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Extracting of I-V and P-V Characteristics of Mono and Poly-Crystalline Si Solar Cells under Various Light Concentrations and Temperatures

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Abstract
Libya has been facing severe electricity crisis since 2014 due to the enormous difference in demand and supply leading to load shedding of several hours daily across the country. In our country, the solar energy would definitely be a best option for future. To solve this issue, and for better solar industry in future in order to resolve energy crisis. We have used two different types of solar panels, monocrystalline and polycrystallinetechniques varying light concentrations for capability of generating power with no noise and emissions. Silicon solar cell as renewable energy resource has been extensively studied in the last three decades.To achieve this goal, the experimental measurementsof the extracting a current-voltage (I-V) and power-voltage (P-V) characteristic of a photovoltaic PV cell, V_{oc} (the open circuit voltage), I_{sc} (the short circuit current), V_{mp} (the maximum power voltage), I_{mp} (the maximum power current) and FF (fill factor), were performance. The results are discussed in terms of temperature and irradiance effect for mono and poly-crystalline Si solar cells.

Key Word: *silicon solar cells;PV performance; I -V and P-V characteristics; Parameters extracting*

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I. INTRODUCTION

The continuous concerns, that, anthropogenic carbon dioxide CO_2 emissions are contributing to the global climate change and reduce the CO_2 emissions of, *e.g*, the transportation sector, thushave pushed all levels of society to solve this issue. Further, "We really need to target negative emissions, meaning that net-zero emission is necessary, but it's not enough, and we need to complement that with a bounty on capturing CO_2 from the atmosphere [1].Current-voltage I -Vand P-V characteristics indicatethe performance of a solar cell, as well as irradiance depends on location [2], time of the day and year. crystalline silicon solar cells dominate the world's PV market due to high power conversion efficiency, high stability, and low cost. In addition, crystalline silicon photovoltaic can be used for renewable energy**.**As a promising renewable energy resource, PV technology enjoys substantial government support in research and application in several major industrial countries [3]. We rely on electricity for communication, food, health, transportation, and other basic needs. One smart grid technology that is crucial for the integration of more distributed renewable electricity into the grid is the grid-tie inverter (GTI) that converts DC electricity into AC. Adding to that, renewable generation from solar PV or wind turbines produces DC electricity, while the grid transmits and distributes AC electricity for use by households and industrial consumers of electricity. The capacity to store electricity so that generation does not have to always meet real time demand, because the wind does not always blow and the sun does not always shine, integrating some kinds of electricity storage into electricity systems seems to be a necessary, for example, Renewable Energy Sources (RES, e.g., hydro, wind, and solar). Furthermore, Electrical energy conversion is either direct or indirect, examples of direct conversion energy are photovoltaic (PV) and thermoelectric (TE), while indirect conversions like hydro power and wind power. Pumped hydro is one important energy storage technology [4], that can be applied at a large scale (100s to 1000s of MWs) and can be released quickly in response to a sudden demand for more power, as well as, battery technology is evolving rapidly and has great potential for energy storage in various types of applications [5, 6]. Also, other energy storage technologies include thermal energy storage, in which energy is stored in hot or cold storage [7, 8].A PV array consists of several PV modules each one is composed of many PV cells in series or parallel connections. When exposed to the light, photon with energy greater than the band gap of the semiconductor can create an electron-hole pair if it knocks an electron in the valence band.

The electron and hole are then separated by the structure of the device, electrons to the negative terminal and holes to the positive terminal,and thus create a current which is proportional to the incident radiation**.** In terms of industrial PV technologies, the PV field has given rise to a global industry capable of producing many Gig watts (GW) of additional installed capacity per year [9].Many studied have been performed on crystalline silicon photovoltaic modules, Waqas et al. [10], Jun Peng et al.[11], W. S. Yang et al. [12],and M. A. Green et al. [13].Further studies have suggested that in the case of dye-sensitized solar cells (DSCs) and perovskite solar cells (PSCs), better performances have been reported under weak irradiation conditions[14, 15], and recently on the optical absorption characteristics of semiconductor nanowire arrays[16]. Significant improvements have been made over the years thatdescribe the perovskite solar cells (PSCs) which are regarded as promising candidate for indoor application[17], and extracted the I-V curve by charging a capacitive load [18].Also, metal halide perovskites have achieved power conversion efficiencies (PCE_S) in both single-junction[19] and solar cells [20].Performance measurement of solar cells at very low irradiance levels is not well established yet their measurement conditions depended largely on the measurement parameters. Furthermore, establishing a standardized method for evaluation under weak irradiation is a necessary step for reliable reports on the power conversion efficiencies (PCE)of solar cells designed for indoor application.

II. THEORY

2. 1 Physics of solar Cells

2.1.1 Solar cells basics

A solar (photovoltaic) cell is device that generates electricity from light. There are different types of solar cellsthe most common group is the silicon cells. The silicon cell with highest efficiency is the mono-crystalline cell, where the atoms are symmetric placed within the structure. Solar cells made from poly-crystalline crystal will have efficiencies up to ~ 22 %, while ~ 25 %, mono-crystalline silicon solar cells [21]. This gives a high efficiency however it is also very costly to manufacture this symmetric structure. These cells usually appear dark blue, because their surface has been treated to minimize reflectance of light in the red part of the spectrum. Under the sun light, a solar cell of this type generates a DC voltage of 0.5-1 V, and a photocurrent on the order of 10 mA/cm^2.To improve the voltage output, the cells are connected in series in different modules. Since the solar light is a power source with a variable output, solar cell modules are usually combined with a battery for storing energy and with electrical components for regulating power. In addition, solar cells generate DC current, and electrical inverters are used to convert it into AC power, which is much more commonly used. Any solar cell has a mechanism to separate the charge carriers (electrons and holes), that are produced when the cell is illuminated, and drive them in opposite directions. By doing this, a solar cell develops a photovoltaic and generates a current.

2.2 Electricity generation in a cell

Silicon, the most common semi-conductor, has the atomic number 14 and has four valence electrons. In the silicon structure each atom shares its valence electrons with four other atoms to create a stable structure. But if a photon hits the atoms, the binding breaks and an electron is released, the material gets electrically charged**.** To increase the conductivity the silicon can be doped with other materials to change the structure.

2.3. How Solar Cells Work

PV cells consist of two layers of semiconductor materials, one p-type and one n-type, sandwiched together forming a p-n junction. When sunlight strikes the cell, the semiconducting material absorbs photons from the light. Due to this absorbed energy, free electrons from one layer to another create an external DC current. This current is captured in the p-n junction and the DC current is converted into AC current using an inverter for different applications. This electricity generated and captured can then be stored in a charging system or converted and used.

