Research Article

Performance Analysis of Photovoltaic Panels Under the Effect of Electrical and Environmental Parameters in Erbil City

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Abstract

This paper presents the performance analysis of a photovoltaic cell derived from a single diode equivalent circuit under the influence of several kinds of electrical and environmental parameters. The characteristics of a solar cell have been investigated using MATLAB simulation and have been validated experimentally. In this paper the photovoltaic cell is represented by an exact equivalent circuit including all parameters such as a diode saturation current, light generated current, temperature effects, series and shunt resistance values. Also, this paper includes the impacts of clouds, dust, chalk powder, fly ash and bird droppings on the efficiency of the photovoltaic panel. A comparison between the experimental and model simulation results confirmed the reality of results, and indicate the validity of the exact model for photovoltaic performance analysis.

Keywords: Photovoltaic (PV), Performance Analysis, Solar Radiation, Electrical and Environmental Factors.

1. Introduction

With the event of world incipient energy technology, the analysis for renewable energy has gradually extended in all countries. In order to push standardization and marketization of the recent energy industry, a series of advancement plans have been suggested. The goal of photovoltaic power (PV) can occupy a very important position within the universal energy consumption market, and become the topic of the world energy [Guo, Y., Song, X. & Dai, Ch., 2017]. In Erbil/Kurdistan Region/Iraq; which is the location of these tests; the solar irradiation has great value and it reaches 5.26 Kwh/m^2/day [Atrooshi, S. & Yassen, S., 2017].

The energy through the PV can be seen to be the major and prerequisite sustainable resource because of the ubiquity, multitude, and sustainability of solar radiant energy [Tasi, H., Tu, Ci., & Su, Y., 2008]. PV cells convert solar irradiation straight into DC electrical power. The fundamental material for assuredly all the PV cells is subsisting within the market demand, which is high clean silicon (Si) and is obtained from sand or quartz. Broadly, there are three kinds: mono-crystalline; polycrystalline; and amorphous silicon. The Crystalline-Si technology is often utilized as a reference, or baseline for solar energy production technology, largely the condition of PV cell technology relies on cell efficiency, and manufacturing cost [Shukla, A., Khare, M., & Shukla, K N., 2015].

The potency of a PV cell is set by the material's competency to absorb photon energy over an extensive area, and on the band gap of the matter. PV cells are semiconductors that have impotently bonded electrons at a caliber of energy called valence band [Guangyu, L., Kiong, S.N, & Ashton, P., 2011; Yahya, M.A., Youm, I., & Kader, A., 2011]. The current engender by a solar cell at any moment is based on its intrinsic characteristics and the solar radiation. The solar irradiation is composed of sundry energies, and some are absorbed at the p-n junction. Photons with energies not up to the troupe gap of the solar cell do nothing and engender no voltage or electrical current Photons with energy superior to the troupe gap engender electricity, but only the energy corresponding to the troupe gap is utilized. The remnant of energy is wasred as heat within the body of the solar cell [Varsheny, A. & Abu, Tariq, 2014]. In general clouds lead the albedo of the atmosphere that finds the amount of solar radiation arriving to the earth's surface through the daylight [Liou, K. N, 2002]. Many researchers have investigated this as seen in the literature.

Salmi, T., Bouzguenda, M., Gastli, A., & Masmoudi, A. [2012], were presented a mathematic Matlab simulink model of a PV solar cell comportment under various physical and various climate parameters such as alteration of solar radiation and temperature both simulation and experiment.

Tobnaghi, M. D., Madatov, R., Naderi D. [2013], studied the efficacy of alteration of the cell temperature which effects the PV performance. Varsheny, A. & Abu, Tariq [2014], studied and calculated different parameters for solar cells by utilizing Matlab Simulink under sundry physical environment conditions. Kumar, M., Kumar, N., & Chandel, S.S. [2015] & Nema, S., Nema, K.R., & Agnihotri, G. [2010], worked on both Matlab simulink and experimental data. They utilized different simulation data for different cell temperatures at 25, 50 and 75 C^o, transmuting the irradiation as 1000, 1200 and 1400 W/m^2 and variable series resistance as 0.221 and 0.400 **Ω** while neglecting shunt resistance. As a result they found that the parameters had an effect on the PV characteristics and output potency. Azzouzi, M., & Bouchahdane, M. [2016], proposed a model and applied different conditions to a PV cell to get better electrical performance from the PV system. The outcome that the variations of temperature, irradiance, series and shunt resistance was that these conditions have a major influence on solar cell performance. Perraki, V. & Kounavis, P. [2016] investigated the effect of temperature and irradiation on the behavior of many types of PV cells at a Mediterranean site in north altitude 38^0. Charfi, W., Chaabane, M., Mihri, H. & Bournot, P. [2018] presented an experimental study of a special panel allowing solar panel natural cooling and computational fluid dynamics which were used for modeling of PV systems.

