Bangladesh University of Engineering & Technology

Department of Electrical and Electronics Engineering

Lab Report

Experiment Name:

6. Measurement and Analysis of I-V Characteristics of Solar Panels and Cells

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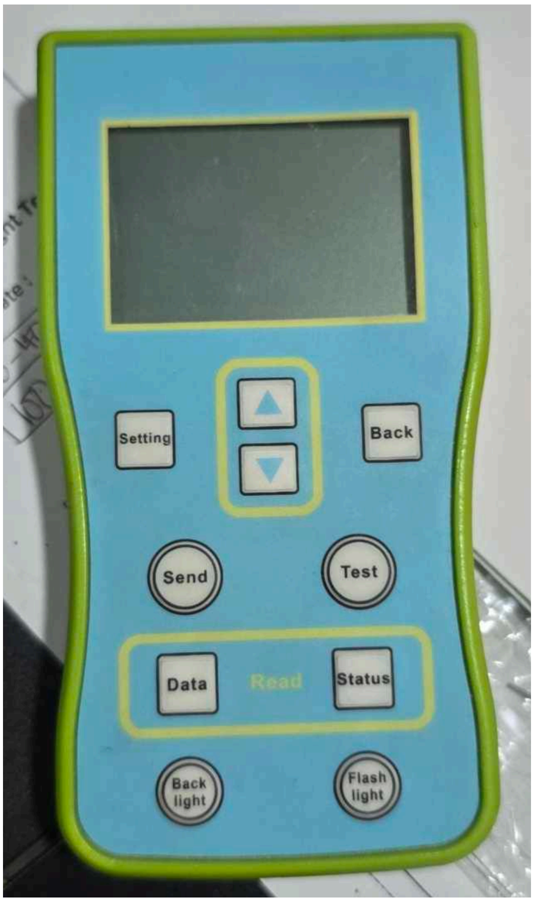
Objectives:

- To experimentally measure the IV Characteristics of a Solar Panel
- To analyse the measured characteristics and derive the figure of merits of the solar panel and cells.

Equipment:

1. Irradiance Meter



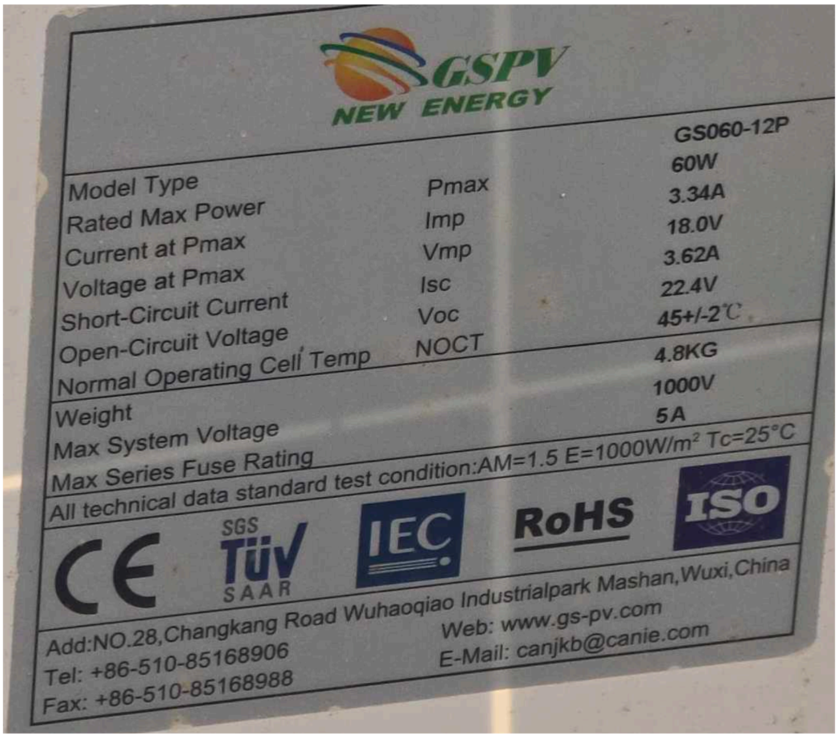
2. Multimeter

3. Connecting Cables
4. Variable Resistor

5. Solar Panel

Measurement:

NamePlate Data:



Model type : GS060-12P

Rated Max Power (P_{max}) : 60W

Current at P_{max} (I_{mp}) : 3.34 A

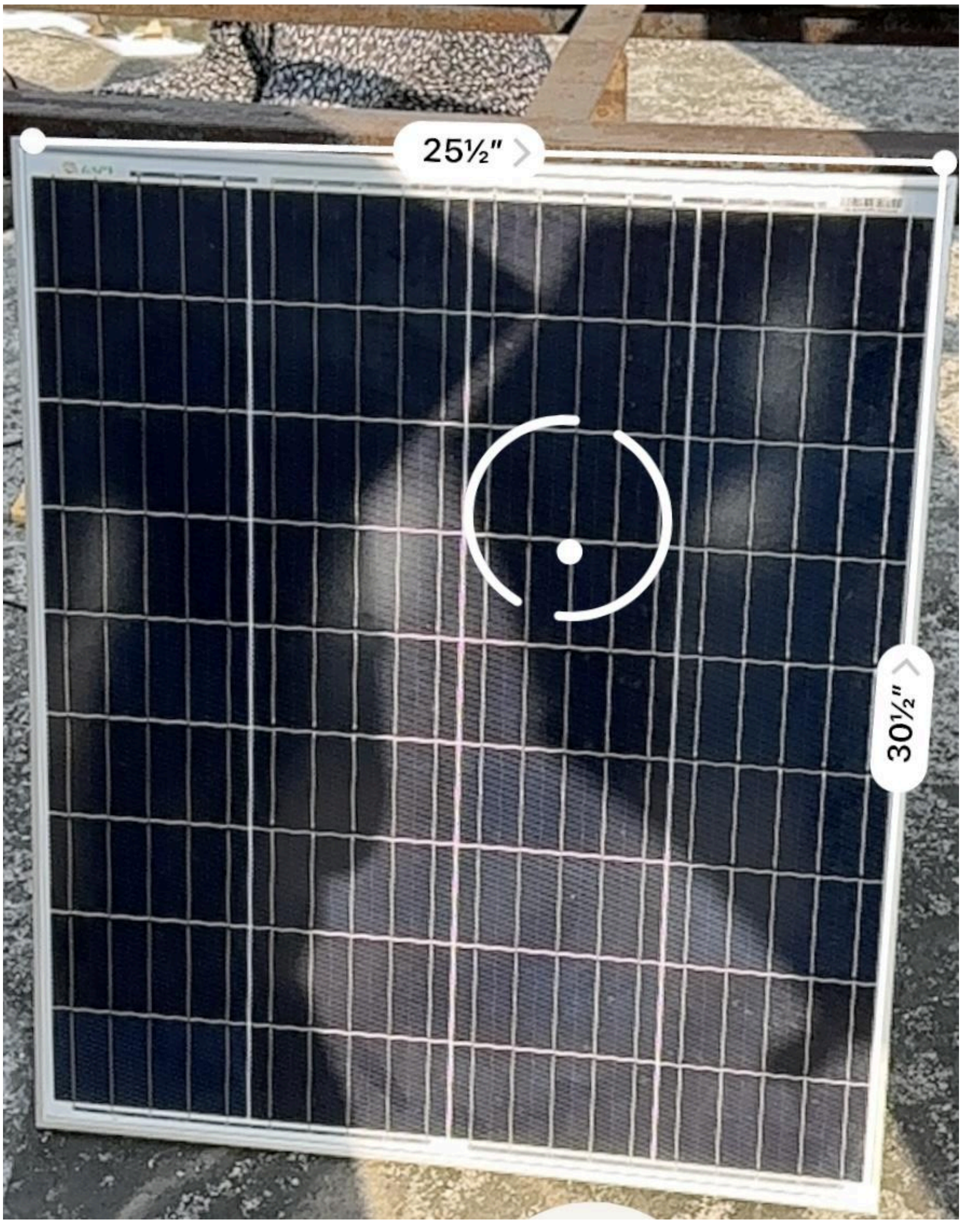
Voltage at P_{max} (V_{mp}) : 18.0 V

Short Circuit Current (I_{sc}) : 3.62 A

Open Circuit Voltage (V_{oc}) : 22.4 V

Normal Operating Temperature (NOCT) : 45 ± 2°C

Solar Panel Dimension:



Unit Cell Size: 6” by 3”
Total Solar Panel Size: 30.5” by 25.5” = 777.75 sq inch = 5017.7319 cm^2
Total No of Cel: 9 x 4 = 36 Unit Cells
Cell Coverage Area: 6 x 3 x 36 = 648 sq inch = 4180.64 cm^2

Measured Data:

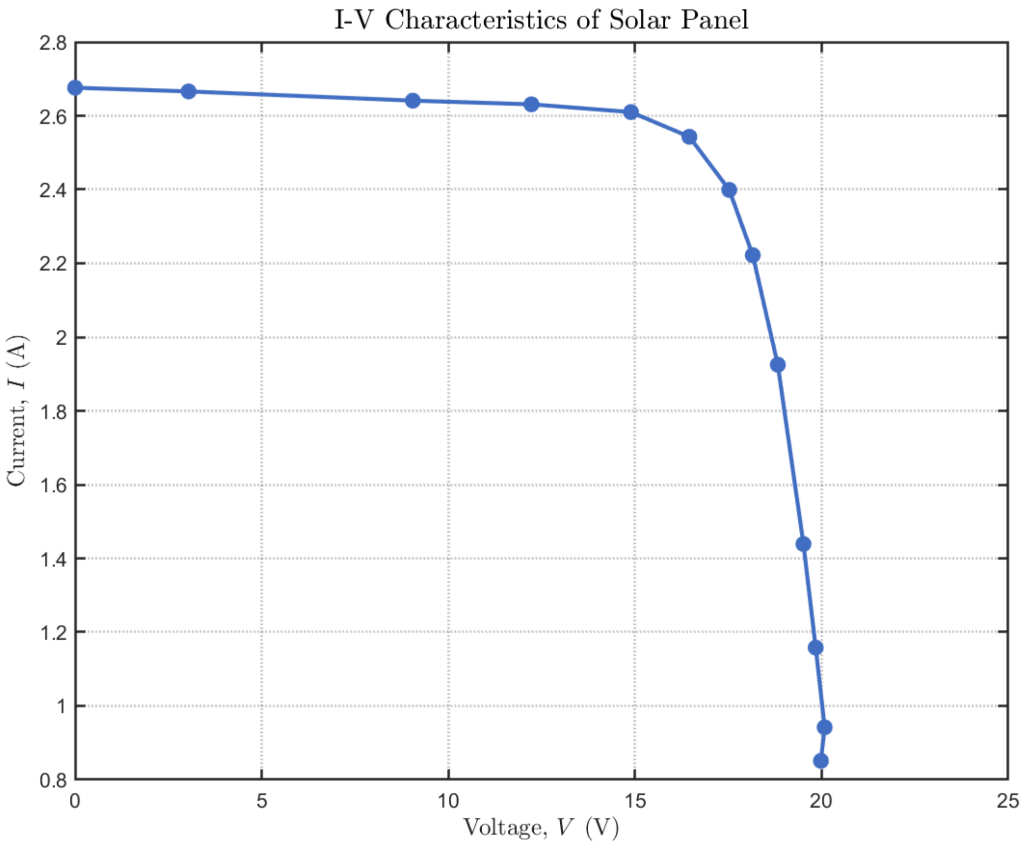
Solar Irradiance, G (W/m^2)	Voltage(V)	Current(A)	Power(W)
634	19.98	0.851	17.00298
633	20.08	0.942	18.91536
632	19.84	1.158	22.97472
632	19.512	1.439	28.077768
632	18.825	1.925	36.238125
630	18.154	2.222	40.338188
629	17.524	2.399	42.040076
625	16.456	2.543	41.847608
623	14.89	2.61	38.8629
621	12.225	2.631	32.163975
620	9.048	2.641	23.895768
621	3.04	2.666	8.10464
620	0	2.676	0

