value. Extracting the maximum power of partially shaded PV arrays has been widely investigated in the literature. The proposed solutions can be categorized into four main groups. The first group includes modified MPPT techniques that properly detect the global MPP. They include power curve slope, load-line MPPT, dividing rectangles techniques, the power increment technique, instantaneous operating power optimization, Fibonacci search, neural networks, and particle swarm optimization. The second category includes different array configurations for interconnecting PV modules, namely series-parallel, total-cross-tie, and bridge-link configurations. The third category includes different PV system architectures, namely centralized architecture, series-connected micro converters, parallel-connected micro converters, and micro inverters. The fourth category includes different converter topologies, namely multilevel converters, voltage injection circuits, generation control circuits, module-integrated converters, and multiple-input converters. In centralized or string photovoltaic (PV) systems, PV modules must be connected in series in order to generate a sufficiently high voltage to avoid further amplification and to efficiently drive further converters. This always requires dozens of PV modules; however some of them maybe suffer from partial shadow caused by trees, clouds or other things. In this case, power generated from each PV module becomes unbalanced so that total output powers greatly decrease. Furthermore, hot-spot effect caused by partial shadow is likely to damage the PV cells and affect the security of PV system. In order to solve these problems, the topology of PV system composed of many series-connected PV modules with corresponding energy feedback circuits is proposed in this paper, a feedback circuit is independently utilized to feed the output energy of PV system to the corresponding circuit including shadowed PV module. The simulation and experimental results verify that the proposed topology can make each PV module operate on the maximum power point individually regardless of partial shadow (Zhang, et.al., 2009). The energy feedback circuits do not operate without partial shadow, they have no power loss under this condition, and therefore the circuit efficiency is improved.

MATERIAL AND METHODS:

To prevent the entire string of cells failing when one cell under shading; the theoretically by using the solar module installation can be fitted with ‘by-pass diodes'. The current around the underperforming cells can be rerouted. The disadvantage is that rerouting the current loses not only potential energy from these cells, but also lowers the voltage of the entire string. Finding a clear solution to the shading problem will help guarantee a reliable power supply for the owners of Solar PV system. By reducing shading induced power losses, installers can potentially increase the available roof area for Solar PV arrays. The existing Photovoltaic modules in Renewable Energy Research Centre (University of Anbar-Iraq) consist of 36 cells. These modules (Kyocera and Solara) are often used for experimental researches. In this experiment PV modules were placed in a dark in order to study their behavior without illumination. Our results contain both experimental with some mathematical calculation used to determine the effect of some the junction parameters through an equivalent circuit model of PV.

A single solar cell consists of a photo current source is the simplest equivalent circuit in addition to a diode, and a series resistor describing an internal resistance of cell to the current flow. More precise mathematical description of a solar cell, which is called the double exponential model that derived from the physical behavior of solar cells constructed from polycrystalline silicon. The details algorithm for fig. 1. is given in ref (Mohammed, et. al., 2011).

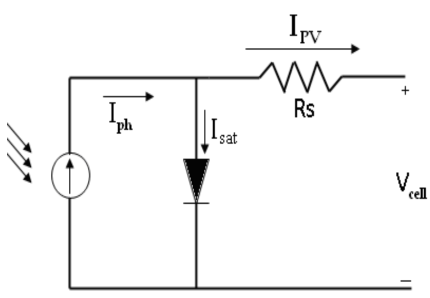

Fig-1-: Equivalent circuit of a solar cell

Equation (1) is commonly referred to as the diode model, where all parameters except *V* and *I* are constants and could be used as a good model for a solar cell, as well as a module.

:$I_{PV}=I_{ph}-I_{sat}*(\exp(V_{cell}+I_{PV}*Rs)/V_t*N)-1)$ (1)

$Vt = A*k*T/q$ (2)

Where

G - solar irradiance

I_{ph}- photo-generated current,

I_{sat}- dark saturation current,

R_s- panel series resistance,

I_{PV} - cell output current,

V_{cell} - cell output voltage,

A - diode quality (or ideality) factor,

K- Boltzmann's constant = 1.38×10^{-23},

q - electron charge 1.6×10^{-19},

N- number of cells connected in series = 36

T - cell temperature.

The calculation is considered of both series along with the junction ideality factor (A). The components of the diode diffusion experimentally collected I-V and P-V curves were introduced into specially designed software that performs numerical calculations (Jihad, et.al. 2010).