The objective of this paper was the development of(I-V) and (P-V) characteristics curves using mono and poly-crystalline Si solar cellstechniques. This work consisted of (a) the extract (I-V) and (P-V) curves under different operating and environmental condition, (b) understand the connections between the power performancein order to determine the technique that provides better results.

A subsequent study will address the measurement of (I-V) and the (P-V) curves to provide charge of mobile phones, laptop and battery chargingunder various conditions of whether.

III. Experimental Section

The first part of this study was done in physics department, Faculty of science at University of Misurata, Libya. While, the second part of this work has been performed within theTajoura research center in Tripoli, Libya.We used the source of light as mimic for solar energy. We calculated I-V and P-V characteristics curves for different distances 20 cm and 30 cm. The first PV cell used in this work is silicon mono crystalline1.3 × 5.2 cm^2 cell, and the area cell (A_C) is 0.0676 m^2. The second PV cell used is polycrystalline1.25 × 5.0 cm^2 cell, and the area cell (A_C) is 0.0625 m^2. The circuit used consists of device to measure the intensity of light and temperature cell (SOLAR-SURVEY200R), voltmeter, ammeter, variable resistance (from 0 to 100 k ohms), Avometer, source of light and different wires as shown in the (Fig. 1).To extract I-V and P-V curves, a light radiation received during the study was1050 W/m^{2}and 630 W/m^2, the variation of temperature was 25 °C, 27 °C, 35 °Cand 37 °Ccell temperatures.During the measurement, several I-V and P-V curves at different variation light are obtained.

Sinceproduction of electrical power is the goal of this study, it is important to determine some fundamentals of electric power. They are listed as follows, (a)the maximum value of current $I_{SC.}$ (b)The maximum voltage V_{OC}(c)The product $P_{Max} = I_{Max}$ and V_{Max} (i.e., current and voltage are maximum power point). (d) Efficiency η = the ratio of output of PV cell (i.e., I_{Max} times V_{Max} at P_{Max} to the input light power as:

$$\eta = \frac{P_{out}}{P_{in}} = \frac{P_{Max}}{G} = \frac{I_{Max}\ V_{Max}}{GA} \quad (1)$$

where I_{MAX} and V_{MAX} are the current and voltage for maximum power, G is the measured in this work solar irradiance, 1050 W/m^2, 650 W/m^2 and A exposed PV cell area in (m^2), FF is the product of the current and voltage (P_{MAX}) divided by I_{SC} times V_{OC} as,

$$FF = \frac{I_{Max}}{I_{sc}} \frac{V_{Max}}{V_{oc}} (2)$$

Fig. 1: Experimental labels: (i) Mono crystalline cell (ii) Polycrystalline cell, and (iii)Circuit system.

IV. Resultsand Discussion

4.1. *I-Vand P-V characteristics of mono-crystalline Si solar cells*

The model was analyzed for two different cell technologies (mono-crystalline and poly-crystalline silicon). The I-V measurements results for mono-crystalline Si solar cell are shown inFigs.2, 3,4 andsummarized in Tables 1, 2, and 3. The influences of light intensities and temperatures on the photovoltaic parameters of mono-crystalline Si solar cells are studied.

Table 1: Parameters extracted of mono crystalline Si solar @ 30 cm *for T* = 25°Ccell temperature and 630(W/m^2) irradiations

I(A)	V(V)	P(W)
0.063	0	0
0.0628	0.775	0
0.0628	1.511	0.04867
0.0625	2.144	0.094891
0.0622	2.767	0.134
0.0588	3.21	0.172107
0.0527	3.41	0.188748
0.0471	3.526	0.179707
0.0424	3.601	0.166075

0.03836	3.656	0.152682
0.0364	3.67	0.140244
0.02451	3.81	0.133588
0.01912	3.87	0.093383
0.0152	3.9	0.073994
0.01293	3.92	0.05928
0.011	3.94	0.050686
0.00975	3.95	0.04334
0.00861	3.96	0.038513
0.0078	3.95	0.034096
0.00705	3.95	0.03081
0.00651	3.96	0.027848
0.00598	3.96	0.02578
0.00558	3.96	0.023681
0.00519	3.97	0.022097
0.00435	3.97	0.020646
0.00392	3.99	0.01727
0.00261	3.99	0.015641
0.00196	3.99	0.010414
0.0013	3.99	0.00782
0.00097	4	0.00518
0.00078	3.99	0.00388
0.00064	3.99	0.003112
0.00055	3.99	0.00255
0.00048	3.99	0.00219
0.00038	3.99	0.00191
0.00012	3.99	0.001516
0.00006	3.98	0.000478
0.00005	3.98	0.000238
0.00004	3.98	0.000199
0.00003	3.97	0.000159
0.00003	3.97	0.000119

Table 2: Parameters extracted of mono crystalline Si solar @ 20 *cm for T* = 27°Ccell temperature and 1050 (W/m^2) irradiations.

I(A)	V(V)	P(W)
0.1022	0	0
0.0989	1.222	0.120856
0.0987	2.38	0.234906
0.0896	3.068	0.274893
0.0752	3.341	0.251243
0.064	3.49	0.22336
0.0555	3.585	0.198968
0.0488	3.635	0.177388
0.0433	3.684	0.159517
0.03905	3.715	0.145071
0.03705	3.74	0.138567

0.02472	3.84	0.094925
0.01921	3.88	0.074535
0.01522	3.9	0.059358
0.0129	3.91	0.050439
0.01094	3.92	0.042885
0.00969	3.92	0.037985
0.00854	3.92	0.03347
0.00773	3.91	0.03022
0.00697	3.9	0.027183
0.00634	3.9	0.024726
0.0059	3.9	0.02301
0.00551	3.91	0.021544
0.00451	3.9	0.020019
0.00427	3.9	0.016653
0.00384	3.9	0.01497
0.00255	3.9	0.00994
0.00191	3.89	0.007429
0.00127	3.89	0.00494
0.00095	3.89	0.003696
0.00075	3.88	0.00291
0.00062	3.88	0.002406
0.00053	3.87	0.002051
0.00046	3.87	0.00178
0.00037	3.87	0.00143
0.00011	3.87	0.000426
0.00006	3.86	0.000232
0.00005	3.86	0.000193
0.00004	3.86	0.000154
0.00003	3.86	0.000116
0.00003	3.86	0.000116

Table 3:Computed values Parameters for mono crystalline Silicon solar cell at 20 cm, 30 cm, at T_C = 25°C and 27°C cell temperatures at 630 and 1050G (W/m^2) light concentration.

