Benchmarking Experimental Performance Analysis of Solar PV Cells Against OEM's Performance Ratings

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Abstract
This study adopted an experimental approach to analyse the core parameters of different photovoltaic modules by applying Krebs' correction to standard test conditions. Current-voltage and power-voltage curves for each PV module were obtained at different illumination levels, in addition to performance parameters ascertained from the fill factor and efficiency values of the PV modules. Ohmic losses present challenges in PV systems and could be addressed by recombination electrons made available by utilising the geometry and thickness to absorb the most wavelengths of incoming light. The parameters were subsequently compared with the manufacturer's specifications, and the modules performance were discussed.

Keywords: PV cells, OEM, Krebs correction, Fill factor.

1. Introduction

Renewable energies have experienced exponential growth during the last decade. Furthermore, from a technological point of view, the development of more efficient and sustainable systems has been achieved [1 – 3]. In this context, electrical energy production through the photovoltaic (PV) conversion of the incident rays from the sun represents one of the alternative solutions due to its advantages which include low maintenance cost, integration with other renewable energy sources, minimal energy loss in systems, etc. which are desirable for the decarbonisation of grid systems [4 – 5]. Therefore, systematic studies are required to determine and explain the operation principles of different related technologies [6 – 7], both existing or in development. This is relevant for maximising operational efficiency and elaborating upon methods used to exploit the electric energy produced [(IEC, 2016)].

Due to the issues relating to climate change and environmental degradation, global attention for sources of energy has been turned towards renewables. A photovoltaic (PV) system is a feasible setup that harnesses solar energy and it ranges from smallest units to complex setups. One of the most economical PV systems is a solar cell which represents smallest unit of the PV system that acts as a two-terminal semiconductor diode and has the ability to convert solar radiations directly into electricity via the photovoltaic effect. PV cells are usually connected, either in parallel or series, to form a module; the modules make up the panel and several panels are termed arrays [8]. Solar PV cells are important because they represent an economical way of converting solar energy into electricity for domestic uses. Despite this benefit, only a fraction of sunlight gets converted due to factors such as temperature, irradiance, and shading, which affect the efficiency of the units. Vergura (2016) identified that the maximum power output of a PV cell is affected by its short-circuit current, caused by irradiance, and open-circuit voltage, caused by temperature [9]. Bunea, et al., (2006) observed that poor performance of mono-crystalline silicon PV cells under was affected by shunt resistance with the cells [10]. In analysing combined insolation and temperature effects on PV cells, Suman et al. (2021) concluded that variations in solar irradiance at a constant temperature result in variations in output current and ultimately variations in output power from PV cells [11]. On the contrary, variations in temperature at constant irradiance resulted to variations in output voltage from the cell and, consequently variations in output power. Similarly, findings showed that the quality and performance of cells are affected by temperature [12]. Using mono-crystalline solar cells, the authors observed that temperature effects had an inverse relationship with cell parameters – efficiency, maximum power point, open circuit voltage at constant irradiance values.

PV modules can be combined in parallel or series connections to form solar arrays to produce large power. The most commonly used materials for the fabrication of solar cells are mono-crystalline silicon, amorphous silicon, poly-crystalline silicon, thin-film technology, and various nanomaterials. The selection of these materials greatly impacts the performance and high-power conversion efficiency of solar cells. Currently, a mono-crystalline silicon-based solar cell dominates the solar market because of its high-power conversion efficiency, long lifespan, and non-toxic and stable nature, with a panel efficiency range between 15 – 25% [15]. However, various studies have shown that nanomaterials also gained importance in solar cell fabrication due to their unique physical, electrical and chemical properties. A solar photovoltaic system is a power generation system that converts solar radiation directly into electrical energy using solar cells that work on the photovoltaic effect. The working idea of a photovoltaic power supply system is that the electricity produced by the solar component will charge for the controller-controlled battery, which will then be directly connected to the load power supply in order to fulfill the load demand when the sun is shining. At low levels of solar irradiance, the battery provides power to the DC load, which a controller sustains. In the case of AC loads, a converter is required for such solar systems. Messenger & Abtahi (2018) noted that PV cells can be characterised as having a nominal operating cell temperature (NOCT) when they are placed in the module [17]. This is the maximum temperature that the cells will reach under open circuit operation with ambient temperatures of 20°C, AM 1.5 irradiance, G = 0.8 kW/m2, and winds less than 1 m/s. Therefore, it is essential to understand the behaviour of PV systems under this condition to estimate PV system efficiency and diagnose various operational and environmental conditions.

This study aims to experimentally evaluate the performance of PV modules under various irradiance levels and subsequent comparison of results with manufacturer's datasheet. Over the past years, PV (photovoltaic) technology has been in upward trend, and this can be categorised into various aspects such as type of material, design configuration etc. Here, classification based on the type of material is made here. It is worthy to note that all PV modules, regardless of configuration and type, are made out of silicon – a semi-conducting material. The ideal current curve applies to all the modules irrespective of the type/category identified.

2. Governing Equations

Mathematical modelling and equations play an essential role as it reduces fabrication costs, save time, and help researchers to predict the behaviour of the PV system. The performance analysis of PV cells is determined from current-voltage and power-voltage curves. This is because parameters such as short-circuit current, open-circuit voltage, maximum power, fill factor, are effectively used to characterize the module. The PV modules data sheet is the manufacturer's information on electrical parameters such as short circuit current, open circuit voltage, the rated value of voltage and current at the maximum power point, and standard test conditions. An idealized diagram of these parameters is shown in Fig. 1 below and the applicable mathematical expression/description is made in the subsequent sections.

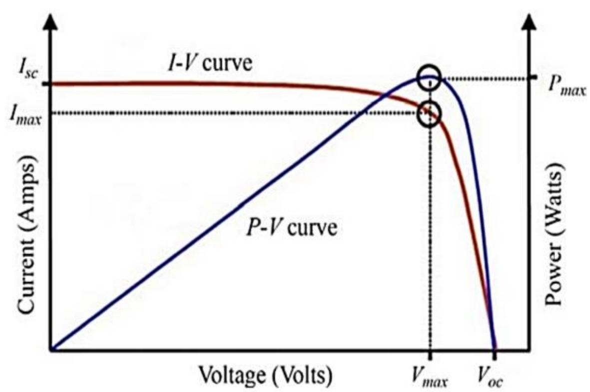


Figure 1: Normalized I-V and P-V curves for a PV device.

Open-circuit Voltage (V_{oc}): This is the voltage measured by putting the PV cell terminals in open-circuit condition under standard testing conditions. As depicted in Fig. 1, open-circuit voltage is usually higher than the voltage attained at the maximum point. Mathematically, this is given as [12,14]:

$$V_{oc} = AV_T ln\left(1 + \frac{I_{sc}}{I_0}\right), at I = 0 \qquad 1$$

Where
V_{oc} = open-circuit voltage
I_0 = leakage current or reverse saturation current of diode

V_T = diode thermal voltage (which is dependent on temperature)
I_{sc} = short-circuit current

Short-circuit Current (I_{sc}): This is the maximum current that is generated when a solar PV cell is configured to operate in real-time conditions. While measuring this current, the PV cell terminals are short-circuited by means of some load. Short-circuit current is higher than the current at maximum power. Mathematically, it is given as [12,14]:

$$I_{sc} = I_{ph} - I_0 \left[exp\left(\frac{V}{AV_T}\right) - 1\right] \text{ at } V = 0 \qquad 2$$

where
I_{sc} short-circuit current
I_0 leakage current or reverse saturation current of diode
V voltage imposed on the diode
I_{ph} photocurrent
A ideality factor of diode
V_T diode thermal voltage (which is dependent on temperature)