The effect of shade on power output of typical PV installations is nonlinear in that a small amount of shade on a portion of the array can cause a large reduction in output power. For instance, completely shading one cell of an array will cause the bypass diode protecting that cell to begin conducting, reducing the power of the module by as much as 1/3–1/2 (depending on the number of groups of cells in the module). Equation (3) is used to compute Shade Impact Factor (SIF) of PV systems (Deline, 2009).

$SIF=[1-P_{shade}/P_{sys})]\times A_{sys}/A_{shade}$ (3)

Where:

P_{sys} and A_{sys} are the nominal system power and area,

A_{shade} is the shaded area, and P_{shade} is the power produced under shaded conditions

SIMULATION RESULTS:

The electrical performance of a solar module is represented by I-V and P-V characteristic curves. In this paper, the I-V curves under different percentage of shading will be analyzed practically and circuit diagram (single diode equivalent circuit diagram). Electrical Output power of PV panels is badly affected by shading that caused by clouds and trees and other blocks that prevent sun's radiation with constant irradiation and temperature. In this research it can be shown the effect of panels' efficiency of Kyocera and Solara PV modules by using Matlab program calculation and lab equipments to compute o/p characteristics. The technical specifications for the simulated PV models are summarized in table (1).

Table-1: Specification of Kyocera and Solara PV models with 1000 (w.m-²) irradiation

Parameter	Kyocera	Solara
Isc (a)	3.31	8.18
I,.(a)	3.11	7.30
Voc(v)	21.7	21.7
V,=(v)	17.4	17.8
P=(w)	54	130
Effective PV aiea (cm)	64×65.3	64×65.3

The output currents and voltages are dependent the instantaneous solar radiation. he generated current is directly proportional to (G), while the voltage reduces slightly with an increasing of shading. The impact of shading on the I-V and P-V curves of a solar panel clarified the basic mechanism that estimates the reduction in output power. Such degradation in maximum power production clearly depends on the shaded area as well as the layout of the modules and the bypass diodes. The analysis was illustrated by experimental data. Many states of shadings are used (No shading, 25%, 50%, 75% and 100% shading) and many connection ways are used to compute the shading effect on the o/p power. The data are collected in same time and location (In 20th of November 2012, 12:30 AM, at the University of Anbar campus. The I-V characteristic curve for Kyocera model is shown in (fig2).

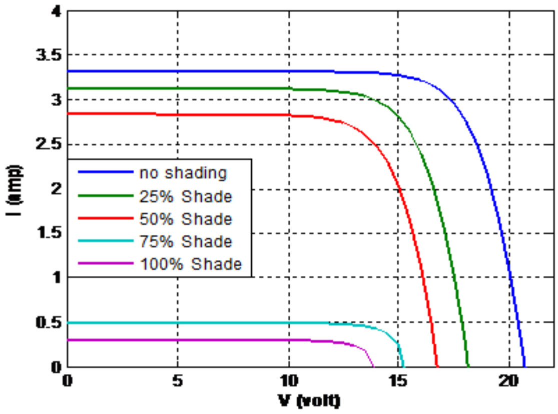

Fig-2: I-V characteristic with shade effect of one Kyocera PV panels (54 W)

From fig. 2. it can be seen that the current of PV model deceases as the shading percentage increase from zero to 100%. Note that when the shading percentage is near equal to or more than 75%, the o/p of current is so effected and less than amount of current that required to use such model for direct connection to load. Note that if the shading is 75% or 100% the charging current is not enough for charging batteries of 12 V even the shading used is soft shading instead of hard shading. Fig. 3. Shows the PV characteristics curves for Kyocera PV module. The SIF of 50% cell shading state = 0.72 and power of this module is reduced by about 36% (1-37W / 53 W) as the shading is 50% of the module size with respect to non-shading case. Also; the maximum o/p power at non-shading is about 53 W instead of 54 W given in the data sheet of such module and this is due to a difference between the simulation modules (which gives an approximate result) and the real generated power in the factories, when they used a solar module tester with constant irradiance and temperature. The authors (Salih, et.al, 2012) gave more details of the extracted results for models by using the existing solar module tester in Renewable Energy Research Center – university of Anbar –

Iraq. In (fig-5). The practical maximum o/p power at non-shading is about 118W which is less than the maximum rating power of this module (i.e.130W) which taken in ideal environment with no efficiency limitations such as dust, humidity and temperature. The maximum power at 50% of shading is 60W. This is less than the maximum power by about 49% (1-60W/118W) and SIF = 0.96

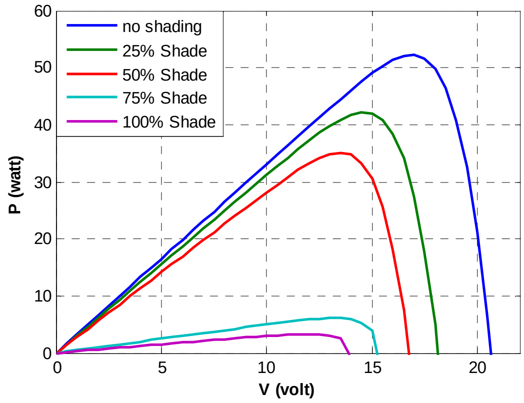

Fig-3: P-V characteristic with shade effect of one Kyocera PV (54W).

