Analysis of Electrical Characteristics and Performance of Poly-Crystalline Solar PV Module by I-V Tester Under Temperature and Solar Irradiance Variation in Spring Season

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***Abstract*-The performance of the Solar photovoltaic (PV) panel depends mainly on two environmental factors, namely temperature and solar irradiance. These factors affect the PV output parameters such as maximum power, short-circuit current and open circuit voltage. This work investigated the behavior of a polycrystalline solar PV panel's electrical characteristics under variation in temperature and solar irradiance in spring season. This was done through experiment and the results validated with simulation in Matlab software. The experimental results were compared to simulation results and showed that the module electrical outputs change with the variation in temperature and solar irradiance. These two factors affect the PV module performance during the spring seasons and its output is more efficient due to favorable surface temperature and solar irradiance variations striking the module during peak hours of the day.**

Keywords—Polycrystalline PV module, solar irradiance, temperature, I-V Tester

I. INTRODUCTION

Solar energy is an environmentally friendly source of energy which is a pollution free and available to everyone. However, solar energy is not used at maximum due to the periodical change of environmental conditions that affect the energy yield from the solar plant. To maintain the high efficiency of the solar Photovoltaic (PV) plant, the system needs a regular performance inspection[1]. I–V characteristics of a PV module are important in identifying its performance and quality as a function of varying environmental parameters. Solar radiation, ambient temperature, wind speed, humidity and dust are the main environmental factors which influence the performance of a PV module output[2]. The solar irradiance and temperature as major factors that affect the solar panel performance are not constant during the spring season therefore, these two factors have been analyzed at each interval of time when exploring the polycrystalline solar PV performance.

II. LITERATURE REVIEW

A. Overview of Beijing temperature profile in April

Beijing is the capital city of China situated on the northeast edge of the North China Plain, located at 39054'20''N and 116025'29''E. This City has a typical climate change, characterized by humid and hot summers due to the East Asian monsoon, and generally cold, windy, dry winters in relation to the vast Siberian anticyclone[3]. Meteorological data are harvested from the China Meteorological Data Sharing Service System in which the maximum atmospheric temperature is 21^0C and low temperature is 10^0C in April. This is the effective working temperature of the solar PV cells for a maximum performance if there is enough solar irradiance.

B. Effect of Temperature on PV cell performance

PV cells are produced in semi-conductor materials that are very sensitive to temperature[4]. Hence the power produced by a solar cell is affected by the ambient temperature when it is exposed to sunlight and that is why solar cells are calibrated to work under standard temperature conditions of 25°C. If there is any change in ambient temperature of the solar cells, this causes performance degradation [2]. Continuous operation of a PV cell in high temperatures reduce its efficiency as well as its life span. This result indicates that it is very important to consider the temperature characteristics in solar cell development [5]. The performance efficiency of the PV panel is also dependent on different environmental conditions such as dust deposited on the panel, shading and operating temperature of the solar panel[6][7].

In [8] the effect of temperature on a Mono-crystalline Solar PV Panel was studied and an experiment conducted starting from 25°C cell operating temperature under a constant irradiance of 458.2 W/m^2. The results showed that by increasing the temperature, the maximum power (Pmax) and the open circuit voltage (Voc) showed a decreasing trend while the short circuit current (Isc) indicated an increasing trend.

Temperature is an important factor to be considered when determining solar PV efficiency and performance. When the temperature increases, the rate of the photon generation increases as well. As a result, the reverse saturation current increases reducing the band gap. Therefore, this causes marginal changes in the current and major changes in the output voltage[8]. Therefore, the open-circuit voltage (Voc) and short-circuit current (Isc) are generally used to characterize the PV cell. The Voc corresponds to the voltage across the internal diode when the total generated photocurrent flows through the diode.

The easiest method to measure the I-V characteristics of a PV module is the use of variable resistor method. The values of I and V will be varied in progressive steps from zero to

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infinite resistance. By monitoring these values, the I-V curves can be extracted. However, this technique can only be used for PV system with small power capacity[9]. Mahmoud in [10] developed a mathematical model enabling measurement of I–V characteristics by capacitor charge technique while respecting the dynamic limits of the measuring equipment. Solar PV manufacturers test PV panels at standard testing condition(STC) and claim that 20% of the efficiency would be depleted after 25 years but this is not applicable to some regions where temperature and irradiance change at a high rate[11].