Maximum Power Point (M_{PP}): This is the single location in which the PV cell produces the most electricity. The voltage and current recorded at this point are termed as maximum voltage and maximum current, respectively. These figures may vary depending on radiation intensity as well as local weather parameters [12,14]. Mathematically, it is expressed as:

$$P_{max} = V_{max} \times I_{max} \qquad 3$$

Where
P_{max} power at maximum point in Watts
V_{max} voltage at maximum power point in volts
I_{max} current at maximum power point in ampere
It is important to point out that Eqn. 6 applies under the condition of ideality wherein all incidence rays are converted into electricity. However, in practice, maximum power is obtained using Eqn. 6 below:

$$P_{max} = V_{oc} \times I_{sc} \times FF \qquad 4$$

And efficiency of conversion is expressed as:

$$\eta = \frac{V_{oc} \times I_{sc} \times FF}{P} \qquad 5$$

Where:
V_{oc} open-circuit voltage
I_{sc} short-circuit current
FF fill factor
η = efficiency

$$I = I_I - I_D \qquad 6$$

where
I = Overall current (A).
I_I is cell current due to photons (A).
I_D is diode current (A)

3. Experimental Setup and Procedure

The set up circuit as shown below in fig 3, describes the arrangement for a steady illumination on the PV module. This done periodically by checking that the short circuit current Isc remains the same, and/or checking the reading on a photometer placed so as to receive the same illumination as that reaching the module. Also to measure the short circuit current Isc and the open circuit voltage Voc.

To also vary the variable resistor so as to obtain current values ranging from 0 to Isc and in each case measure the corresponding voltage. (Try using variable resistor settings of 100k, 50k, 20K, 10 K, 5K etc. down to 10, 5, 2 and 1 Ohm). Also calculate the power in each case (P = VI). Vary the illuminance value (say two or three times the original value) and again record corresponding values of I and V. Calculate the power in each case as before. If time allows, carry out 5 above at a higher illuminance level etc. the Plot power against voltage curves on the same graph. And Plot curves of current I against voltage V and find Vmax and Imax for each curve. Also estimate the fill factor for each plot. Then, determine the module efficiencies at the maximum power output values.

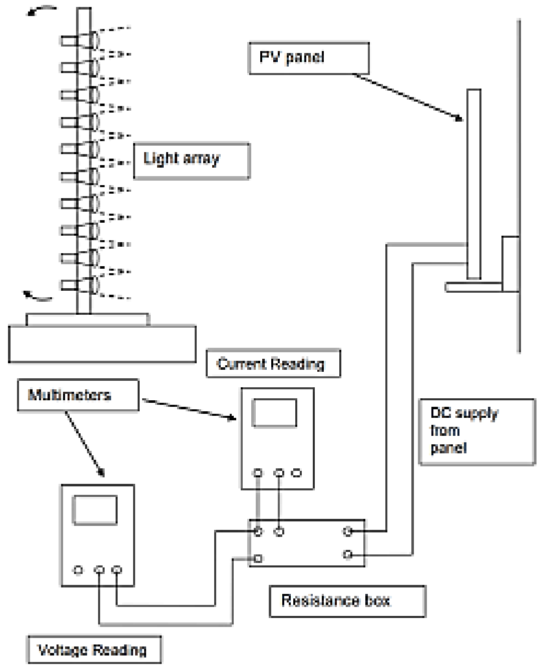


Figure 2: Schematic diagram of all equipment used in the experimental analysis.

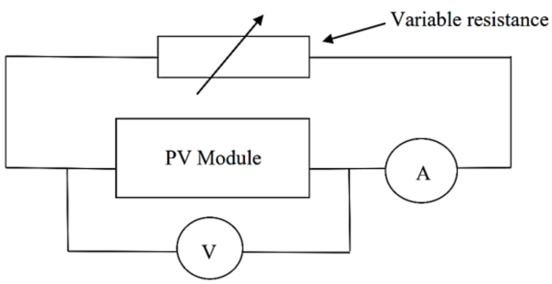


Figure 3: Experimental circuit setup of the PV module.

Two solar panels are taken into consideration for the experiment one is 1.5W and the other one is 5.0Wp. The 1.5W was first taken into consideration, the light array was incident on to it. The irradiance of the light array was noted. When the light array strikes the panel using regulators of variable resistances, the resistance was changed and each reading of voltage and current of the panel will be noted by the voltage reading multimeter and current reading multimeter. For each irradiance the resistance was changed and the maximum voltage and current reading are noted. For the same panel, 3 individual and different readings were taken at different irradiance reading. Then the second panel of 5Wp was taken into the experiment, this panel is a poly-crystalline solar panel. The same experiment was conducted on the panel, using the same resistance regulators. The maximum voltage reading and maximum current readings are noted for different irradiance and resistances.

The equipment used for this experimental analysis include:

- Artificial light source to provide irradiation.
- Solar PV panels – fat plate and poly-crystalline.
- Variable resistance box.
- Digital multimeter – to obtain readings of voltage and irradiance.
- PC – for data logging.

The next section shows the data obtained during the experiment by the data logger in the computer, there were about 5 excel files exported from the data logger.