Single Solara PV panel testing under shading effect was investigated by I-V and P-V characteristics curve that shown in fig. 4. and (fig-5). respectively. (Fig-4). shows that the voltage generated at shade up to 50% is gradually decreased. As the shading increased to 75% or 100% the o/p voltage will be less than 12V, which means the charging of batteries will stop, if the module is used with battery backup.

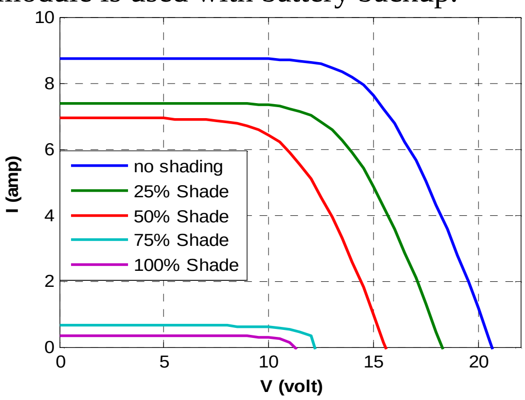

Fig-4: I-V characteristic with shade effect of one Solara PV module (130W)

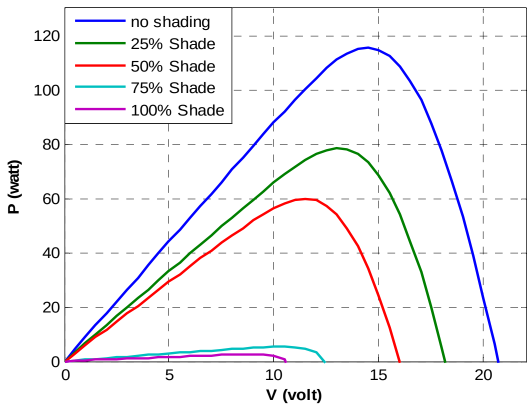

Fig- 5: P-V characteristic with shade effect of one Solara PV module (130W)

The previous results show that the Kyocera PV panel is less affected by shading than Solara PV panel when the same percentage of shading was applied. Next, the PV modules are connected in parallel or in serial in order to increase the generated to be close to or greater than the level of voltage of the required batteries to be charged.

The series connection of two modules will be used for doubling the voltage with a constant current.

This type of connection is suitable for overcoming the problem of hard drop voltage due to shading effect.

The parallel connection of modules is used for doubling the current at a constant voltage. This type of connection is suitable for fast charging of batteries due to high current that can be obtained from the panels, and also it is suitable for direct connection to the driven current load.

(Table-2) shows more explanation of shading impact factor and maximum power point (MPP). SIF of Kyocera modules and series connection is less than SIF of solara modules and parallel connection respectively.

That prove shading has less effect on models with smaller size and it has higher effect of parallel than series connected PV panels. So

Table -2: Shading impact factor and maximum power

Model and Connection Type	Shading	A.,./A.,.	MPP(watt)	SIF
One panrl Kyocera	No shading	00	54	.
	25%	4	45	0.668
	50%	2	37	0.63
	75%	1.333	7	1.161
	100%	1	4	0.925
Two parallel panels Kyocera	No shading	00	107.2	.
	25%	4	90	0.666
	50%	2	74	0.626
	75%	1.333	15	1.145
	100%	1	8.2	0.921
Two series panels Kyocera	No shading	00	107.4	.
	25%	4	92	0.593
	50%	2	75.35	0.604
	75%	1.333	18	1.11
	100%	1	11	0.898
One panrl Solara	No shading	00	116.3	.
	25%	4	79	1.282
	50%	2	60	0.968
	75%	1.333	7	1.25
	100%	1	3	0.974
Two parallel panels Solara	No shading	09	234.5	-
	25%	4	160.9	1.255
	50%	2	124	0.942
	75%	1.333	14	1.253
	100%	1	7	0.97
Two series panels Solara	No shading	00	236	-
	25%	4	167.87	1.154
	50%	2	125	0.940
	75%	1.333	17	1.23
	100%	1	9	0.961

series effect connection has more immunity to shade effect than parallel connection. Despite panels is identical and radiation and temperature is constant but there are deference of characteristics between series and parallel ones. The details results of experimental tests given in (table-2) are summarized in (fig-6) and (fig-7).