In this paper, an I-V tester is used to analyze the electrical characteristics and performance of a polycrystalline solar PV panel installed at the top roof of North China Electric Power University, Beijing. In this study, the PV system is exposed to irradiance and temperature variations. The output behavior of a polycrystalline solar panel was recorded at every 15 minutes of the experiment. The OriginPro software used to plot the characteristics of the output graphs of the module parameters.

C. Poly-crystalline solar PV panel

A solar cell is fundamentally a p-n junction in a thin wafer of a semiconductor. When it is exposed to sunlight, solar radiations may be reflected, absorbed, or transmitted through the materials of the cell. The photons that have greater energy than the band-gap energy of the semiconductor is absorbed creating a number of electron-hole pairs proportional to the incident irradiation. The absorbed light generates electricity [12]. Although the efficiency of monocrystalline is higher than the Polycrystalline modules, the latter is the most popular on the PV market because of its low cost [13]. In this study the polycrystalline solar cell is used. The Figure 1 shows a Polycrystalline PV panel used during the experiment.

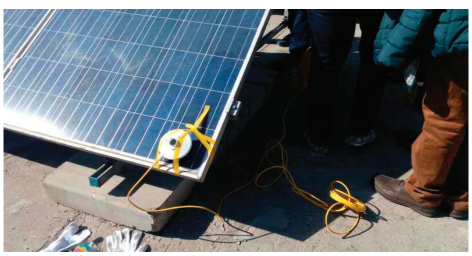

Fig.1. Polycrystalline solar panel

The STC for the performance of the solar cell include a solar spectrum irradiance called the Air Mass of 1.5, irradiance of 1000 W/m^2, and 25°C cell temperature. Figure 2 shows an electrical circuit of a solar panel in [14] adopted in this study. The I-V tester is connected at the PV output and Voc and Isc measurements taken for analysis. In this research work a 240W polycrystalline solar PV panel with specifications in Table 1 installed at the rooftop of the building was taken into consideration.

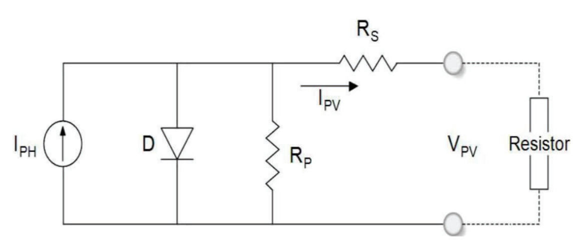

Fig.2. Electric circuit of a solar panel[15]

TABLE I. ELECTRICAL CHARACTERISTICS OF A 240W POLYCRYSTALLINE PANEL

Parameter	Variable	Value
Maximum rated power W	Pmax	240W
Voltage at maximum power	Vmp	30.2V
Current at maximum power	Imp	7.95
Open-circuit voltage	Voc	37V
Short-circuit current	Isc	8.54A
Total number of cells in series	Ns	60
Total number of cells in parallel	Np	1
Module surface	A	165m^2

III. MATERIALS AND METHOD

A. Data collection

The experiment was conducted on 240W panel at a 10kW solar PV array installed on the rooftop of the main building office at North China Electric Power University during the spring time. Measurements were taken in the same weather conditions in April 2018, using thermometers, pyrometer, ammeter and voltmeter. The solar PV panel dimensions are 1.65mx1.0mx0.045m. The results are captured in Table 2 at 15minute intervals during the peak hours of the day.

B. Instruments used

a. Pyranometer

A pyranometer attached on the polycrystalline pv panel used in the experiment as shown in Figure 3, is a type of actinometer used to measure the solar irradiance on a plane surface and designed for measuring the solar radiation flux density (W/m^2) from the hemisphere within a wavelength range of 0.3-3 μm. Pyranometer is widely used in meteorology, climatology, agriculture and solar energy studies among others[16].

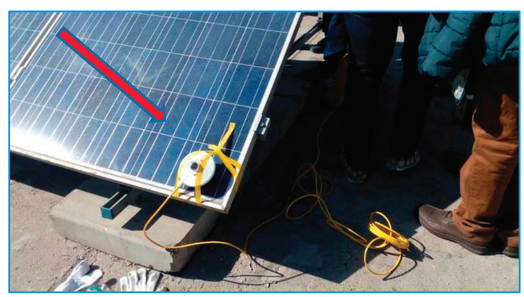

Fig.3. Pyranometer for irradiance measurement

b. I-V Tester of solar Array characteristics

The I-V tester shown in Figure 4.a is a device used to analyze the current and voltage characteristics as shown in Figure 4.b under environmental conditions (temperature and irradiance). This device has the irradiance and the temperature inputs and generates the current, voltage and power generated from the polycrystalline solar panel exposed under the sunlight.