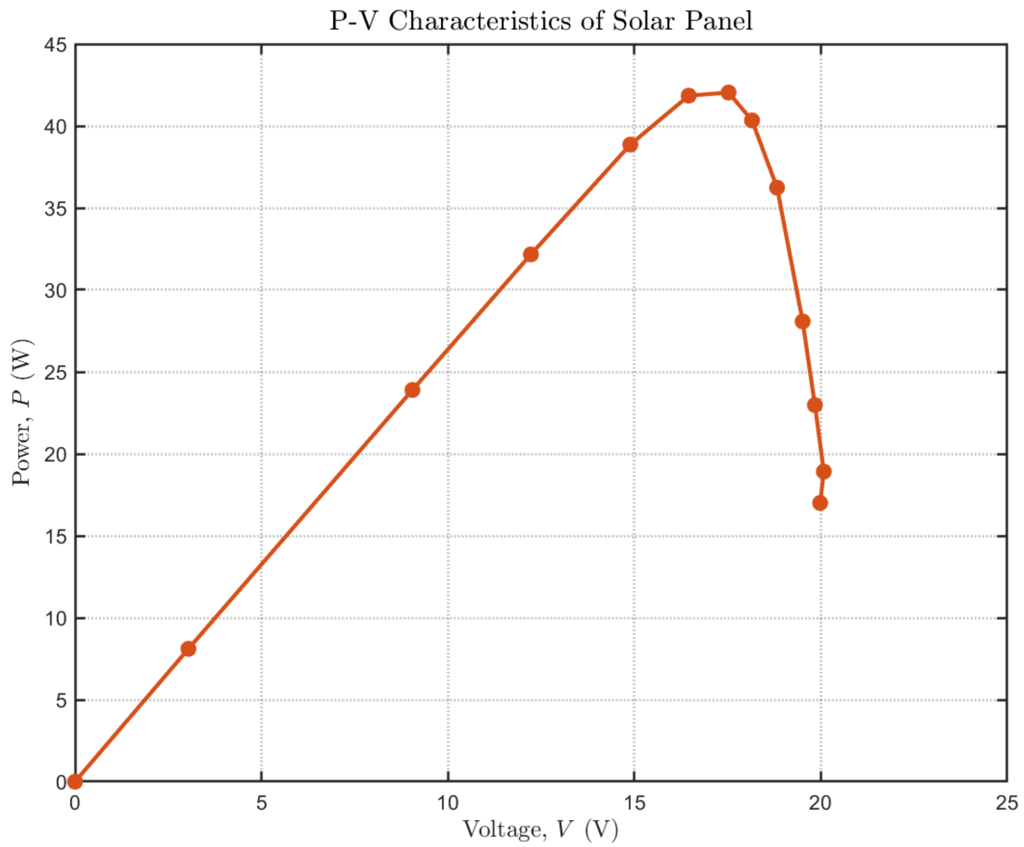
Rated Measurement Comparison:

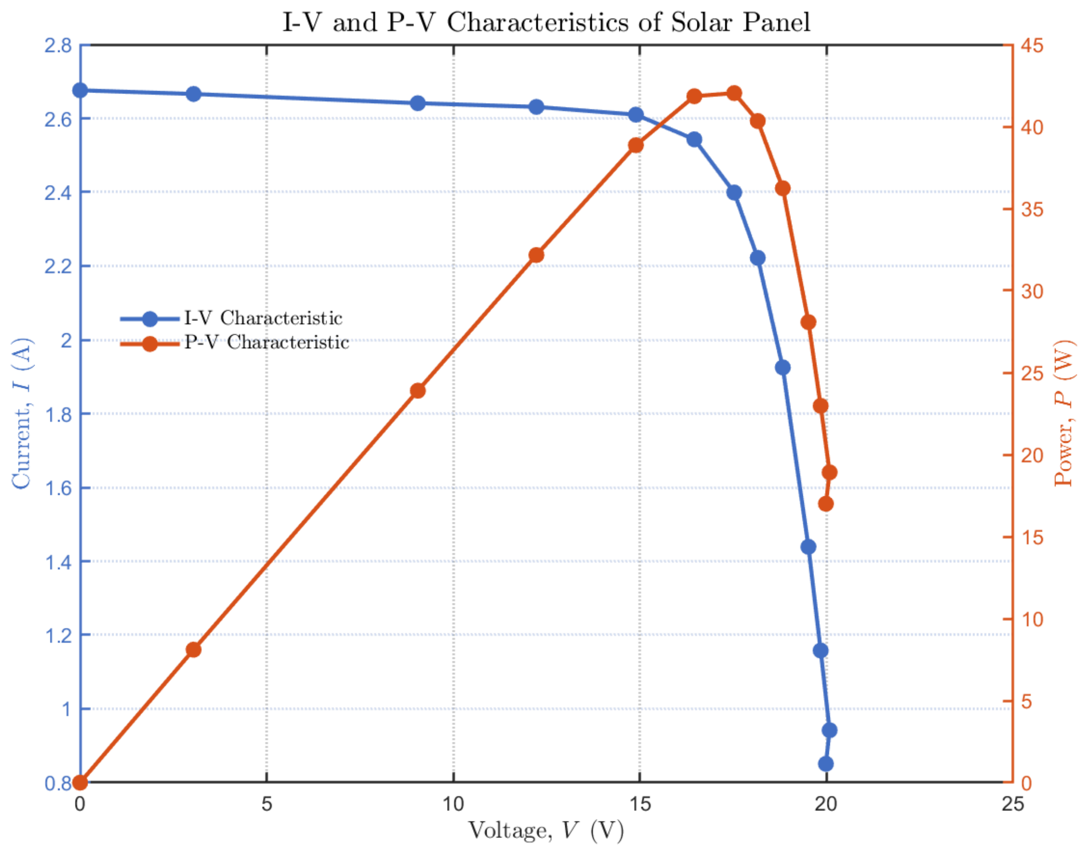
Parameters of Solar Panel	Measured	Rated (From Nameplate)
Average Solar Irridiance, G (W/m^2)	627.0769231	1000
Maximum Power (W)	42.040076	60
Current at Pmax (A)	2.4	3.34
Voltage at Pmax (V)	17.524	18
Short Circuit current (A)	2.676	3.62
Open Circuit Voltage (V)	21.4	22.4

Analysis and Report Writing:

IV and PV Characteristics of the Solar Panel:




P-V Characteristics of Solar Panel
Power, P (W)
Voltage, V (V)
0
5
10
15
20
25
30
35
40
45
0
5
10
15
20
25


I-V and P-V Characteristics of Solar Panel
I-V Characteristic
P-V Characteristic
Current, I (A)
Power, P (W)
Voltage, V (V)
0.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4
2.6
2.8
0
5
10
15
20
25
30
35
40
45
0
5
10
15
20
25

Comments:

Based on my experimental data from the solar panel measurements, I analyzed both the I-V (current-voltage) and P-V (power-voltage) characteristics to understand its performance parameters. Looking at the I-V curve, I observed that when the voltage was near zero, the current reached its maximum value of approximately 2.676A (short-circuit current). As the voltage increased, the current maintained relatively stable values with a slight decrease until around 16-17V, representing the maximum power point (MPP) region. Beyond this point, I noticed a sharp decline in current as the voltage approached its maximum value of about 20V (open-circuit voltage 21.4 V measured). The P-V characteristics, calculated from the product of current and voltage, revealed interesting behavior that helped me identify the optimal operating point. The power curve initially increased with voltage, reaching its peak at the MPP, which occurred around 16-17V. This peak power point represents the most efficient operating condition for the solar panel. After this point, I observed that the power output decreased significantly, primarily due to the rapid drop in current while approaching the open-circuit voltage. These characteristic curves align well with typical solar panel behavior, where the I-V curve demonstrates a distinctive knee point at the MPP, and the P-V curve shows a clear maximum. This analysis helps me understand the panel's performance limitations and optimal operating conditions, which is crucial for maximizing energy harvesting efficiency in practical applications.

Solar Panel Fill Factor Analysis:

To calculate the fill factor of the solar panel, we can use the following formula:

$$\text{Fill Factor, FF} = \frac{P_{max}}{V_{oc} \times I_{sc}}$$

where P_{max} = maximum power output of the solar panel.
V_{oc} = Open Circuit Voltage
I_{sc} = Short Circuit Current

Using the formula, we can calculate the following for the solar panel from the measured data table is as follows:

Parameters of Solar Panel	Measured	Rated (From Nameplate)	Deviation (in %)
Fill Factor	0.734	0.740	0.79

Comments:

From my analysis of the fill factor values, I observed a remarkably close correlation between the measured (0.73) and rated (0.74) specifications, with only a minimal deviation of 0.79%. This small difference indicates excellent manufacturing quality and performance consistency of the solar panel. The fill factor, being a critical parameter that quantifies the panel's ability to deliver maximum power to the load, shows that my experimental setup achieved near-ideal operating conditions. This close agreement is particularly noteworthy considering that my measurements were conducted at a lower solar irradiance (627.07 W/m^2) compared to the standard test conditions (1000 W/m^2) used for rated specifications. Several factors could influence this slight variance, including environmental conditions such as temperature fluctuations and potential partial shading during testing, which can affect the panel's efficiency. Additionally, the significant difference in irradiance levels between my experimental conditions and standard test conditions (STC) could impact the panel's performance, as lower irradiance typically results in reduced power output and efficiency. However, despite these potential influencing factors and the considerably lower irradiance level, the minimal deviation in fill factor suggests that the panel maintains its fundamental electrical characteristics and performance efficiency across varying environmental conditions. This consistency in fill factor not only validates the accuracy of my measurement methodology but also confirms the panel's robust design characteristics and its ability to maintain performance stability under different operating conditions.

Solar Panel Efficiency Analysis:

The formula to calculate the solar panel efficiency is as follows:

$$\text{Efficiency}, \eta = \frac{P_{max}}{A \times G} \times 100\%$$

where,
P_{max} = maximum power output of the solar panel.
A = the area of the solar panel
G = Solar Irradiance

Using the measured data, we get the following calculated values,

Parameters of Solar Panel	Measured in %	Rated (From Nameplate) in %	Deviation (in %)
Efficiency	13.36	11.96	-11.74

Comments:

In my analysis of the solar panel's efficiency, I observed an interesting phenomenon where the measured efficiency (13.36%) exceeded the rated specification (11.96%). This higher-than-rated efficiency, despite operating at lower irradiance levels (627.07 W/m² compared to rated 1000 W/m²), can be attributed to several factors. One primary reason is the temperature dependency of solar panel efficiency - at lower irradiance levels, the panel typically operates at a lower temperature than standard test conditions (STC), which can lead to improved efficiency as solar cells generally perform better at cooler temperatures. Additionally, modern solar panels often include features like anti-reflective coatings and improved cell architectures that may perform better than their conservative rated specifications under real-world conditions. The spectral quality of the natural sunlight during my testing might have also been more favorable compared to the standardized testing conditions used for rating. This finding demonstrates that while manufacturer ratings provide a reliable baseline, actual performance can exceed these specifications under favorable operating conditions, even at lower irradiance levels.

IV and PV Characteristics of the Solar Cell:

Since the solar panel consists of 36 cells connected in 9 rows and 4 columns, each row represents a series connection of four cells, and there are 9 parallel branches.

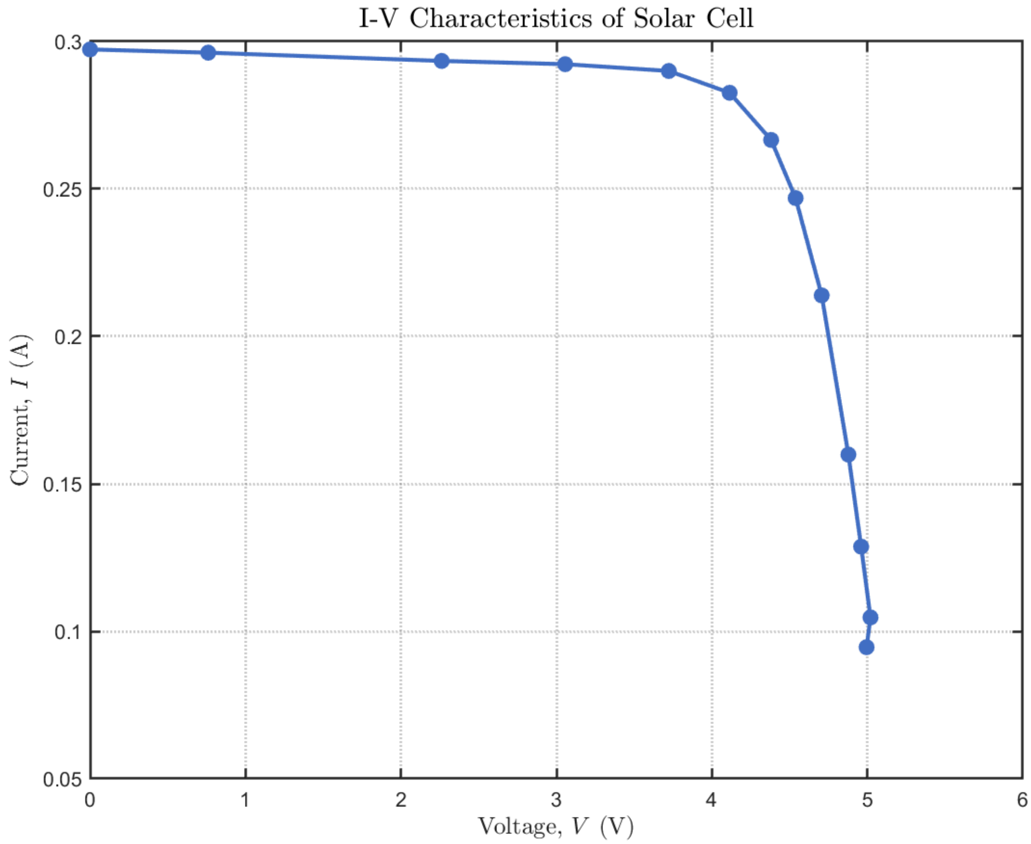
For a single solar cell, the current of the solar panel is divided by the number of parallel branches (9 in this case) to obtain the current of a single cell at each voltage point.