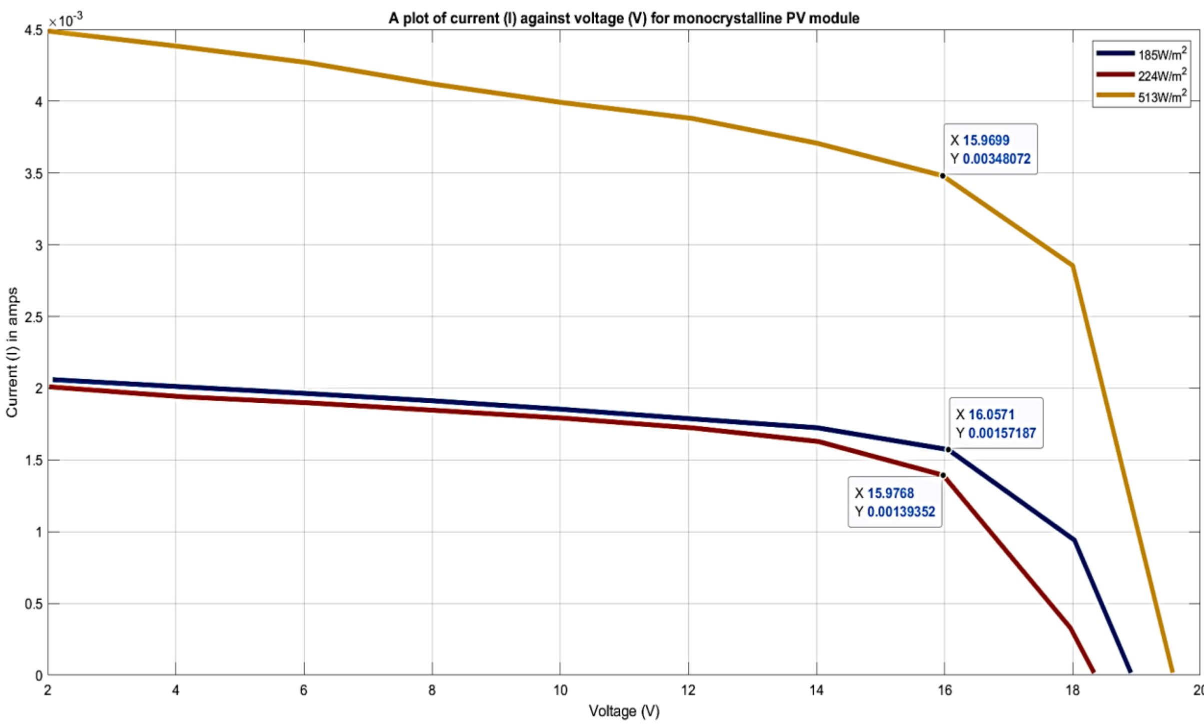
4. Results and Discussions

4.1 I-V & P-V Characterisation of PV Cells

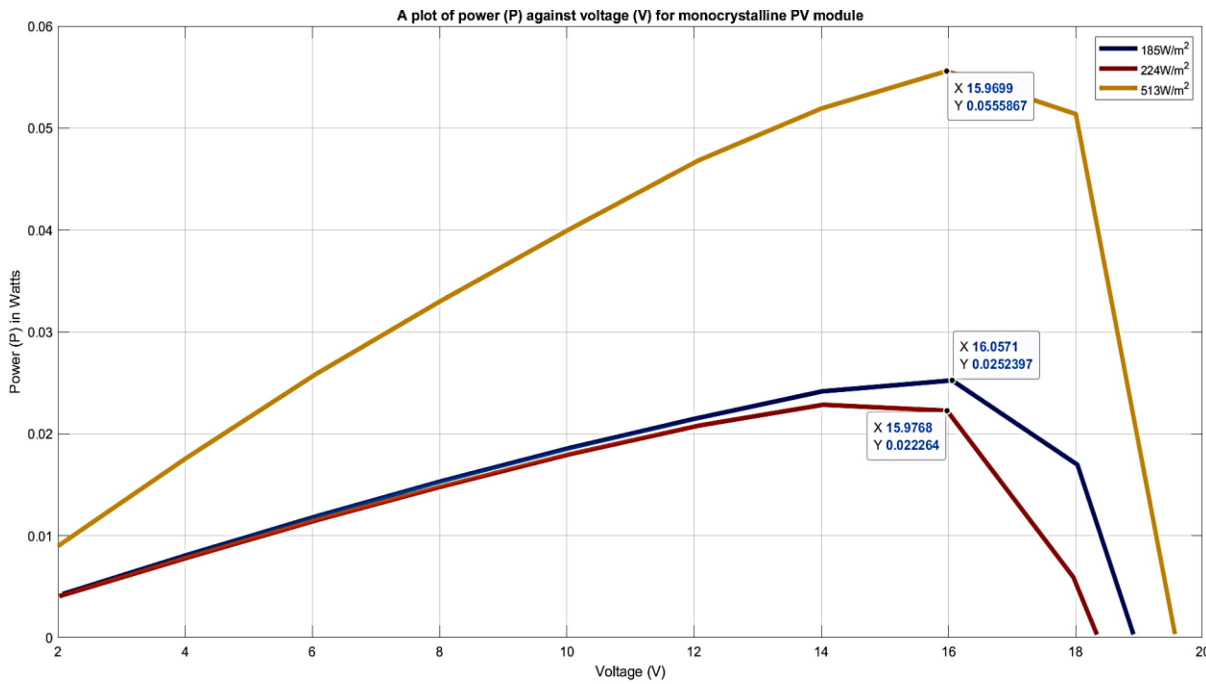
In order to ascertain deviations from the manufacturer's datasheet, the two PV modules were exposed to different levels of solar irradiation, and the I-V and P-V properties were obtained. A summary of findings are presented in Table 1 (for mono-crystalline PV module) and Table 2 (for poly-crystalline PV module), which are depicted in Figs. 4 – 5. Considering the mono-crystalline module, open-circuit voltage (V_{oc}) and short-circuit current (I_{sc}) for irradiance of 185W/m^2 were obtained as 18.91 V and 0.00206 A, respectively. Maximum power of 0.025 W was calculated from maximum voltage and current values of 16.0571 V and 0.00157 A, respectively, and depicted by the blue legend in Fig. 4b. For irradiance of 224W/m^2, open-circuit voltage (V_{oc}) and short-circuit current (I_{sc}) of 18.3325 V and 0.00201 A. Consequently, the maximum power point was calculated as 0.0228 W from maximum voltage and maximum current values of 15.9786 V and 0.00139 A, respectively. For solar irradiance of 513W/m^2, open-circuit voltage (V_{oc}) of 19.56 V and short-circuit current (I_{sc}) of 0.00449 A was obtained which yielded maximum power of 0.056 W at maximum voltage and current of 15.97 W and 0.0035 A, respectively.

Table 1: Comparative Analysis of Experimental Data with Manufacturer Datasheet for RS PRO Mono Crystalline

Solar irradiance	Parameters	RS PRO	
		Experimental	Datasheet
185 W/m^2	V_{oc} (V)	18.91	21
	I_{sc} (A)	0.00206	0.39
	V_{mpp} (V)	16.0571	16.8
	I_{mpp} (A)	0.00157	000.3
	P_{max} (W)	0.025	5
224 W/m^2	V_{oc} (V)	18.3325	
	I_{sc} (A)	0.00201	
	V_{mpp} (V)	15.9786	
	I_{mpp} (A)	0.00139	
	P_{max} (W)	0.0228	
513 W/m^2	V_{oc} (V)	19.56	
	I_{sc} (A)	0.00449	
	V_{mpp} (V)	15.97	
	I_{mpp} (A)	0.0035	
	P_{max} (W)	0.056	



(a)



(b)

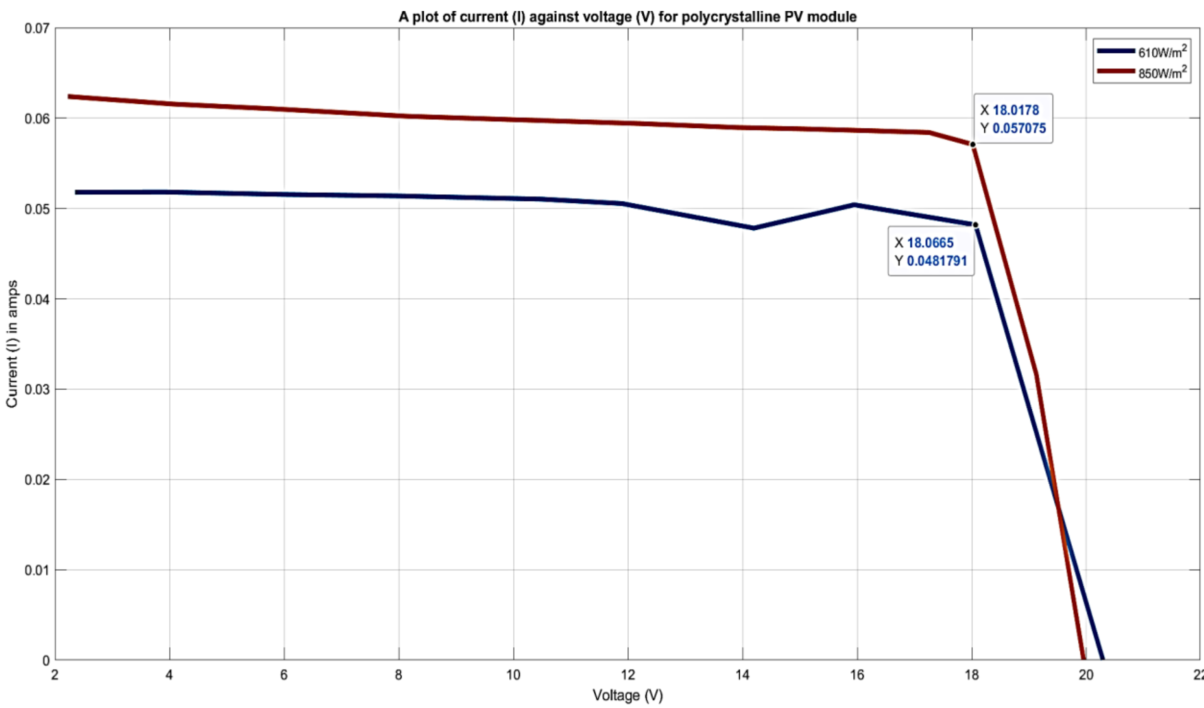
Figure 4: I-V and P-V characteristics for RS-PRO PV cells at 25°C for different solar irradiation.