(a) (b)

Fig.4. Tester of solar Array I-V characteristics (a) Device connected in the system (b) I-V testing in progress

c. Multimeter

The Figure 5 shows a multimeter that was used to measure current and voltage values.

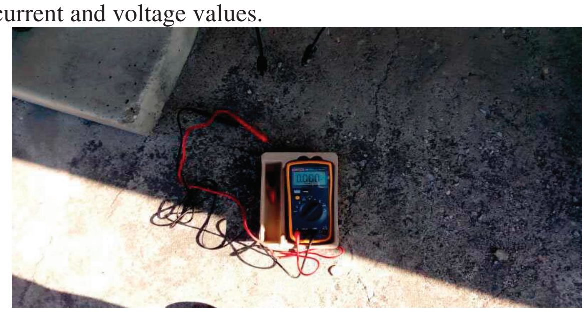

Fig.5. Multimeter for current and voltage measurement

d. Temperature sensor

The temperature sensor shown in Figure 6 was used to measure the variation of temperatures of the PV module and send the data to the I-V tester.

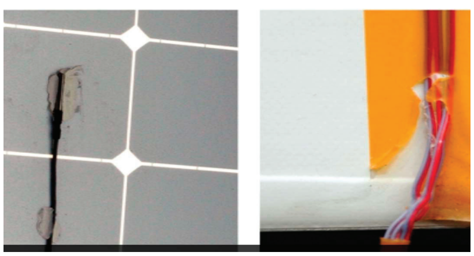

Fig.6. Temperature sensor attached on the PV panel

IV. Results and Discussion

A. Experiment

From this experiment, various data for the Voc, Isc and maximum power (Pmax) against temperature and irradiance are recorded in Table 2. It can be observed that while the Ioc reduces with the increase in temperature the Voc increases.in this case the irradiance trend is the same as Ioc. Figure 7 and 8 respectively shows the I-V and P-V characteristics of the polycrystalline module at sampled temperature of 28°C. From the curves, the Isc is 4.2A and the Voc is 30.4V whereas the Imp and Vmp are 3.8A 28.3V respectively.

The PV characteristics were analyzed at different temperature levels as shown in Figure 7 to 13. The band gap of the solar cell reduces with the temperature increase, this phenomenon affects the electrical parameters of solar cell such as maximum power, open circuit voltage and short circuit current. This is observed from the experiment work done by measuring the solar panel parameters under variable temperatures and variable solar irradiances. Based on the experiment results a dominant effect with temperature increase of the solar panel causes a decrease of the open circuit voltage and the increase of the short circuit current. As the irradiance decreases the maximum power also decreases, this is illustrated in the Table 2 where the irradiance is at Maximum and the power generated is at maximum but when the irradiance started decreasing the maximum power produced also started decreasing. These results show a great effect of temperature and solar irradiance variation on the solar PV modules.

TABLE II. Solar PV Parameters Versus Temperature And Irradiance Recorded During The Experiment

No	Time	Temp (oC)	Isc (A)	Voc (V)	Irradiance (W/Sq.m)	Pm (W)
1	13:00	29	4.203	30.1	575	113.9
2	13:15	28	3.37	30.4	562	79.7
3	13:30	28	3.30	33.3	526	50.8
4	13:45	27	3.17	33.4	516	48.1
5	14:00	25	2.42	33.5	480	47.9
6	14:15	25	2.32	33.5	466	47.3
7	14:30	24	2.38	33.5	467	47.6
8	14:45	23	2.01	33.6	434	37.8
9	15:00	22	1.64	33.6	400	37.4
10	15:15	20	1.52	33.9	398	37.1
11	15:30	19	1.47	34.0	388	36.9
12	15:45	18	1.24	34.5	387	36.16

The Figures below show the PV characteristic plotted at different temperatures measured during the experiment under temperature and solar irradiance variation. The open circuit voltage decreases and the short circuit current increases due to the rise of temperature and this results in the decrease of the maximum power output.