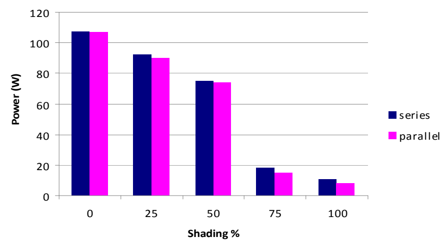

Fig-6: Comparison of power generation between two connected Kyocera PV panels

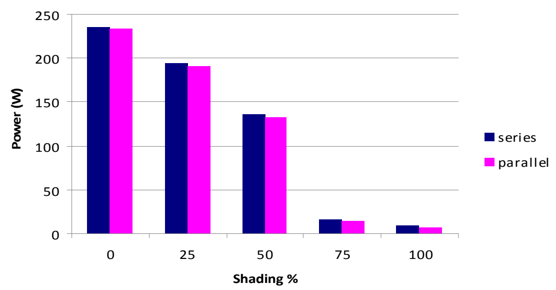

Fig-7: Comparison of power generation between two connected Solara PV panels

(Table-3) gives some of practical types of shading extracted from reference (Lijun, et.al., 2009). The table shows that there are different resources of shading, the shading types is considered as a soft shading and for this reason the o/p of PV will not drop to a high values as in the hard shading case. Also our extracted results are in the case of soft shading.

Table-3: Types of shading

	place	Test description
1.	Out of doors	-Area lias no shade -panels stationary -panels positioned horizontal
2.	Out of doors	Area shaded by tree- - panels constant movement - panels positioned horizontal
3.	Out of doors	-Area shaded by tree - panels constant movement - panels positioned at an -assigne degree to the horizon
4.	Out of doors	- Area shaded railing -panels stationary - panels positioned horizontal

Even panels that have identical performance ratings will usually display some variance in their characteristics due to manufacturing processes, but the actual operating characteristics of two panels from the same manufacturer can vary by as much as ±10%. Whenever possible, it is a good idea to test the real-world performance of individual panels to verify their operating characteristics before assembling them into an array.

CHARGING OF BATTERIES:

Stand-alone photovoltaic systems (The electrical energy produced by the PV array) cannot always be used when it is produced due to shading effect or dusty weather. As the demand for energy does not always coincide with its production, electrical storage batteries are commonly used in PV systems (Internet Survey, 2013).

The primary functions of a storage battery in a PV system are to store electrical energy when it is produced by the PV array and to supply energy to electrical loads as needed or on demand, to supply power to electrical loads at stable voltages and currents, and supply surge or high peak operating currents to electrical loads or appliances. (Table-4) gives the concluded results of shading effect on charging performance of batteries from above I-V and P-V characteristics curves to all states related to the shading effect of batteries charging.

Table-4: Shading effect on battery's charging in single PV module [at 12 volt].

PV Model	Shading percentage	Ia	Power
Kyocera	No shading	3.31	39.72
	25%	3.05	37.8
	50%	2.85	33
	75%	0.48	5.7
	100%	0.31	4.2
solara	No shading	8.75	104.64
	25%	7	68
	50%	5.1	58
	75%	0.3	4.5
	100%	No shading	No shading

(Fig-8). shows the performance Comparison between the percentage charging powers under shading effect with charging power. From (table-4), it can conclude that the model with a small size (Kyocera–54W) is less affected by shading than the module with a big size (solara–130W). for example, at 25% shading the percentage of charging power is 37.8/39.72= 95.1 % for Kyocera, while it is about 68/104.64= 64.9 % for Solara–130 module. As the shading increases the module with a small size still has better performance than the bigger one at same percentage of shading.