Based on the Original Equipment Manufacturer datasheet for the mono-crystalline PV cell, its expected output power was rated at 5W, V_{oc} of 21 V, I_{sc} of 0.39A, V_{mp} of 16.8 V, I_{mp} of 0.3A. This is at variance with the experimental findings reported above and the differences could be attributed to an effect of ambient temperature on the solar cell, which affects the performance of PVs. Bunea et al., (2006) observed that PV cells with low shunt resistances behave differently as irradiation decreases [10]. As a result, low illumination levels cause such devices' open circuit voltage (V_{oc}) to degrade as the current lowers because the cell will be in the shunt region of the I-V curve. This challenge can be overcome by considering an ideality factor, a corrective approach to measuring the current independent of the resistance. A closer look at Fig. 4 showed that the highest illumination produced the most significant current and power. However, this is not consistent with other levels of illumination, which could be attributed to shunt variation and insolation; consequently, the performance of the PV modules becomes affected. Since irradiation significantly influences the photon current of PV cells (I_{ph}), at a constant temperature, photon current would increase as solar radiation levels increase, increasing the PV's output power [16]. This is particularly true for all types of PV modules and could be seen in Figs. 4 & 5. However, it is essential to note that solar insolation does not affect output voltage (V_{oc}); hence, it remains primarily unaffected.

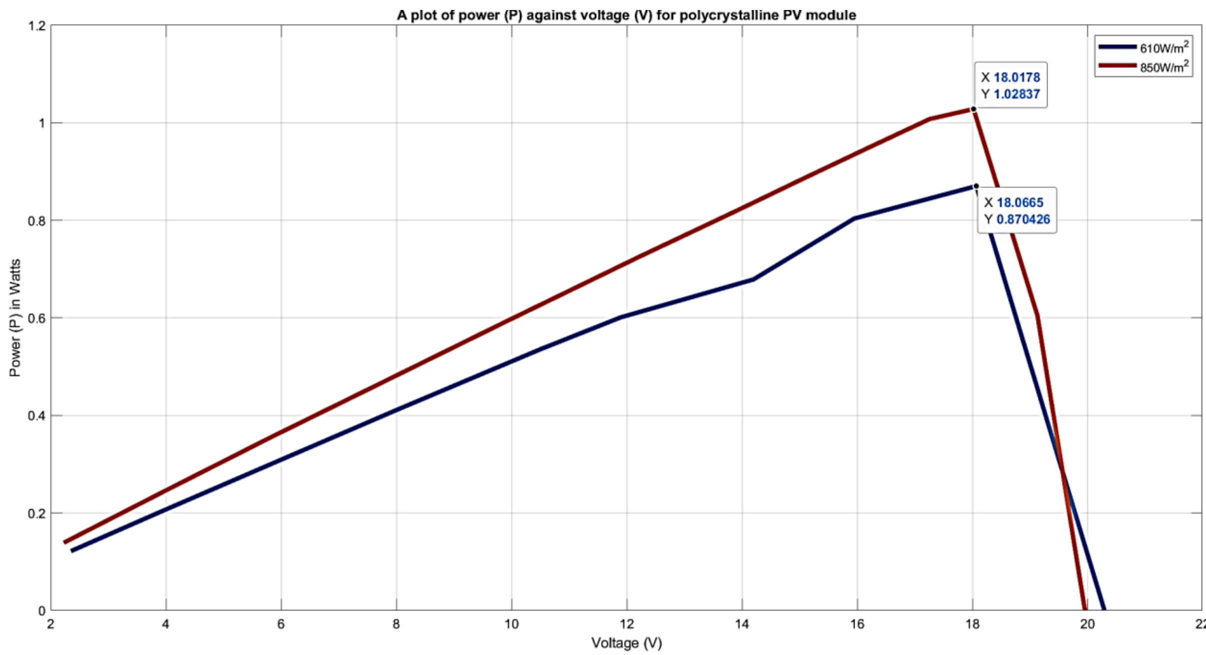
Considering the poly-crystalline PV module, at an irradiance of 610W/m^2, open-circuit voltage (V_{oc}) and short-circuit current (I_{sc}) of 20.29 V and 0.052 A were obtained, respectively, with a maximum power of 0.87 W obtained at maximum voltage and current of 18.07 V and 0.048 A. For irradiance of 850W/m^2, open-circuit voltage (V_{oc}) and short-circuit current (I_{sc}) of 19.95 V and 0.062 A was obtained as maximum power of 1.02 W was calculated from maximum voltage and maximum current values of 18.02 V and 0.057 A, respectively. A summary of these parameters are presented in Table 2 below for the poly-crystalline device and shown in Fig. 5.

Table 2: Comparative Analysis of Experimental Data with Manufacturer Datasheet for TPS-946 Poly Crystalline

Operating conditions	Parameters	TPS-946	
Solar irradiance 610 W/m^2		Experimental	Datasheet
	V_{oc} (V)	20.29	17.5
	I_{sc} (A)	0.052	N/A
	V_{mpp} (V)	18.07	N/A
	I_{mpp} (A)	0.048	N/A
	P_{max} (W)	0.87	1.5
STC of 850 W/m^2	V_{oc} (V)	19.95	
	I_{sc} (A)	0.062	
	V_{mpp} (V)	18.02	
	I_{mpp} (A)	0.057	
	P_{max} (W)	1.02	



(a)



(b)

Figure 5: I-V & P-V plots for polycrystalline TPS-946 solar module at 25°C and different solar irradiation.

In summary, the variations in experimental findings from information contained in OEM datasheet contribute to ohmic losses in PV systems which affect energy output from such technologies. These ohmic losses could be addressed by the availability of recombination electrons in PV cells which entails utilising the suitable wafer geometry and thickness to absorb the most wavelengths of incoming light.

4.2 Fill Factor

This is an important parameter that denotes quality of the PV cell and it is defined as the ratio of maximum power to the product of open-circuit voltage and short-circuit current [12,14], thus:

$$FF = \frac{P_{max}}{V_{oc} \times I_{sc}} = \frac{V_{max} \times I_{max}}{V_{oc} \times I_{sc}} \qquad 7$$

Where
FF fill factor
P_{max} maximum power output from the cell
V_{max} voltage at maximum power point in volts
I_{max} current at maximum power point in amperes
V_{oc} open-circuit voltage in volts
I_{sc} short-circuit current in amperes

From the results, the fill factors for at irradiance values of 185W/m^2, 224W/m^2, 513W/m^2, 610W/m^2, and 850W/m^2 were obtained as 0.6482, 0.6200, 0.6330, 0.8280 and 0.8261, respectively. It is important to note that mono-crystalline PV module had values the first to the third whilst poly-crystalline PV module had the fourth and fifth values. Based on the calculated fill factor values, it could be inferred that an inverse relationship exists between irradiance and fill factor as distance increases. This is because at lower irradiance, more cell areas are covered than at higher irradiance and this is applicable for the two types of PV modules is being considered.

4.3 Efficiency

The capacity of a PV cell to convert solar energy into electrical energy (DC) is described as its efficiency and this is given as [12,14]:

$$\eta = \frac{P_{max}}{P} = \frac{V_{max} \times I_{max}}{I(t) \times A} = \frac{FF \times V_{oc} \times I_{sc}}{I(t) \times A} \qquad 8$$

Where
FF fill factor
P_{max} maximum power output from the cell

P power into the system
$I(t)$ irradiance
A panel area, m^2
V_{max} voltage at maximum power point in volts
I_{max} current at maximum power point in amperes
V_{oc} open-circuit voltage in volts
I_{sc} short-circuit current in amperes

Based on Eqn. 7, the calculated module efficiencies at 185W/m^2, 224W/m^2, 513W/m^2, 610W/m^2, and 850W/m^2 irradiances were calculated as 0.51%, 0.38%, 0.41%, 3.67% and 3.11%, respectively. It is important to note that mono-crystalline PV module had values the first to the third whilst poly-crystalline PV module had the fourth and fifth values.