D (cm) A_C (m^2)T_C (°C) G (W/m^2)V_{OC} (V)I_{SC} (A)P $_{Max}$(W)η (%) FF

300.07 256304.18 0.0990 0.31167 4.57 0.75
20 0.07 27 1050 4.07 0.1831 0.48416 4.26 0.65

For determination of light radiation dependencies of the photovoltaic parameters of the silicon mono crystalline Si model, such I-V characteristics, were calculated for the light radiation under (1050 W/m^2) at 27°C cell temperature, and (630 W/m^2) at 25°Crespectively. For each point in the I-V curve, the product of the current and voltage represents the output power for that operating condition. By changing the concentration of global irradiance, the current-voltage and power-voltage characteristics wereobtained, which satisfy the data obtained, (Table 1, 2, 3 and Figs. 2, 3, 4). In this context, at d=30 cm and 630 W/m^2, this solar cell has a short circuit current of order ~ 0.1 A, the open circuit voltage ~ 4.20 V, P $_{Max}$~ 0.3 W, η (%) ~ 4.6 and FF = 0.75. While, at d=20 cm and 1050 W/m^2, this solar cell has a short circuit current of order ~ 0.2 A, the open circuit voltage ~ 4 V, P $_{Max}$~ 0.5 W, η (%) ~ 4.3 and FF = 0.65. This can be seen from the I-V characteristic given in Figs.2, 3, and Table 3. Fig. 4 shows a comparison of performance under (630 W/m^2) and (1050W/m^2). I-Vcurves perhaps the most important technical aspect of a solar cell and it forms the basis for understanding of all solar cell design. Further, the size of the short-circuit current (I_{SC}) is directly dependent of the solar radiation. Hence, we use the points that are near to the three most important points of a cell I-V curveshort circuit, maximum power and open-circuit [22].The amount of power produced by a solar cell depends on how much light is hitting it. It will perform at its best when pointed directly at the overhead sun on a bright and clear day. The maximum power output is called its peak power (watts /peak or W_p). In this context,Figs. 5, 6 show the curve of power against voltage at conditions of 630 G/m^2, d=30, 25°C and 1050 G/m^2,d =30, 27°C respectively. Fig. 7 shows also a comparison of power performance for a mono crystalline cell.

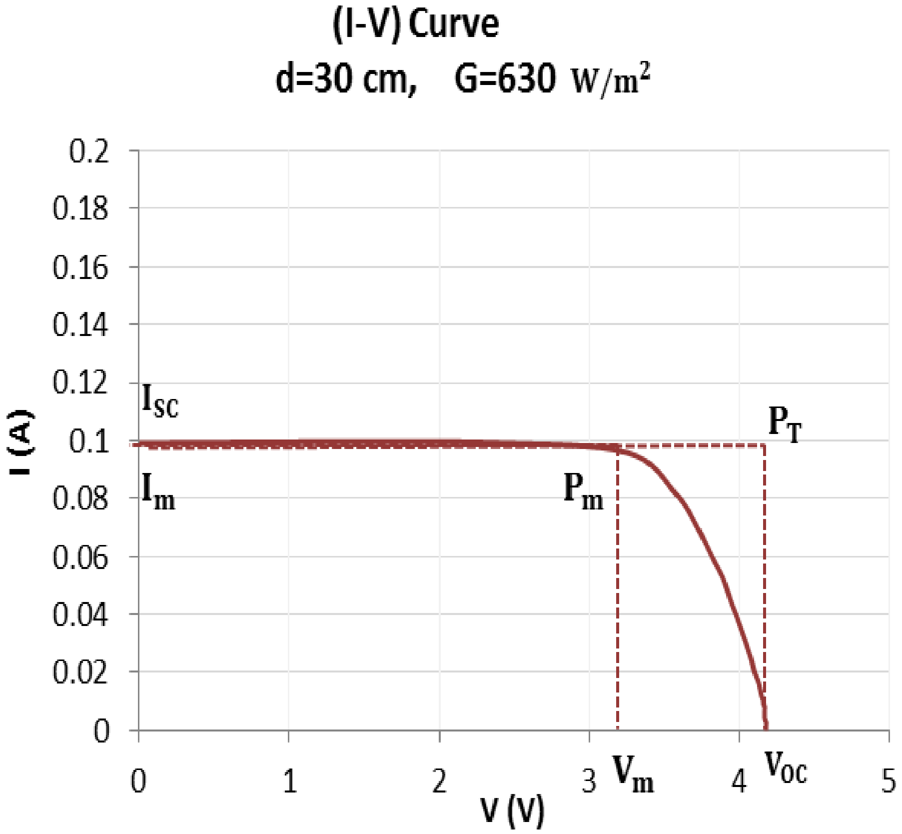

Fig. 2:shows a measured I-V characteristic for a solar cell mono Sicell at distance of 30 cm for intensity of 630 w/m^2

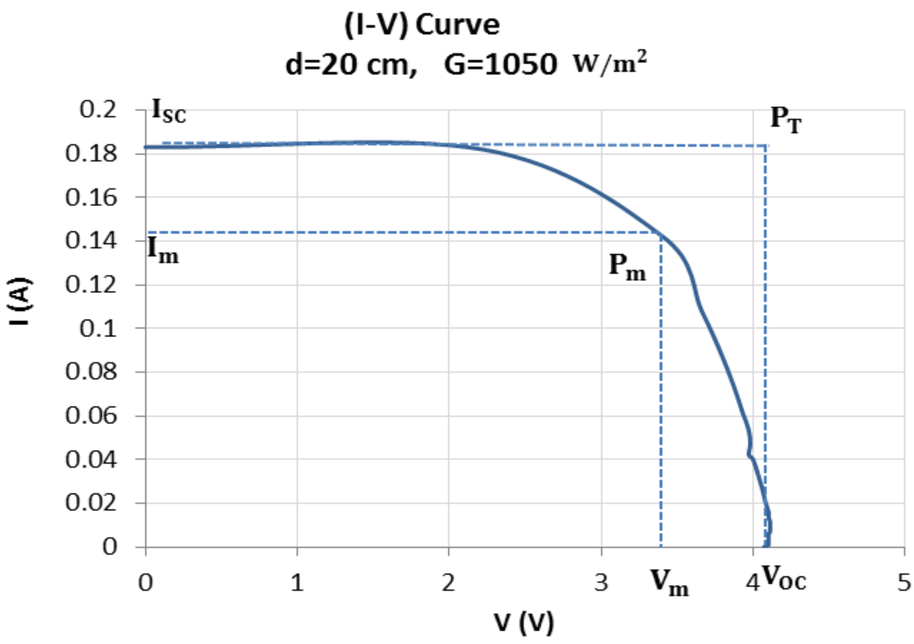

Fig. 3:shows a measuredI-V characteristic for a solar cellmono Sicell at distance of20 cm for intensity of 1050 w/m^2