The graphs in Figure 7 and Figure 8 show the voltage-current and power-voltage characteristics respectively plotted at a sample temperature of 28°C.

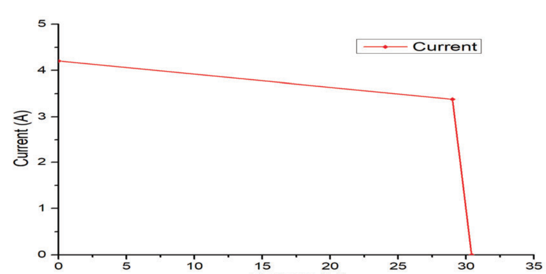

Fig.7. V-I characteristics at 28°C temperature level

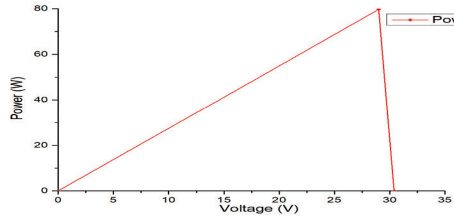

Fig.8. P-V characteristics at 28°C temperature level

The graphs in Figure 9 to 11 shows the effect of temperature on the output power, open circuit voltage and short circuit current under variation of irradiance. The output power remains constant during the variation in temperature up to 23^{0}C. a rapid increase in power is observed at about 28^{0}C. The open circuit voltage is observed to decrease gradually with increase in temperature. On the other hand, the short circuit increase with increase in temperature. It can be noted that the trends in output power and short circuit voltage are not exactly the same as expected as experiment was done an open environment with various intervening variables.

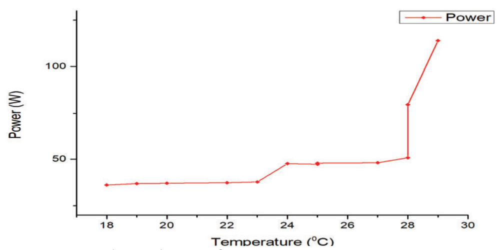

Fig.9. Temperature dependence of Pmax

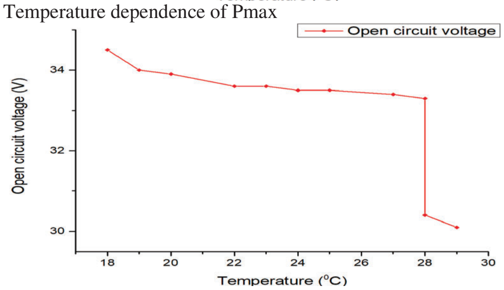

Fig.10. Temperature dependence of $V^{o}c$

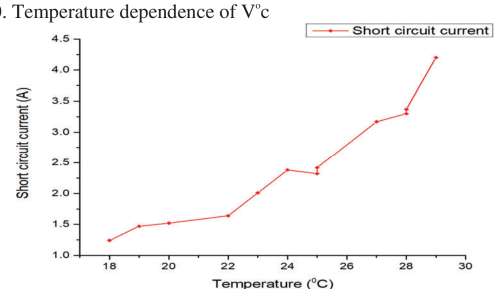

Fig.11. Temperature dependence of Short circuit current

The graphs in Figure 12 and 13 shows the effect of irradiance on the short-circuit and power. It can be observed that the irradiance increases with the short circuit and power.

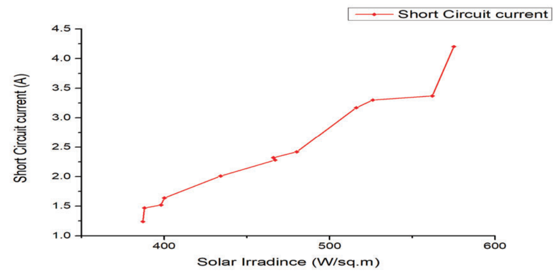

Fig.12. Irradiance dependence of Short circuit current

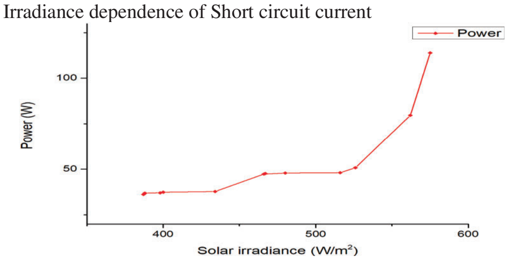

Fig.13. Solar irradiance-power

B. *Validation of Experimental Results in Matlab*

A 240W polycrystalline solar panel was modelled and validated in Matlab. The Table 3 illustrates the comparison of the experimental data and the simulation results.