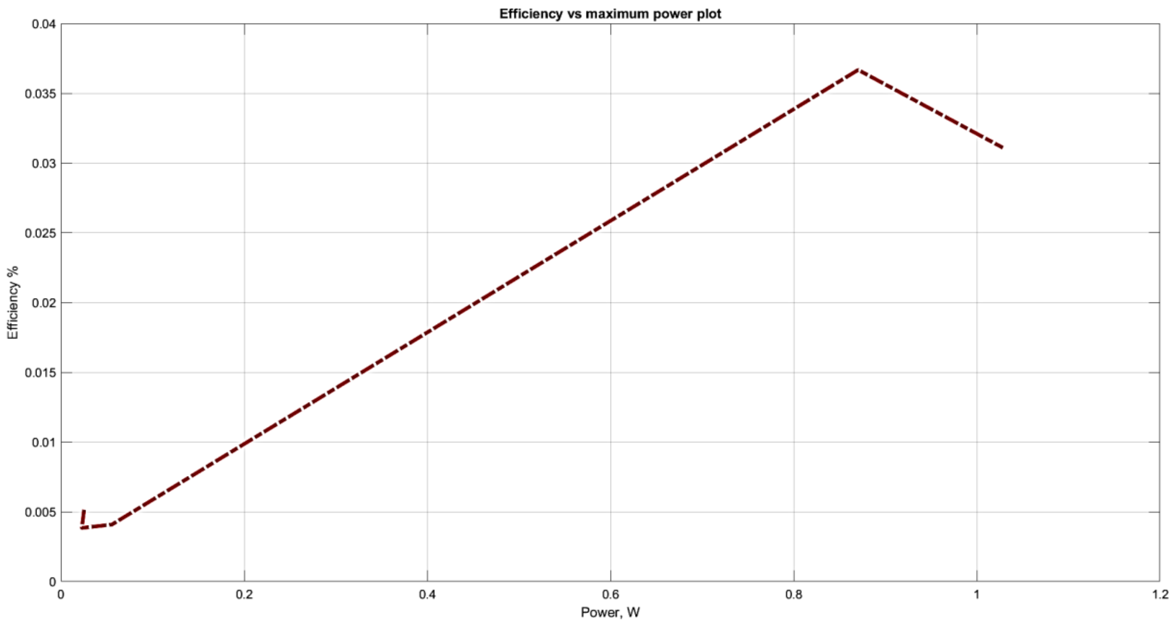


Figure 6: A plot of efficiency against maximum power for mono-crystalline PV module.

Conclusion

This study has analysed a PV cell's core parameters, using Krebs correction to standard test conditions. The results obtained from the setup were used to plot the current-voltage and power-voltage curves for a PV module at different illumination levels. These results were used to estimate the module's fill factor and efficiency. The results were compared to the manufacturer's specifications in the appended OEM datasheet. Hence the performance of the module during the analysis and its expected performance rating was correlated. Most losses in PV systems are attributed to shunting in cells, affecting energy output from such technologies. These ohmic losses could be addressed by utilising the suitable wafer geometry and thickness to absorb the most wavelengths of incoming light. Thus, benchmarking experimental results of core parameters for solar cells against their OEM datasheet would provide more analytical insights into critical performance ratings of different solar cells.

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Appendix

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Solar Energy 1

Appendix A: Krebs Correction to Standard Test Conditions

The Krebs method is used to convert an IV curve measured under certain environmental conditions to the equivalent curve under standard test conditions (1000 W/m², 25°C). These are the conditions for which manufacturers give the specifications of modules and cells, and in which most cell research results are published.

The method requires the temperature coefficients for current and voltage, α and β respectively, which are calculated using the following equations:

$$\alpha = \frac{I_{sc,2} - I_{sc,1}}{T_2 - T_1} \quad (A.1)$$

$$\beta = \frac{V_{oc,2} - V_{oc,1}}{T_2 - T_1} \quad (A.2)$$

Where $I_{sc,1}$, $V_{oc,1}$, and T_1 are the short-circuit current, open-circuit voltage and temperature of one measured IV curve, and $I_{sc,2}$, $V_{oc,2}$, and T_2 are the short-circuit current, open-circuit voltage and temperature of another IV curve measured at a higher temperature.

- These coefficients are specific to the PV sample and depend on the material and production processes.
- The Krebs method is given in its full form in equations (5.5) and (5.6) in the PV Systems notes. For this experiment, the method has been simplified to the following:

$$I_{STC} = I_{meas} + I_{SC,meas}\left(\frac{G_{STC}}{G_{meas}} - 1\right) + \alpha(T_{STC} - T_{meas}) \quad (A.3)$$

$$V_{STC} = V_{meas} + \beta(T_{STC} - T_{meas}) \quad (A.4)$$

Where G_{STC}, G_{meas}, T_{STC} and T_{meas} are the irradiance under standard test conditions (1000 W/m²), the irradiance under which the IV curve was actually measured, the temperature under standard test conditions (25°C) and the temperature under which the IV curve was actually measured, respectively. $I_{sc,meas}$ is the short-circuit current as measured, I_{meas} and V_{meas} are the data points of the measured IV curve and I_{STC} and V_{STC} are the data points of the IV curve translated to standard test conditions.

- NB: equations A.3 and A.4 are applied to every point on the I-V curve you are correcting.
- After correction, you'll notice you no longer have a data point for the open circuit condition. This is normal in the correction process - but it should be easy to extrapolate by eye/hand.

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LAB MANUAL (PG 3)

B. Manufacturer's datasheet

RS PRO

Datasheet

ENGLISH

12V Solar Panels

BENEFITS

Reliable and Robust Design
Proven materials, tempered front glass, and a sturdy anodized frame allow panels to operate reliably in multiple mounting configurations.

Classic Design
Combines high efficiency and attractive crystalline cells give an elegant appearance.

More Power
Using industry leading 17.0% efficiency solar cells delivers incredible performance.

(10WP Panel shown)

MONO & POLY-CRYSTALLINE (12 VOLT) SILICONE SOLAR CELL MODULES

5WP - 150WP

Features

- Modules are designed in accordance with IEC61215:1993 standards, manufactured with proven materials and tested to ensure electrical performance and service life.
- SiN film deposited on the front surface by PECVD acts as anti- reflection coating and gives a uniform dark blue appearance.
- Cells are laminated between highly transparent low-iron 3mm tempered glass, TPT and two layers of EVA to prevent moisture penetrating the module.
- Heavy duty anodized aluminium frame provides high wind resistance and convenient mounting access.
- Waterproof junction box and terminals allows for quick and simple connection.
- Modules will either be supplied with no cable, cable supplied but not connected to the junction box or fully fitted – depending on the option selected. Supplied cables guarantee excellent power transmission throughout the year.
- There is no current requirement for the STI Solar Modules to comply with ROHS.
- 20 year power output transferable warranty

RS, Professionally Approved Products, gives you professional quality parts across all products categories. Our range has been testified by engineers as giving comparable quality to that of the leading brands without paying a premium price.