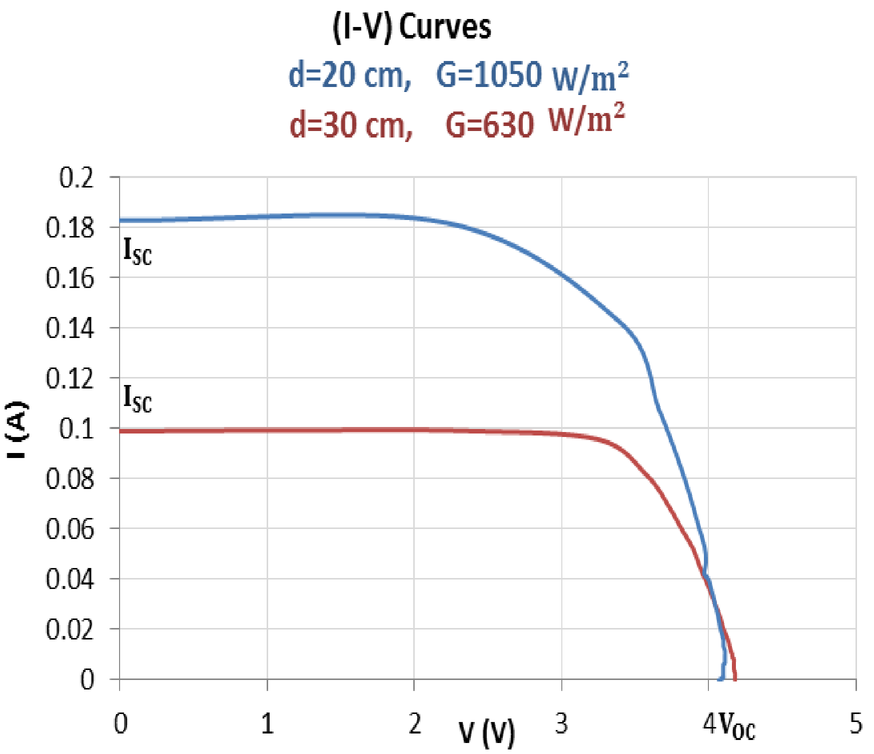

Fig. 4:shows the corresponding Isc (V) characteristic for distances, intensities andalso for T_c25°C and 27°C[23]

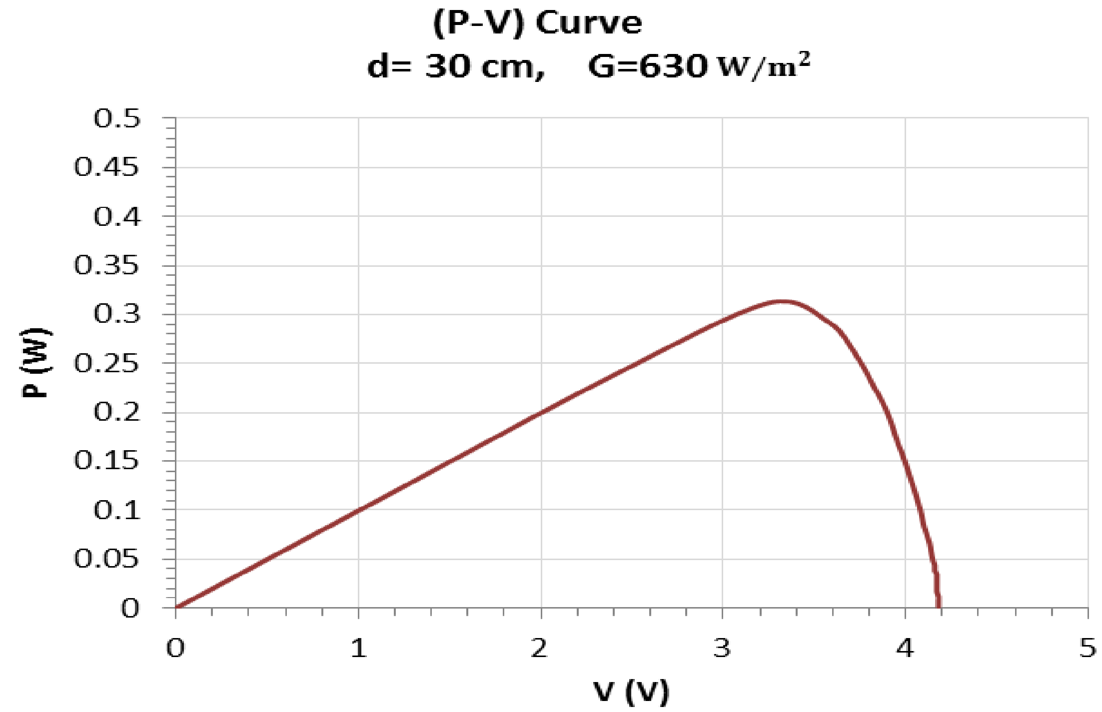

Fig. 5:shows a measured P-V characteristic for a mono crystalline silicon cell, distance of 30 cm for intensity of 630 w/m^2

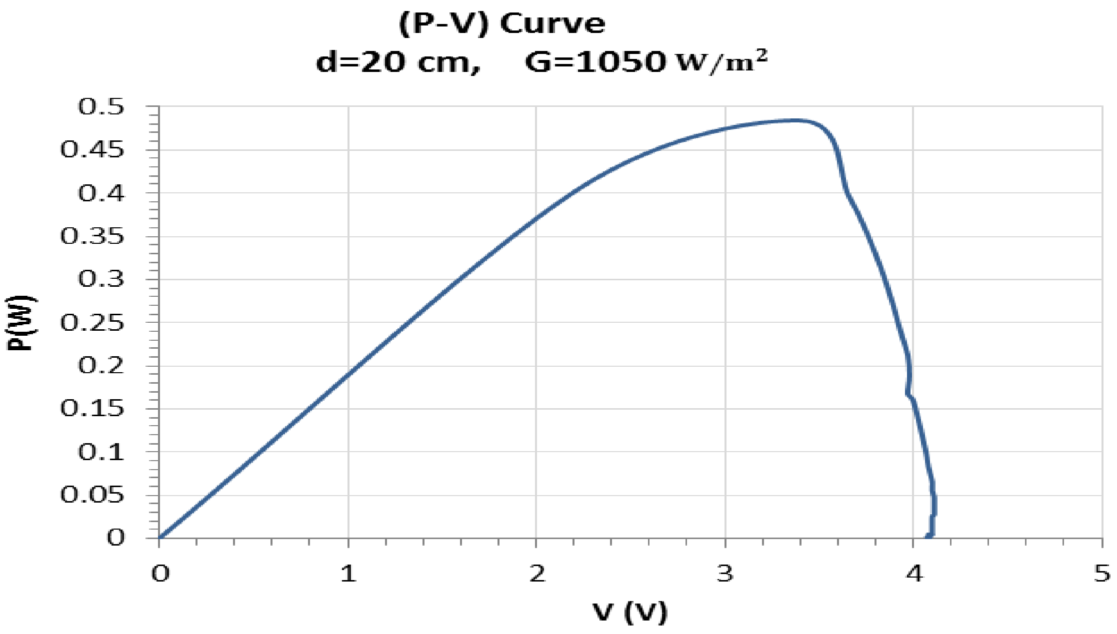

Fig. 6:shows a measured P-V characteristic for a mono crystalline silicon cell, distance of 20 cm and intensity of 1050 w/m^2