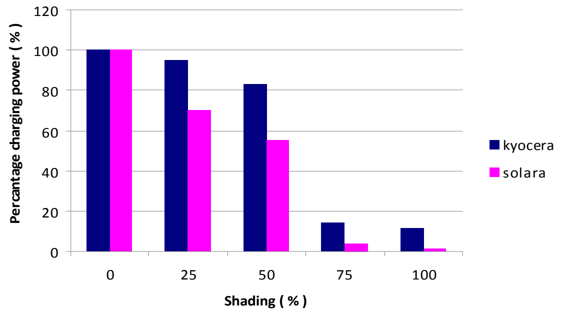

Fig-8: Percentage of charging power

SOLAR MODULE TESTER:

The solar module tester can be used for evaluation of PV modules. The I-V and P-V characteristic curves can be obtained directly from the tester module under STCs (T = 25 °C, G = 1000 W/m2, and Air Mass (AM) = 1.5). the values of solar irradiance can also be changed at different specified values. Fig. 9 shows the I–V and P–V characteristic curves and the other key specifications (i.e. I_{sc}, V_{oc}, P_m, I_{pm}, V_{pm}, and FF) for the Solara PV module. Note that the output of this module is the same as the output value in the nameplate of the module from the supplied company which is 130W. So, the solar module tester can confirm the output values from the manufacturing companies at standard solar irradiance (Salih, et.al., 2012.)

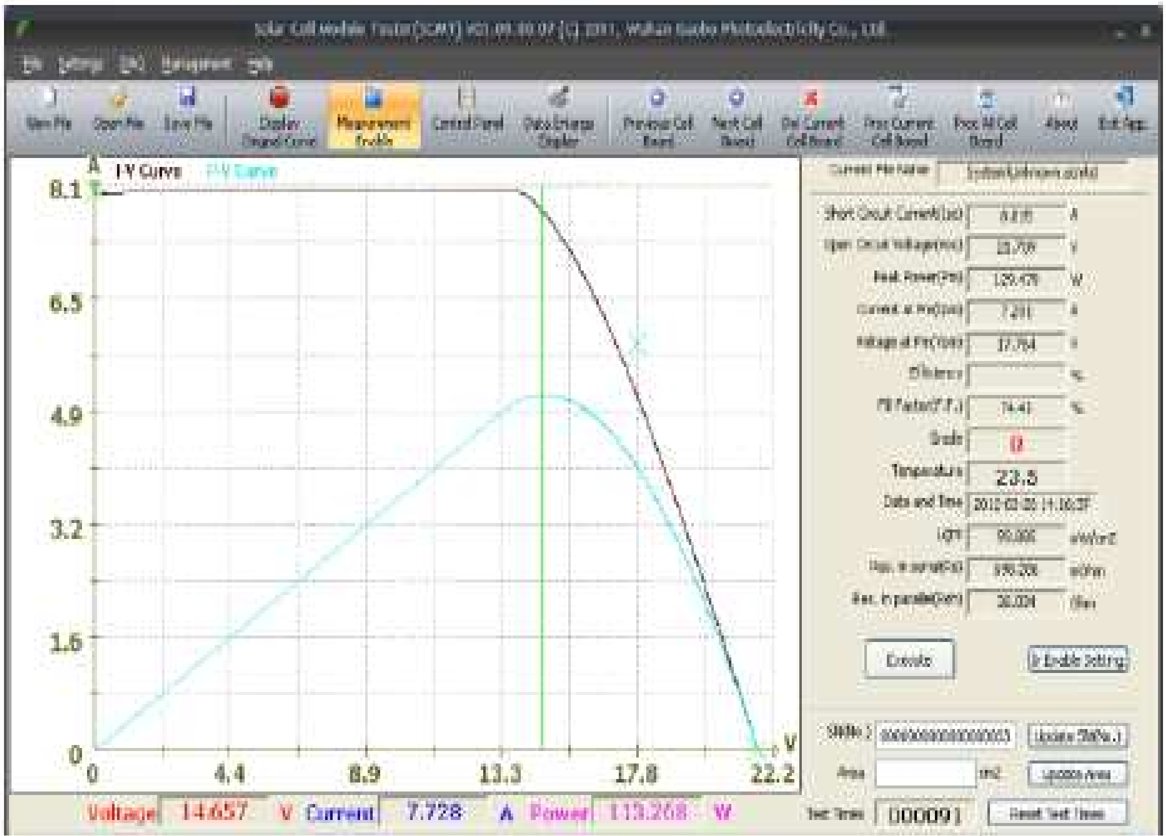

Fig-9: I–V and P–V characteristics of Solara PV model at 1000 W/m^2

CONCLUSION:

The analysis of shading impact factor on the performance of two PV models (Kyocera–54W and Solara–130W) is tested under different percentage of shading effect. The results showed that the shading can has more effect on current of PV than generated voltage, which causes a reduction of the generated power. Because the generated voltage is less than (12 volt), the charging of batteries will stop if the shading near 75% or more. The photovoltaic systems with small modules sizes (dimensions) are less affected by shading than the systems with larger modules sizes. The solar module tester can be used for extracting the power values of the new fabricated PV modules.

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