RS PRO

ENGLISH

PV MODULES MADE WITH IEC 61215 CERTIFICATION

Model	Output Wp	Size mm	Weight Kgm	Pmax W	Vmp V	Imp A	Voc V	Isc A
9046128	5	250 x 200 x 25	1.0	5	16.8	0.3	21	0.39
9046121	10	397 x 280 x 25	1.5	10	16.8	0.59	21	0.66
9046125	20	638 x 278 x 25	2.2	20	17.5	1.15	22	1.27
9046134	30	660 x 380 x 25	2.8	30	17.5	1.72	22	1.90
9046137	45	634 x 535 x 25	4.5	45	17.5	2.58	22	2.86
9046131	60	685 x 670 x 35	6.0	60	17.2	3.49	21.6	3.97
9046140	80	815 x 670 x 35	7.8	80	17.2	4.65	21.6	5.00
9046143	100	1055 x 670 x 35	8.0	100	19.55	5.12	23.15	5.45
9046147	120	1250 x 670 x 35	12.0	120	17.2	6.98	21.6	7.93
9046156	150	1490 x 670 x 35	15.2	150	17.2	8.72	21.6	9.72

ABSOLUTE MAXIMUM LIMITS

PARAMETERS	RATING	UNIT
Operating temperature	-40 to +85	°C
Storage temperature	-40 to +85	°C
Dielectric voltage withstood	3000max	V-DC
NOCT	48	°C

TEMPERATURE COEFFICIENTS

Current temperature coefficient	dIsc/dT	+0.003A/K
Voltage temperature coefficient	dVoc/dT	– 0.13V/K
Power temperature coefficient	dPm/dT	– 0.675W/K

CERTIFICATIONS

ISO9001 (2008)	1014QMO5
TUV / IEC61215	PV60040905
IEC61710 (Salt Mist Corrosion Test)	4786191107-NABL-S1
CE	G4M20301-0199-E-16

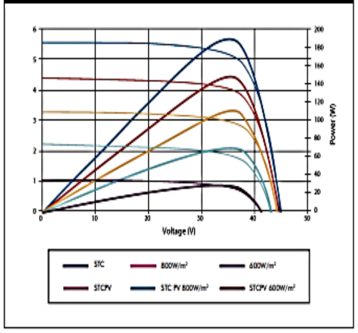
MATERIALS

Frame	Aluminium 6063 T5
Front Cover	High-transmission Glass

WARRANTY

All RS Components solar modules are supplied with a 20 year limited peak power warranty. The warranty claim will deemed to be valid if within 20 years any solar module exhibits power output at less than 80% of minimum 'Peak Power Standard Test Conditions' as noted on the data plate of each module and/or any fault is determined to be the cause of defects in materials and workmanship but not where interference with the module/s by an unauthorised person (of RS Components) has caused the fault or defect. The warranty includes any call outs, labour and other expenses associated with the repair or replacement of the defective part module. RS Components may, at its discretion offer one of the following remedies in the event of a successful claim against the module performance warranty: 1) to replace the defective module/s 2) refund the percentage of the cost of the module to the customer representing the percentage of the power output less than 80% of the minimum. RS Components endeavours to but is not bound by its commitment to rectify any fault within 7 days of notification.

IV CURVE

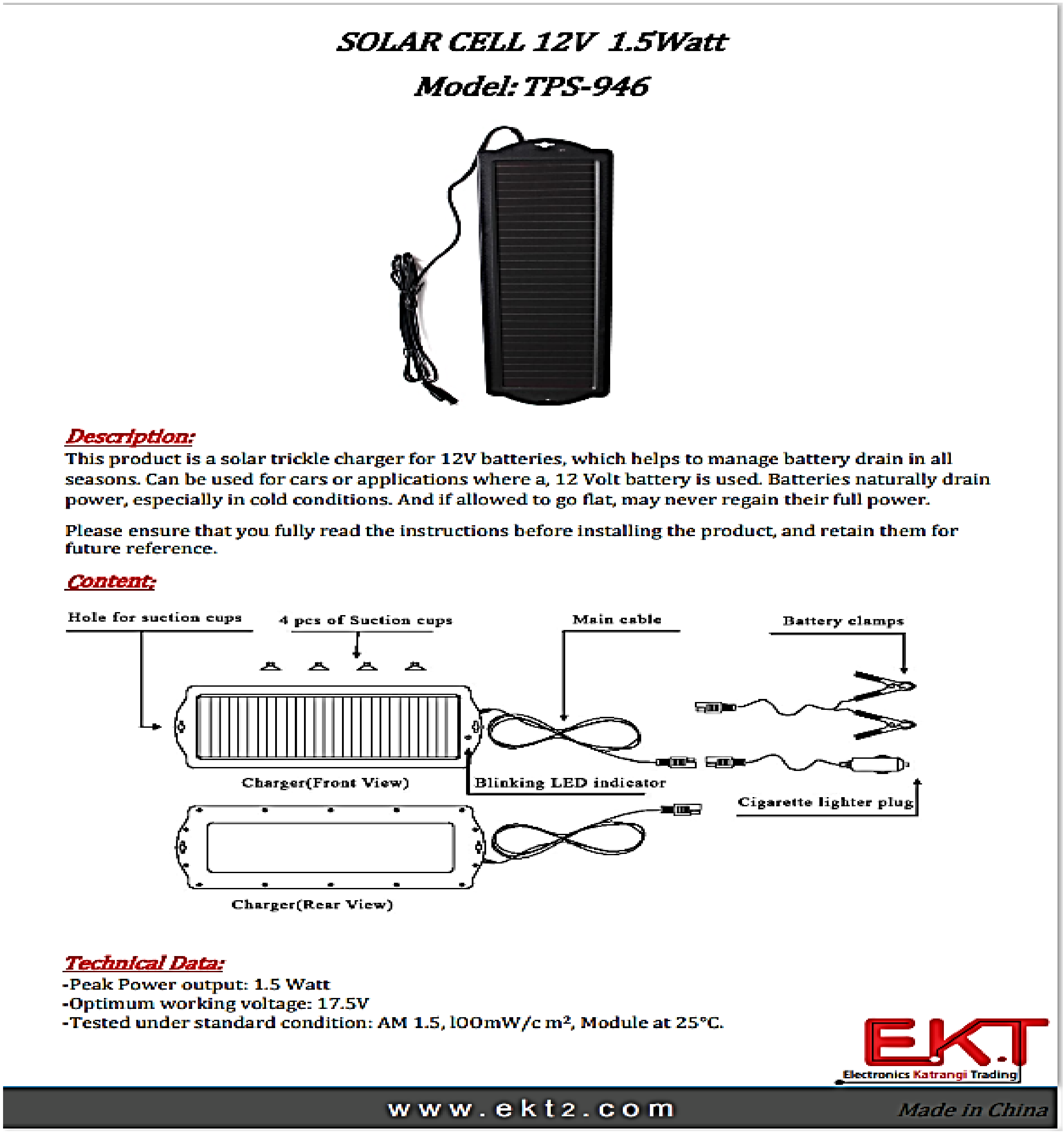


ALL FIGURES TAKEN UNDER THE FOLLOWING STANDARD TEST CONDITIONS: IRRADIANCE 1000W/M², MODULE TEMPERATURE 25°C, AM=1.5

(All technical data subject to changes without prior notice)

RS, Professionally Approved Products, gives you professional quality parts across all products categories. Our range has been testified by engineers as giving comparable quality to that of the leading brands without paying a premium price.

THE 5W SOLAR PANEL OEM DATA-SHEET



SOLAR CELL 12V 1.5Watt

Model: TPS-946

Description:

This product is a solar trickle charger for 12V batteries, which helps to manage battery drain in all seasons. Can be used for cars or applications where a, 12 Volt battery is used. Batteries naturally drain power, especially in cold conditions. And if allowed to go flat, may never regain their full power.

Please ensure that you fully read the instructions before installing the product, and retain them for future reference.