And, the voltage of the solar panel is divided by the number of cells in series (4 in this case) to obtain the voltage corresponding to a single cell.

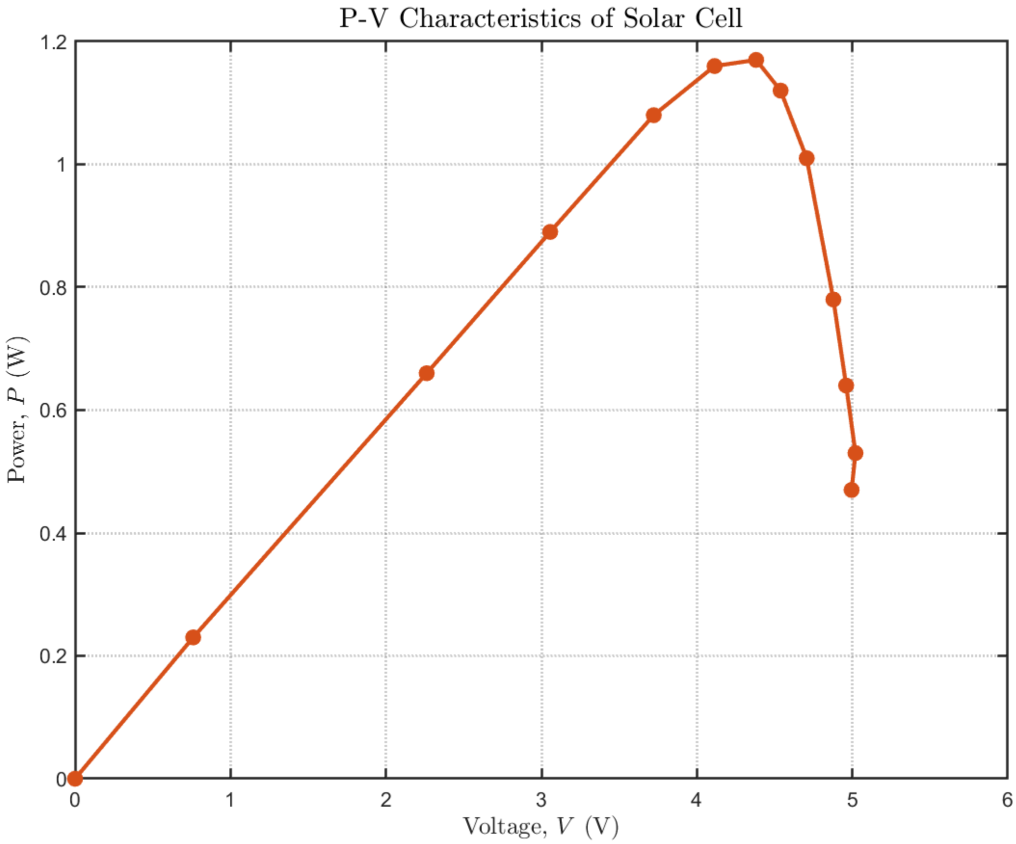
We obtain the following data:

Solar Irridiance, G (W/m^2)	Voltage(V) of a Solar Cell	Current(A) of a Solar Cell	Power(W) of a Solar Cell
634	4.995	0.0946	0.47
633	5.02	0.1047	0.53
632	4.96	0.1287	0.64
632	4.878	0.1599	0.78
632	4.70625	0.2139	1.01
630	4.5385	0.2469	1.12
629	4.381	0.2666	1.17
625	4.114	0.2826	1.16
623	3.7225	0.2900	1.08
621	3.05625	0.2923	0.89
620	2.262	0.2934	0.66
621	0.76	0.2962	0.23
620	0	0.2973	0.00