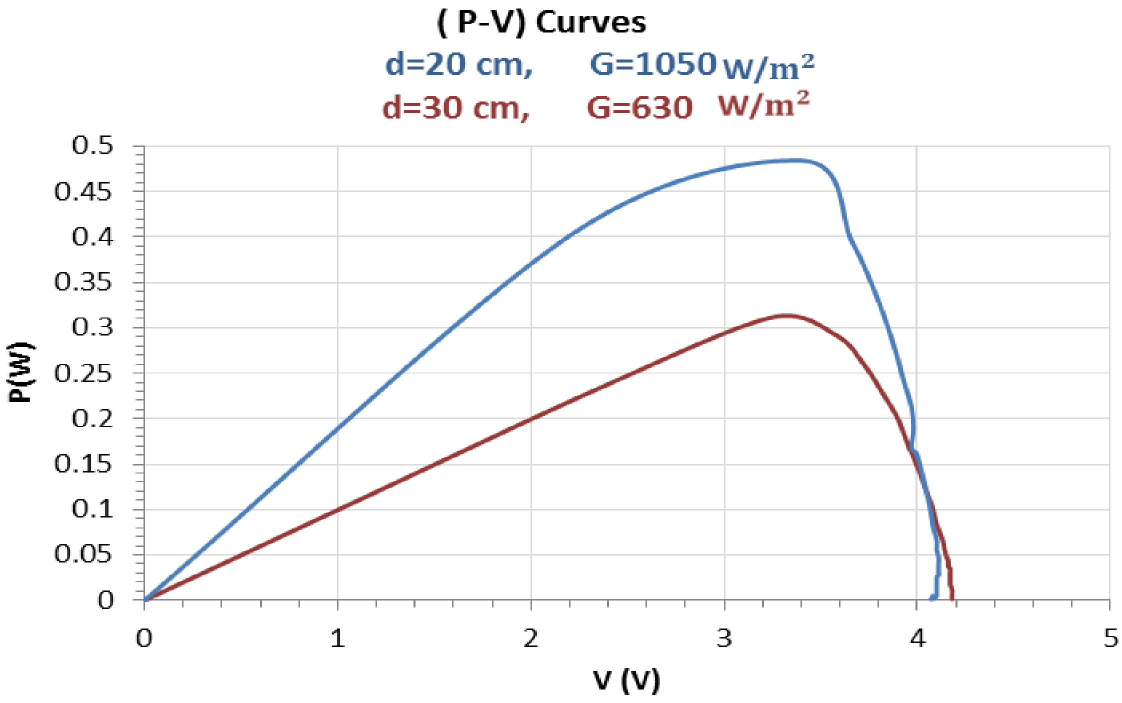

Fig. 7:shows the corresponding P-V characteristic for distances, intensities and also for T_c25°C and 27°C for a mono crystalline Si cell module

4.2. *I-V* and*P-V characteristics of poly- crystalline Si solar cells*

The I-V and P-V experimental results for poly-crystalline Si solar cell are shown in Tables 4, 5, 6 and Figs.8, 9, 10, 11, 12, and 13. The influences of light intensities, distances and temperatures on the photovoltaic parameters are studied.

Table4: Parameters extracted of poly crystalline Si solar @ 30 cm *for T* = 35°Ccell temperature and 630(W/m^2) irradiations.

I(A)	V(V)	P(W)
0.063	0	0
0.0628	0.775	0
0.0628	1.511	0.04867
0.0625	2.144	0.094891
0.0622	2.767	0.134
0.0588	3.21	0.172107
0.0527	3.41	0.188748
0.0471	3.526	0.179707
0.0424	3.601	0.166075
0.03836	3.656	0.152682
0.0364	3.67	0.140244
0.02451	3.81	0.133588
0.01912	3.87	0.093383
0.0152	3.9	0.073994
0.01293	3.92	0.05928
0.011	3.94	0.050686
0.00975	3.95	0.04334

0.00861	3.96	0.038513
0.0078	3.95	0.034096
0.00705	3.95	0.03081
0.00651	3.96	0.027848
0.00598	3.96	0.02578
0.00558	3.96	0.023681
0.00519	3.97	0.022097
0.00435	3.97	0.020646
0.00392	3.99	0.01727
0.00261	3.99	0.015641
0.00196	3.99	0.010414
0.0013	3.99	0.00782
0.00097	4	0.00518
0.00078	3.99	0.00388
0.00064	3.99	0.003112
0.00055	3.99	0.00255
0.00048	3.99	0.00219
0.00038	3.99	0.00191
0.00012	3.99	0.001516
0.00006	3.98	0.000478
0.00005	3.98	0.000238
0.00004	3.98	0.000199
0.00003	3.97	0.000159
0.00003	3.97	0.000119

Table5: Parameters extracted of poly crystalline Si solar @ 20 *cm for T* = 37°Ccell temperature and 1050 (W/m^2) irradiations.

I(A)	V(V)	P(W)
0.1022	0	0
0.0989	1.222	0.120856
0.0987	2.38	0.234906
0.0896	3.068	0.274893
0.0752	3.341	0.251243
0.064	3.49	0.22336
0.0555	3.585	0.198968
0.0488	3.635	0.177388
0.0433	3.684	0.159517
0.03905	3.715	0.145071
0.03705	3.74	0.138567
0.02472	3.84	0.094925
0.01921	3.88	0.074535
0.01522	3.9	0.059358
0.0129	3.91	0.050439
0.01094	3.92	0.042885
0.00969	3.92	0.037985

0.00854	3.92	0.03347
0.00773	3.91	0.03022
0.00697	3.9	0.027183
0.00634	3.9	0.024726
0.0059	3.9	0.02301
0.00551	3.91	0.021544
0.00451	3.9	0.020019
0.00427	3.9	0.016653
0.00384	3.9	0.01497
0.00255	3.9	0.00994
0.00191	3.89	0.007429
0.00127	3.89	0.00494
0.00095	3.89	0.003696
0.00075	3.88	0.00291
0.00062	3.88	0.002406
0.00053	3.87	0.002051
0.00046	3.87	0.00178
0.00037	3.87	0.00143
0.00011	3.87	0.000426
0.00006	3.86	0.000232
0.00005	3.86	0.000193
0.00004	3.86	0.000154
0.00003	3.86	0.000116
0.00003	3.86	0.000116

Table 6: Computed values Parameters for poly crystalline Silicon solar cell at 20, 30 cm at T_C = 35°C and 37°Ccell temperatures at 630 and 1050 light concentration.