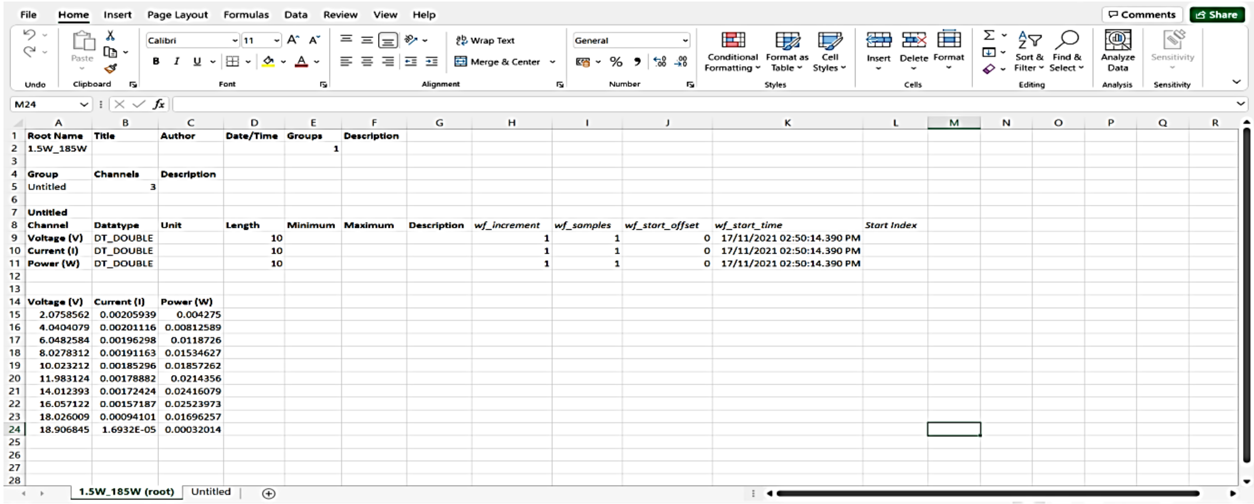
Content:

Technical Data:

-Peak Power output: 1.5 Watt
-Optimum working voltage: 17.5V
-Tested under standard condition: AM 1.5, 100mW/c m², Module at 25°C.

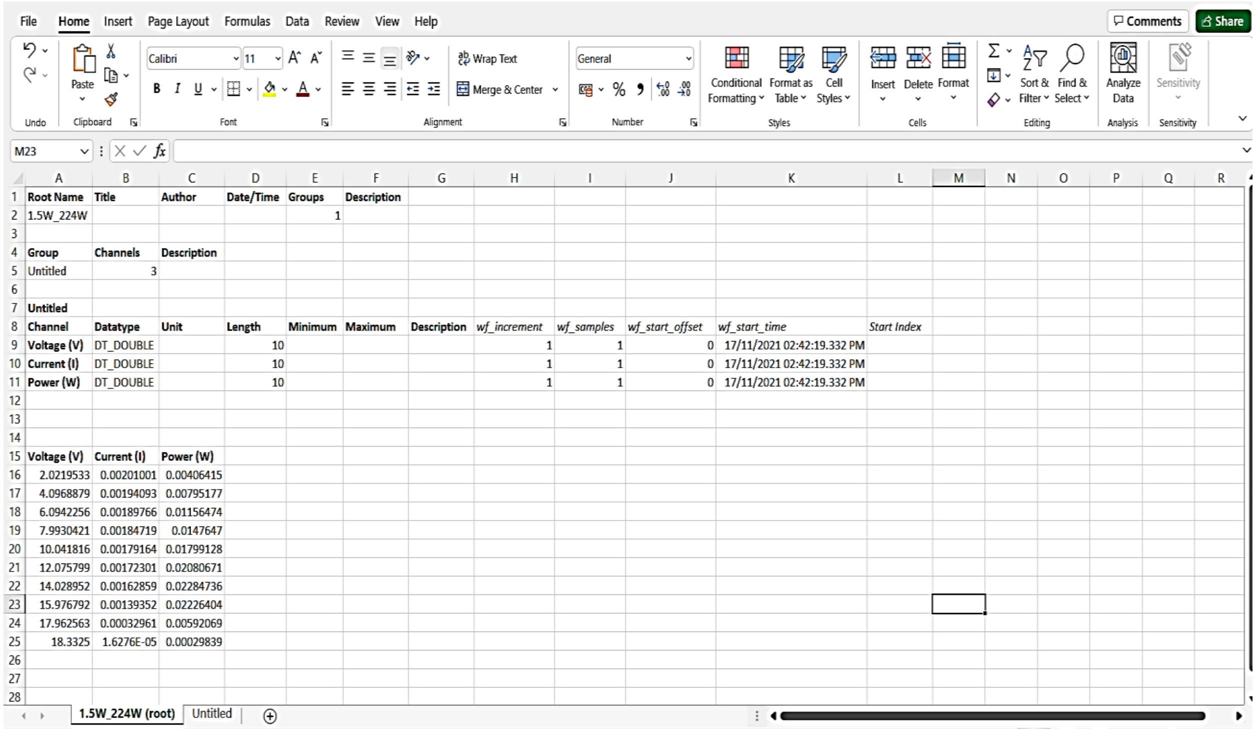
1.5W POLYCRYSTALLINE SOLAR PV OEM DATA SHEET
(Ref: Electronics Katrangi Trading)

C. Data output



Root Name	Title	Author	Date/Time	Groups	Description						
1.5W_185W				1							
Group	Channels	Description									
Untitled	3										
Untitled											
Channel	Datatype	Unit	Length	Minimum	Maximum	Description	*wf_increment*	*wf_samples*	*wf_start_offset*	*wf_start_time*	*Start Index*
Voltage (V)	DT_DOUBLE		10				1	1	0	17/11/2021 02:50:14.390 PM	
Current (I)	DT_DOUBLE		10				1	1	0	17/11/2021 02:50:14.390 PM	
Power (W)	DT_DOUBLE		10				1	1	0	17/11/2021 02:50:14.390 PM	
Voltage (V)	Current (I)	Power (W)									
2.0758562	0.00205939	0.004275									
4.0404079	0.00201116	0.00812589									
6.0482584	0.00196298	0.0118726									
8.0278312	0.00191163	0.01534627									
10.023212	0.00185296	0.01857262									
11.983124	0.00178882	0.0214356									
14.012393	0.00172424	0.02416079									
16.057122	0.00157187	0.02523973									
18.026009	0.00094101	0.01696257									
18.906845	1.6932E-05	0.00032014									

DATA OUTPUT 0F THE 5W MONOCRYSTALLINE PV MODULE AT OF IRRADIANCE 185W/M^2



Root Name	Title	Author	Date/Time	Groups	Description						
1.5W_224W				1							
Group	Channels	Description									
Untitled	3										
Untitled											
Channel	Datatype	Unit	Length	Minimum	Maximum	Description	*wf_increment*	*wf_samples*	*wf_start_offset*	*wf_start_time*	*Start Index*
Voltage (V)	DT_DOUBLE		10				1	1	0	17/11/2021 02:42:19.332 PM	
Current (I)	DT_DOUBLE		10				1	1	0	17/11/2021 02:42:19.332 PM	
Power (W)	DT_DOUBLE		10				1	1	0	17/11/2021 02:42:19.332 PM	
Voltage (V)	Current (I)	Power (W)									
2.0219533	0.00201001	0.00406415									
4.0968879	0.00194093	0.00795177									
6.0942256	0.00189766	0.01156474									
7.9930421	0.00184719	0.0147647									
10.041816	0.00179164	0.01799128									
12.075799	0.00172301	0.02080671									
14.028952	0.00162859	0.02284736									
15.976792	0.00139352	0.02226404									
17.962563	0.00032961	0.00592069									
18.3325	1.6276E-05	0.00029839									