TABLE III. EXPERIMENTAL AND SIMULATION RESULTS FOR VARIOUS TEMPERATURES

No	Time	Temp	Experiment results				Matlab simulation results			Diff. power
		Temp (oC)	*Isc (A)*	*Voc (V)*	*Irradiance (W/Sq.m)*	*Pm (W)*	*Voc (v)*	*Isc (A)*	*Pm (W)*	*ΔP*
1	13:00	29	4.203	30.1	575	113.9	28.1	6.2	141.1	27.2
2	13:15	28	3.37	30.4	562	79.7	29.02	5.9	87.6	7.9
3	13:30	28	3.30	33.3	526	50.8	29.66	5.71	63.6	12.8
4	13:45	27	3.17	33.4	516	48.1	29.8	4.3	46.1	2
5	14:00	25	2.42	33.5	480	47.9	30.02	4.02	42.02	5.88
6	14:15	25	2.32	33.5	466	47.3	30.23	4.0	40.1	7.2
7	14:30	24	2.38	33.5	467	47.6	30.9	3.79	38.77	8.83
8	14:45	23	2.01	33.6	434	37.8	31.02	3.01	36.8	1
9	15:00	22	1.64	33.6	400	37.4	32.05	2.88	36.1	1.3
10	15:15	20	1.52	33.9	398	37.1	32.78	2.5	31.2	5.9
11	15:30	19	1.47	34.0	388	36.9	33.1	2.48	28.03	8.87
12	15:45	18	1.24	34.5	387	36.16	33.5	2.06	27.77	8.39

Generally, the simulation results are slightly higher than the experimental results. From the simulation results, it can be observed that the surface temperature of the polycrystalline PV panel and the solar irradiance striking it affect the output. The maximum power and the open circuit voltage decrease while the short circuit current increases when the temperature increases. When the solar irradiance is high, the power generated is also high.

The Figure 14 and 15 show the impact of temperature on current and output power respectively at a sampled instant of 28^{0}C with varying solar irradiance. The I-V and the P-V curves obtained are much closer to the ideal characteristics than in the figure 7 and 8 due to the Matlab model assumptions. From the curves, the Isc is 5.8A and the Voc is 33.1V whereas the Imp and Vmp are 4.5A, 25V respectively.

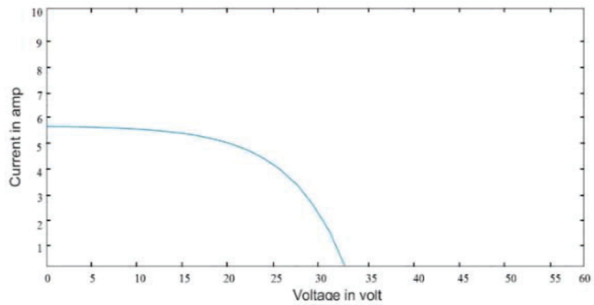

Fig.14. V-I characteristics of a solar panel at 28^{0}C

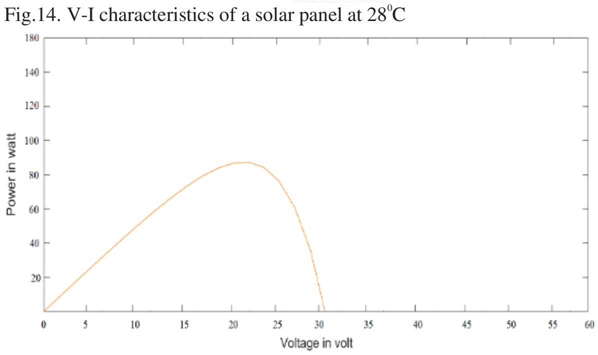

Fig.15. P-V characteristics of the solar panel at 28^{0}C

V. Conclusion

This work investigated the behavior of a polycrystalline solar PV panel electrical characteristics under varying temperature and solar irradiance during spring season. The results show that while the open circuit voltage decreases with increase in temperature, the power increases at rising values of irradiance. These two parameters are very important in determining the best site for solar PV system design and installation.

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