D(cm) $(A_C)(m^2)T_C$ (°C) G (W/m^2) V_{OC} (V) I_{SC} (A) P_{Max}(W) η (%) FF

30 0.0635 630 4.02 0.0063 0.188748 4.68 0.74
20 0.0637 1050 4.33 0.0932 0.274893 4.09 0.68

The extracting, I-V curves and the maximum power from the PV panel, indeed it is necessary to operate the PV panel at their maximum power point (P_{Max}). The output I-V, and P-V poweroutput characteristics are shown in Figs. 8, 9, 10, 11, 12, and 13. The I-V and P-V curves of the poly-crystalline Si are influenced by the variation of the incident solar irradiance and the temperature to describe their effects on the short circuit current Isc and open-circuit voltage Voc, and the current I_{Max} and the voltage V_{Max} of the maximum power P_{Max}.

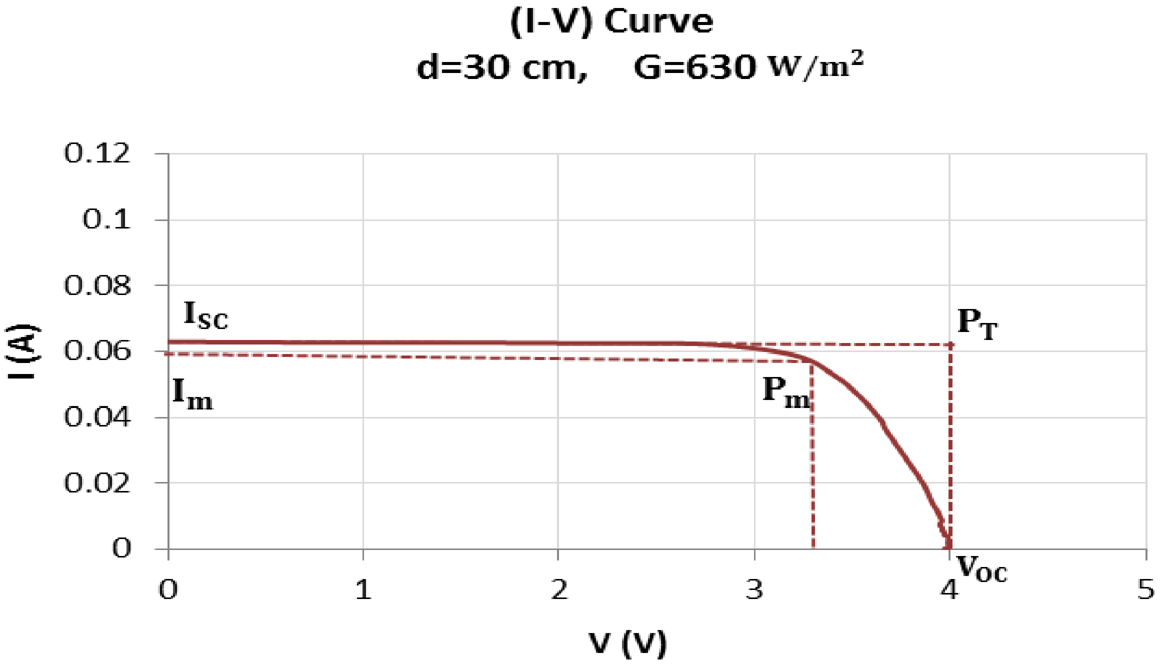

Fig. 8:shows a measured I-V characteristic for a solar cell for poly solar cell at distance of 30 cm and intensity 630 w/m^{2}and also for T_c35°C and 37°C

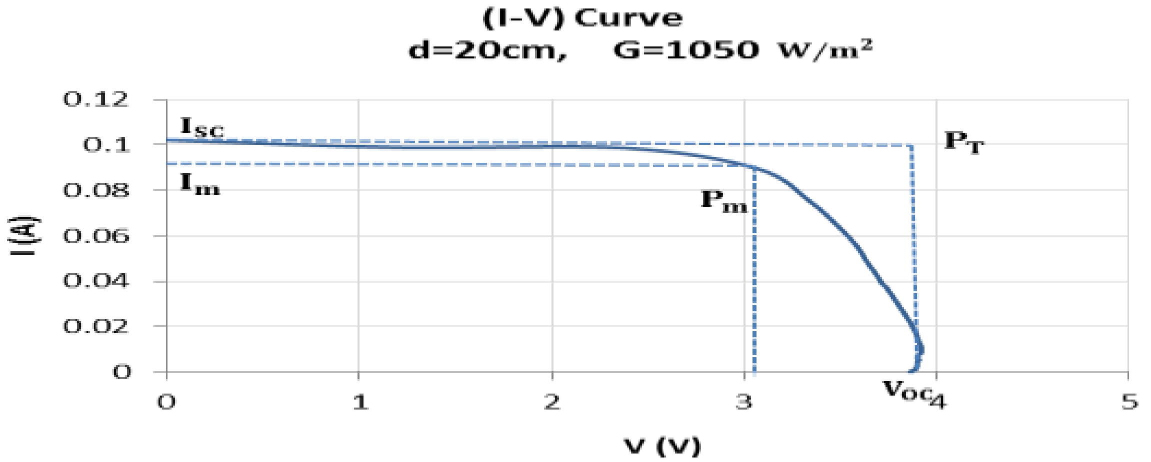

Fig. 9:shows a measured I-V characteristic for a solar cell for poly solar cell at distance of 20 cm and intensity 1050 w/m^{2}and also for T_c35°C and 37°Cfor polysolar cell