DATA OF 5W MONO-CRYSTALLINE PV MODULE AT IRRADIANCE OF 224W/M^2

	A	B	C	D	E	F	G	H	I	J	K	L
1	**Root Name**	**Title**	**Author**	**Date/Time**	**Groups**	**Description**						
2	600_1.5				1							
3												
4	**Group**	**Channels**	**Description**									
5	Untitled	3										
6												
7	**Untitled**											
8	**Channel**	**Datatype**	**Unit**	**Length**	**Minimum**	**Maximum**	**Description**	*wf_increment*	*wf_samples*	*wf_start_offset*	*wf_start_time*	*Start Index*
9	**Voltage (V)**	DT_DOUBLE		10				1	1	0	17/11/2021 02:57:43.952 PM	
10	**Current (I)**	DT_DOUBLE		10				1	1	0	17/11/2021 02:57:43.952 PM	
11	**Power (W)**	DT_DOUBLE		10				1	1	0	17/11/2021 02:57:43.952 PM	
12												
13												
14												
15	**Voltage (V)**	**Current (I)**	**Power (W)**									
16	2.3506546	0.05178683	0.12173295									
17	3.9090259	0.05181492	0.20254588									
18	5.9630922	0.0515482	0.30738664									
19	7.9757358	0.05138318	0.40981867									
20	10.49817	0.05102512	0.53567036									
21	11.894986	0.05054006	0.60117329									
22	14.197392	0.0478167	0.67887239									
23	15.947481	0.05040372	0.8038123									
24	18.066469	0.0481791	0.87042613									
25	20.289097	3.1965E-05	0.00064855									

600_1.5 (root) | Untitled

RAW DATA OF THE 1.5W POLYCRYSTALLINE PV MODULE AT IRRADIANCE 610W/M^2

	A	B	C	D	E	F	G	H	I	J	K	L
1	**Root Name**	**Title**	**Author**	**Date/Time**	**Groups**	**Description**						
2	850_0.3				1							
3												
4	**Group**	**Channels**	**Description**									
5	Untitled	3										
6												
7	**Untitled**											
8	**Channel**	**Datatype**	**Unit**	**Length**	**Minimum**	**Maximum**	**Description**	*wf_increment*	*wf_samples*	*wf_start_offset*	*wf_start_time*	*Start Index*
9	**Voltage (V)**	DT_DOUBLE		13				1	1	0	17/11/2021 03:03:41.521 PM	
10	**Current (I)**	DT_DOUBLE		13				1	1	0	17/11/2021 03:03:41.521 PM	
11	**Power (W)**	DT_DOUBLE		13				1	1	0	17/11/2021 03:03:41.521 PM	
12												
13												
14	**Voltage (V)**	**Current (I)**	**Power (W)**									
15	2.2263946	0.06239019	0.13890519									
16	4.0612551	0.06154957	0.24996848									
17	5.811826	0.06102662	0.35467607									
18	8.1487621	0.06020145	0.49056732									
19	9.8845744	0.0598479	0.59157102									
20	12.199708	0.05939192	0.72456413									
21	13.893015	0.05896012	0.81913382									
22	15.014528	0.05880808	0.88297556									
23	16.163852	0.05861265	0.94740612									
24	17.255574	0.0584065	1.0078377									
25	18.017803	0.05707498	1.02836569									
26	19.127552	0.03161269	0.60467339									
27	19.951431	3.2821E-05	0.00065482									

850_0.3 (root) | Untitled

RAW-DATA OF 1.5W POLYCRYSTALLINE PV MODULE AT IRRADIANE 850W/M^2

D. Calculations

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Name: ADESIYAN AYOMIDE EMMANUEL       %
% Date:  20/12/2021                     %
%THIS IS A MATLAB CODE FOR THE DATA-ANALYSIS %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% House keeping %

clc;            % clear workspace
clear all;      % clear command window
close all;      % close all figure and plot

% Importing input data %

solar_data = xlsread ('1.5W_185W.xlsx','untitled');
solar_data1 = xlsread ('1.5W_224W.xlsx','untitled');
solar_data2 = xlsread ('1.5W_513W.xlsx','untitled');
solar_data3 = xlsread ('610_0.3.xlsx','untitled');
solar_data4 = xlsread ('850_0.3.xlsx','untitled');

V_data = solar_data(:,1);
I_data = solar_data(:,2);
P_data = solar_data(:,3);

V_data1 = solar_data1(:,1);
I_data1 = solar_data1(:,2);
P_data1 = solar_data1(:,3);

V_data2 = solar_data2(:,1);
I_data2 = solar_data2(:,2);
P_data2 = solar_data2(:,3);

V_data3 = solar_data3(:,1);
I_data3 = solar_data3(:,2);
P_data3 = solar_data3(:,3);

V_data4 = solar_data4(:,1);
I_data4 = solar_data4(:,2);
P_data4 = solar_data4(:,3);

%% Graph plotting

figure()
plot (V_data,I_data,V_data1,I_data1,V_data2,I_data2, 'linewidth', 3.5)
xlabel('Voltage (V)')
ylabel('Current (I) in amps')
grid on
title(‘A plot of current (I) against voltage (V) for mono-crystalline PV module’)
legend('185W/m^2','224W/m^2','513W/m^2')
```

```
figure()
plot(V_data,P_data, V_data1,P_data1,V_data2,P_data2, 'linewidth', 3.5)
xlabel('Voltage (V)')
ylabel('Power (P) in Watts')
grid on
title(‘A plot of power (P) against voltage (V) for mono-crystalline PV module’)
legend('185W/m^2','224W/m^2','513W/m^2')

figure()
plot(V_data3,I_data3,V_data4,I_data4, 'linewidth', 3.5)
xlabel('Voltage (V)')
ylabel('Current (I) in amps')
grid on
title(‘A plot of current (I) against voltage (V) for poly-crystalline PV module’)
legend('610W/m^2','850W/m^2')

figure()
plot(V_data3,P_data3,V_data4,P_data4,'linewidth', 3.5)
xlabel('Voltage (V)')
ylabel('Power (P) in Watts')
grid on
title(‘A plot of power (P) against voltage (V) for poly-crystalline PV module’)
legend('610W/m^2','850W/m^2')

%% Fill factor calculations
I_sc_185W = max(I_data);
V_oc_185W = max(V_data);
P_max_185W = max(P_data);
FF_185W = (P_max_185W/(I_sc_185W*V_oc_185W));

I_sc_224W = max(I_data1);
V_oc_224W = max(V_data1);
P_max_224W = max(P_data1);
FF_224W = (P_max_224W/(I_sc_224W*V_oc_224W));

I_sc_513W = max(I_data2);
V_oc_513W = max(V_data2);
P_max_513W = max(P_data2);
FF_513W = (P_max_513W/(I_sc_513W*V_oc_513W));

I_sc_610W = max(I_data3);
V_oc_610W = max(V_data3);
P_max_610W = max(P_data3);
FF_610W = (P_max_610W/(I_sc_610W*V_oc_610W));

I_sc_850W = max(I_data4);
V_oc_850W = max(V_data4);
P_max_850W = max(P_data4);
FF_850W = (P_max_850W/(I_sc_850W*V_oc_850W));
```

```
%% Efficiency calculations
Area_1 = 0.09*0.295;
E_185W = P_max_185W/(Area_1*185);
E_224W = P_max_224W/(Area_1*224);
E_513W = P_max_513W/(Area_1*513);

Area_2 = 0.251*0.155;
E_610W = P_max_610W/(Area_2*610);
E_850W = P_max_850W/(Area_2*850);

%% Plots of efficiency and P_max
E = [E_185W,E_224W,E_513W,E_610W,E_850W];
P = [P_max_185W,P_max_224W,P_max_513W,P_max_610W,P_max_850W];

figure()
plot(P,E, 'r -.', 'LineWidth',3)
ylabel('Efficiency %')
xlabel('Power, W')
grid on
title('Efficiency vs maximum power plot')
```