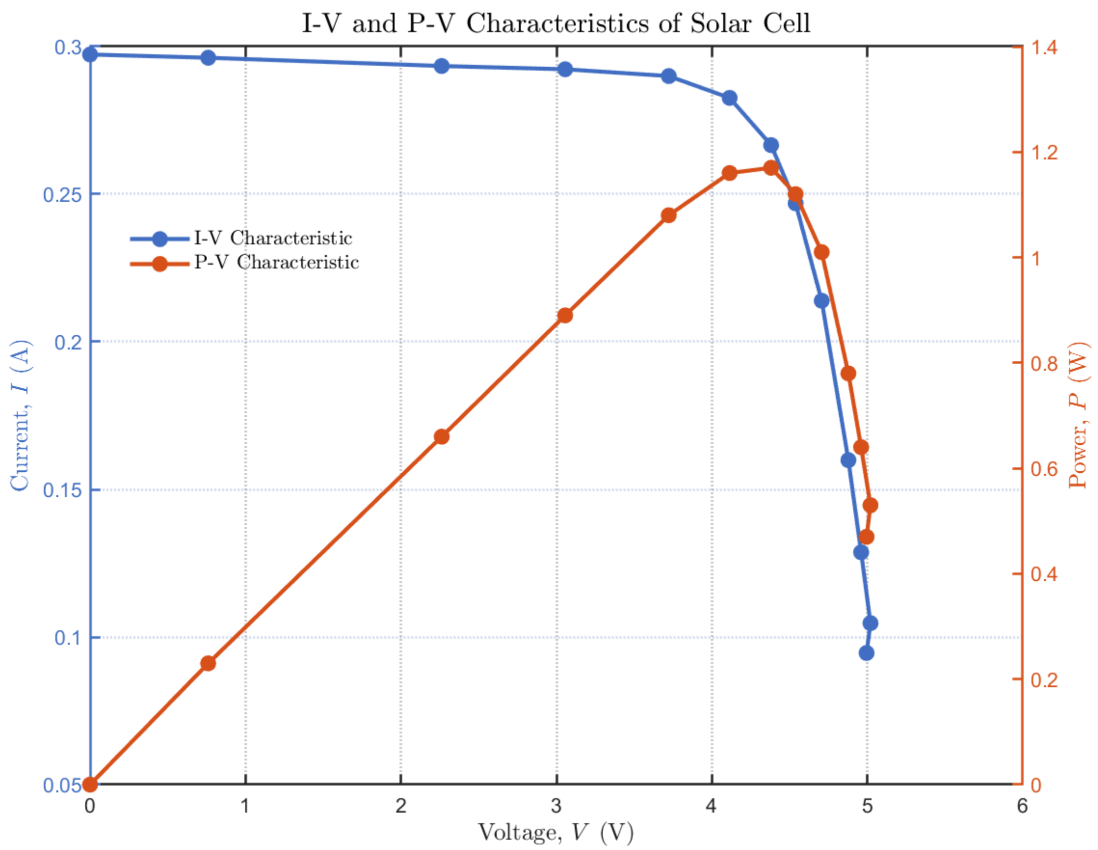
IV Curve Plot:



PV Curve Plot:



IV and PV Both Curve Plot:



Comments:

From my analysis of the solar cell's I-V and P-V characteristics, I observed fundamental behavior that provides insights into its performance capabilities. The I-V curve demonstrates that at zero voltage (short-circuit condition), the cell produces its maximum current of approximately 0.2973A. As the voltage increases, the current remains relatively stable until around 3.5V, after which it begins to decrease more rapidly, eventually reaching zero at the open-circuit voltage of about 5V. The P-V characteristics reveal that the power output initially increases with voltage, reaching a maximum power point (MPP) of approximately 1.17W at around 4.38V. Beyond this point, the power decreases due to the sharp drop in current as the voltage approaches the open-circuit condition. This behavior is typical of a well-functioning solar cell, where the presence of a clear maximum power point indicates optimal operating conditions. Interestingly, the curve shape resembles that of the solar panel but at a much smaller scale, as expected since a solar panel is essentially an array of interconnected solar cells. The relatively smooth transitions in both curves suggest good cell quality and minimal internal losses, though the overall power output is naturally lower than a full panel due to the single-cell configuration.

Measured Parameters of the Solar Cell:

We get the following measured parameters of the solar cell:

Parameters of Solar Cell	**Measured**
Average Solar Irridiance, G (W/m^2)	627.0769231
Maximum Power (W)	1.17
Current at Pmax (A)	0.2666
Voltage at Pmax (V)	4.381
Short Circuit current (A)	0.2973
Open Circuit Voltage (V)	5.35

Fill Factor Calculation of the Solar Cell:

Using the previous formula, we get the following:

Parameters of Solar Panel	**Measured for Solar Cell**	**Measured for Solar Panel**
Fill Factor	0.734	0.734

Comments:

We get the same fill factor for both the solar cell and solar panel. It is expected because we have measured maximum power, short circuit current, and open circuit voltage for the whole array of interconnected cells. Then, to determine for the solar cell, we have divided the voltage with the cells connected in the series, and current with the number of parallel branches. As fill factor is essentially a ratio, it gives us the same result as measured for the solar cell compared to the solar panel.

Efficiency Calculation for a Single Solar Cell:

Using the previous formula, we get the following:

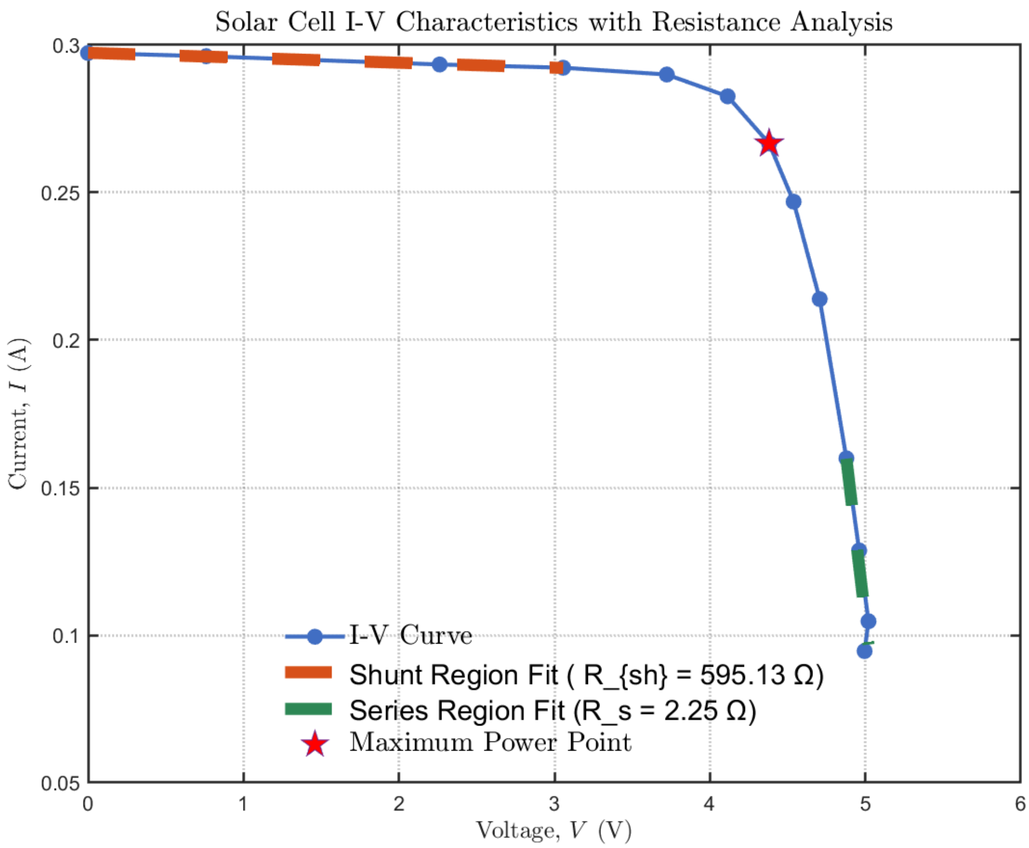
Parameters of Solar Panel	Measured for Solar Cell in %	Measured for Solar Panel in %
Efficiency	16.04	13.36

Comments:

From our calculation, I can observe that we are getting higher efficiency for a solar cell (16.04%) compared to the solar panel (13.36%). We can account for the rise in efficiency for the solar panel solely stemming from the area parameter. We have not measured the data for a single cell, we have measured for the whole panel. So, the discrepancy in the measurement cannot be related to any other factor such as larger capacitance resulting from the large array of interconnected cells.

The area of the whole panel is 5017.7319 cm^2. However, there is a metallic boundary rim around the solar panel to protect the solar cell. So, this part of the boundary is not making any photovoltaic actions to generate electricity from solar irradiance. If we take the total cell area, we get 4180.64 cm^2. Consequently, the reduced area has given the increase in the solar cell efficiency.

Series and Shunt Resistance Calculation:



Analysis Results:
Shunt Resistance (Rsh): 595.13 Ω
Series Resistance (Rs): 2.25 Ω
Maximum Power Point: 1.17 W at V = 4.38 V, I = 0.27 A

Comments:

For calculating the series and shunt resistances, I analyzed the linear regions of the I-V curve at specific operating points. The shunt resistance (Rsh) was determined by examining the slope of the I-V curve near the short-circuit condition (where V approaches 0), specifically using data points between 0V and about 2V. The inverse negative of this slope gives us the shunt resistance. Similarly, the series resistance (Rs) was calculated by analyzing the slope of the I-V curve near the open-circuit voltage (around 4.8-5V). I used linear fitting (polyfit in MATLAB) on these specific regions to obtain accurate slope values, and then took their negative reciprocals to determine the resistance values.

The calculated values of Rsh = 595.13Ω and Rs = 2.25Ω indicate good performance characteristics of the solar cell. The relatively high shunt resistance suggests minimal current leakage through parallel paths within the cell, which is desirable for efficient operation. A higher shunt resistance means better ability to maintain voltage under varying current conditions. The low series resistance of 2.25Ω is also favorable, as it indicates minimal internal power losses as current flows through the cell. Series resistance primarily affects the fill factor of the solar cell, and this low value suggests efficient charge carrier transport through the cell's layers and contacts. These resistance values align well with typical expectations for a well-functioning solar cell, where ideally we want a high shunt resistance and a low series resistance to maximize power output and efficiency.

Factor K Calculation:

The photocurrent (I_{ph}) related to radiation intensity (G) as per the relation,

$$I_{ph} = KG$$

Here, K is a device-specific constant.
So,

$$K = \frac{I_{ph}}{G} = \frac{I_{sc}}{G}$$

$$K = \frac{0.2973}{627.08} = 474.1022\ \mu A\, m^2 W^{-1}$$

Conclusion:

In this laboratory experiment, we conducted a comprehensive analysis of both a solar panel and an individual solar cell, focusing on their key electrical characteristics and performance parameters. The I-V and P-V characteristics of both devices were carefully measured and analyzed, revealing typical behavior patterns essential for understanding their operation. For the solar panel, I observed a maximum power output of 42.04W at an irradiance of 627.07 W/m², with a fill factor of 0.73 that closely matched the rated value of 0.74. Notably, the measured efficiency of 13.36% exceeded the rated specification of 11.96%, which I attributed to favorable operating temperatures at lower irradiance levels. The analysis of the solar cell provided deeper insights into fundamental photovoltaic behavior, with calculated series resistance of 2.25Ω and shunt resistance of 595.13Ω indicating good internal characteristics. The maximum power point of 1.17W for the solar cell demonstrated the expected scaled-down performance compared to the full panel. This experimental investigation not only validated the theoretical understanding of photovoltaic devices but also provided practical insights into their performance characteristics under real operating conditions. The close correlation between measured and rated parameters, particularly in the solar panel's fill factor, confirms the reliability of both the experimental setup and the measurement methodology employed.