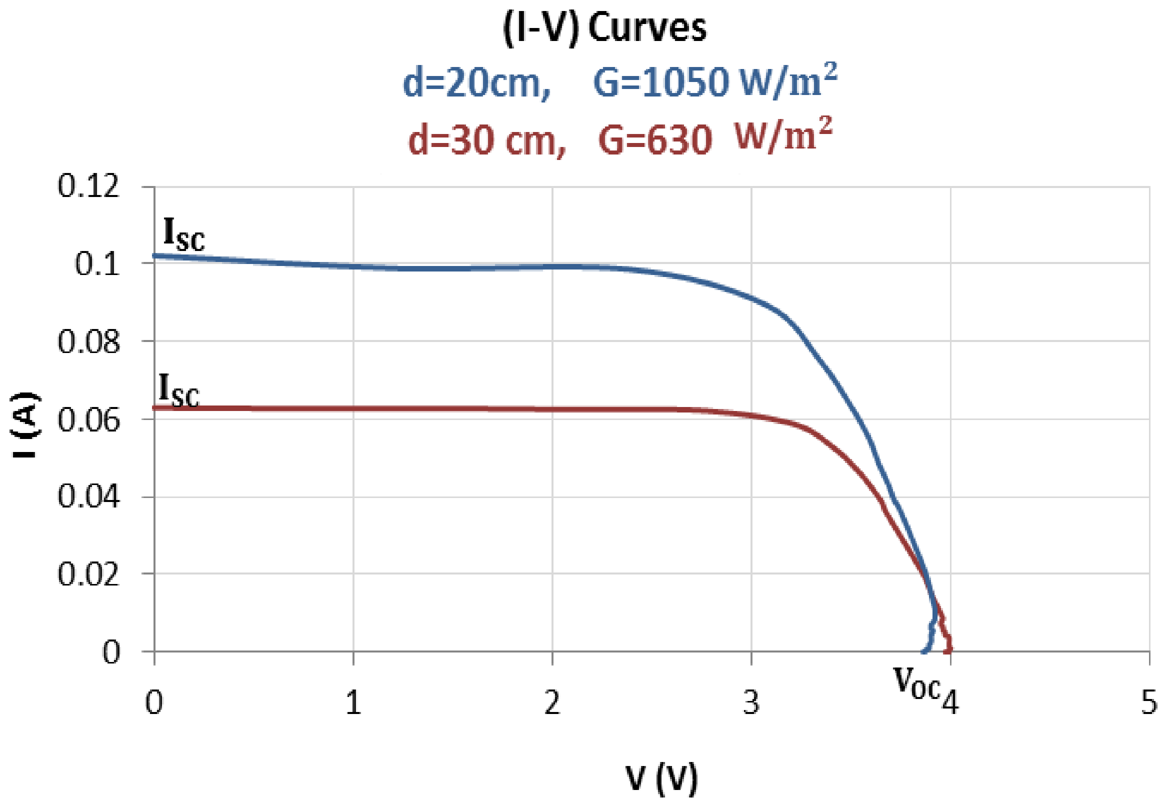

Fig. 10: shows the corresponding Isc (V) characteristic for distances, intensities and also for T_c35°C and 37°Cfor poly crystalline silicon cell

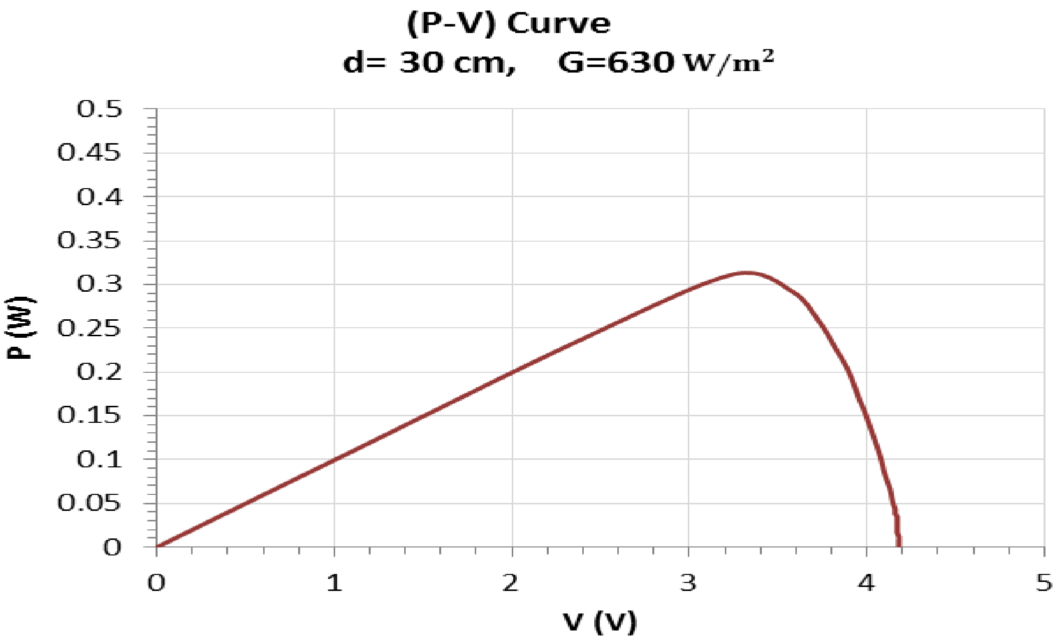

Fig.11:shows a measured P-V characteristic for a for a poly crystalline Si cell,distance of 30 cm for intensity of 630 w/m²

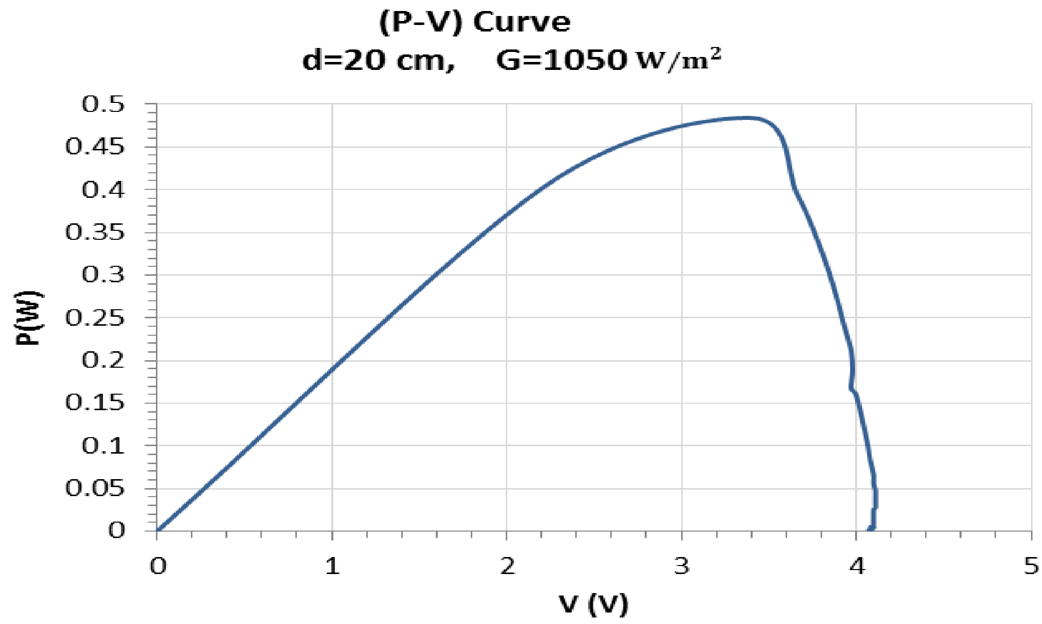

Fig. 12:**shows a measured P-V characteristic for a poly crystalline Si cell,distance of 20 cm for intensity of 1050 w/m^2**

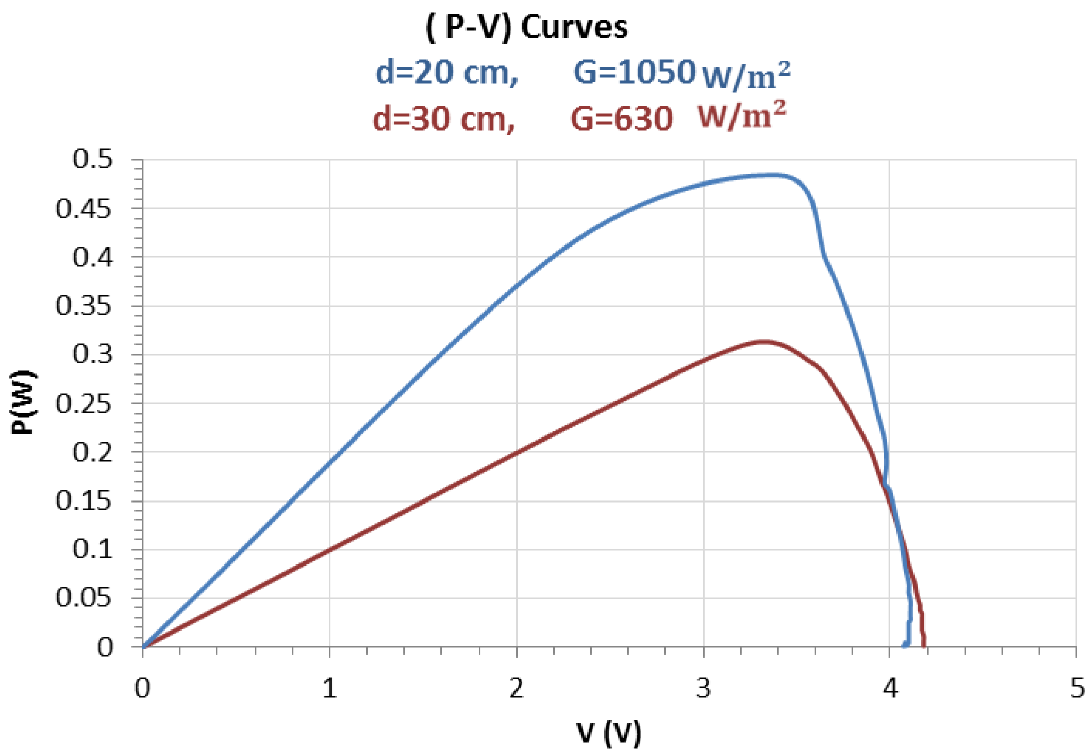

Fig. 13:**shows the corresponding P-V characteristic for distances, intensities and also for T_c35°C and 37°C for a poly crystalline Si cell**

In the case of G = 630 W/m^2, d=30 cm,35°C, this solar cell has a short circuit current of order ~ 0.01 A, the open circuit voltage ~ 4 V, P_{Max}~ 0.2 W. Also, for this solar cell found fill factor of the I-V characteristic 0.74 and energyconversion efficiency ~ 4.7.While, at G = 1050 W/m^2,d=20 cm and 37°C, this solar cell has a short circuit current ~ 0.1 A, and the open circuit voltage of order 4.3 V, P_{Max}~ 0.3 W, fill factor of the I-V characteristic 0.68 and energyconversion efficiency ~ 4.1. See Table 6 and Figures 11, 12, and Figure 13 as well.In Fig.11, 12, and 13, it can be seen that the power output from the cell depends on the operating voltage. In addition, from Fig. 8,9 and 10, the short circuit current, Isc, is the largest value of the current that is generated by solar cell when the voltage of the solar cell is equal to zero (short circuit condition). The maximum power point of the solar cell is the operating point in which the power extracted from the solarcell is the maximum, while the resistive load is given by Ohm's law (V/I), these quantities can be computed directly from the I-V curves.The power production in relation to the product of the short-circuit current and the open-circuit voltage is called the Fill Factor.

V. Conclusions

The influences of varying temperatures (25°C, 27°C, 35°C, 37°C) with 630 W/m^2 and 1050 W/m^2 irradiations on the I-V and P-V characteristics are determined experimentally. Applying and understanding of mono crystalline silicon and polycrystalline Si techniquesis crucial importance to extractPV modules on certain conditions for the open circuit (V_{OC}), short circuit current (I_{SC}), maximum power (P_{Max}), efficiency (η %) and fill factor(FF).We conclude the following points:

- In general, the mono crystalline cells achieve I_{SC}, V_{OC}, P_{Max}, and FF values higher compared to the multi crystalline cell.
- I-V and P-V curves dependence of the temperature [22].
- Solar irradiance has major role on the performance of solar cell. As solar irradiance increases from 630 Wm^{-2} to 1050 Wm^{-2}, the performance of solar cell increases accordingly, I-V and P-V curves.
- The performance of solar cell depends on atmospheric conditions, because one of the problems of solar cell is the unpredicted output power due to the variation in solar radiation and temperatures.
- The paper investigates the applications of mono and poly-crystalline Si is governed by the electrical properties.
- For poly crystalline Si solar cell, the maximum output power occurs in the knee at the point, called the maximum power point, where the voltage is approximately 3.4 V. After that point, the curve decreases and the output power declines, as illustrated in Fig. 8. In the figure, the blue curve is the power. In this particular case, the maximum output power is $P_{OUT(MAX)} = V_{MPP} \times I_{MPP}$ = (3.4 V) (0.06 A) = 0.20 W. While, in Fig. 9, the maximum output power is $P_{OUT(MAX)}$ = (3.1 V) (0.11 A) = 0.34 W.
- For mono crystalline Si, Fig. 2 shows a typical I-V curve for which the short-circuit output current, I_{SC} is 0.1 A, because the output terminals are shorted, the output voltage is 0V. For an open output, the voltage, V_{OC} is maximum (4.2V) in this case, but the current is 0A, as indicated.
- For poly crystalline Si, Fig. 9 shows a typical I-V curve for which the short-circuit output current, I_{SC} is 0.1 A. Because the output terminals are shorted, the output voltage is 0V. For an open output, the voltage, V_{OC} is maximum (3.8 V) in this case, but the current is 0A, as indicated.
- The output of silicon solar cell depends on, irradiance spectrum[**23**], the angle of the incidence[24], the temperature of the cell [25] and the solar cells design.
- Figure 6 indicates a peak electrical power output of roughly 0.5 W. While, the intensity of the incident sunlight is measured to be 1050 W/m^2. We computed the area of the mono solar panel of 0.0676 m^2. Therefore, the total optical power input is the product of the intensity and the area, which gives 525 W. The resulting efficiency is 10 %.
- We recommended chemists and researchers to improve materials, ability to absorb sunlight, conduct charges and resist degradation.

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