Ali & Abdulsalam, I. G. [2016] studied the effect of clouds on the performance of a PV panel using both outdoor experiments and Matlab simulations. The results show that cloud cover reduces the efficiency of the PV module, and this reduction in efficiency were found to be from 0.96% to 3.77% in the three experimental locations. Athar, H., Ankit, B. & Rupendra, P. [2017] investigated experimentally using different dust samples with different irradiation levels such as 650, 750 and 850 W/m^2. The results show that the power is reduced to a large extent during dust accumulation. Rani, S.P., Giridhar, M.S, & Prasad, S. R. [2018] analyzed theoretically the variance of radiance and temperature effects on solar cell performance. Ali, H. N., Zahraa, S. D., & Hashim, A. H. [2020] discussed the influence of clouds on the characteristics of a Mono-crystalline solar module during November, December and January (2018-2019) in Baghdad. Also, PV parameters were simulated by using MATLAB. The effects of various environmental factors on the performance of the PV system has been investigated by Mustafa, R., Gomaa, M., Al-Dhaifallah, M. & Rezk, M. [2020].

In this paper, the influence of internal and external parameters on PV cells was analyzed and investigated. The effect of a series of changes in resistance, shunt resistance, rising temperature and saturation currents was verified by simulations. The effects of clouds, dust, chalk powder, fly ash and bird dropping accumulation on PV panel performance was taken into consideration during the experimental work and were compared with a clean PV panel in the Erbil city environment.

2. The Single Diode Solar Cell Module

The most popular equivalent circuit used to presage energy output in PV cell modeling is the single diode circuit model that represents the electrical comportment of the p-n junction. The single diode PV cell equivalent circuit with five parameters is shown in Figure 1. The PV cell is characterized by its equivalent outline which consists of a source of electrical current which models the transmutation of the shining flow in electrical energy. The system performances was analysed in the computer by utilizing the Matlab simulation process. To consider physical phenomena at the caliber of the cell, the model is consummated by two resistances, series R_S and shunt R_{Sh} as the time exhibitor the equivalent electric circuit.

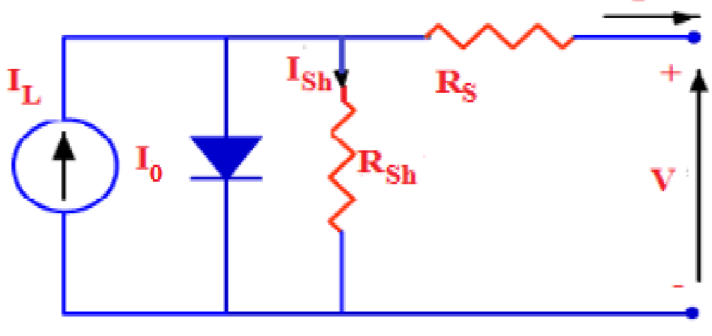

Figure 1. The schematic diagram of a single diode solar cell.

This sample can be represented by Equation 1 [Shukla, A., Khare, M., & Shukla, K N., 2015].

$$I_{Total} = I_L - I_o\left\{\exp\left[\frac{q(V+I\,R_S)}{\alpha\,ɑ\,T_{Cell}}\right] - 1\right\} - \frac{(V+I\,R_S)}{R_{Sh}} \quad (1)$$

Where I_L is the light engendered current, Io is the inversion saturation current of the diode, q is the electron charge, V is the voltage across the diode, ɑ is the Boltzmann's constant is 1.38×10^{-23} W/m²K, T_{Cell} is the cell temperature and α is the ideality factor of the diode.

3. Effect of Parameters on the Model and Discussions

3.1. The Solar Radiation Effect

Solar radiation fall on atmosphere from the orientation of the sun is the solar ethereal ray. We can modulate the Matlab model in two subsystems, the first one which calculates the photocurrent, robustly dependent upon cell temperature and solar irradiance, consequently Equation 2 can be simplified as follows [Shukla, A., Khare, M., & Shukla, K N., 2015].

$$I_L = [I_{S.C} + ϰ(T_{Cell} - T_{ref})]\frac{G}{1000} \quad (2)$$

Where $I_{S.C}$, is the short circuit, current, ϰ is the short circuit current coefficient usually 25C°and 1000 W/m², T_{ref} is the ambient temperature and G is the solar irradiation in W/m². Figure 2 shows the Matlab simulink for I-V characteristics of various sundry solar radiation at (200, 400, 600, 800 and 1000) W/m² with constant cell temperature at 25 C° and the number of cells is the 60 cells.

It is shown that when the solar radiation is varied, all the cell parameters transmuted such as the light engendered current is straightway proportional to the flux of photons, consequently $I_{S.C}$ is directly proportional to light intensity. It designates an increase in the irradiance leads to a diminutively minuscule incrimination in the open circuit voltage and a sizably voluminous increase in the short circuit current, consequently more power is engendered. The results are shown in Figure 3.

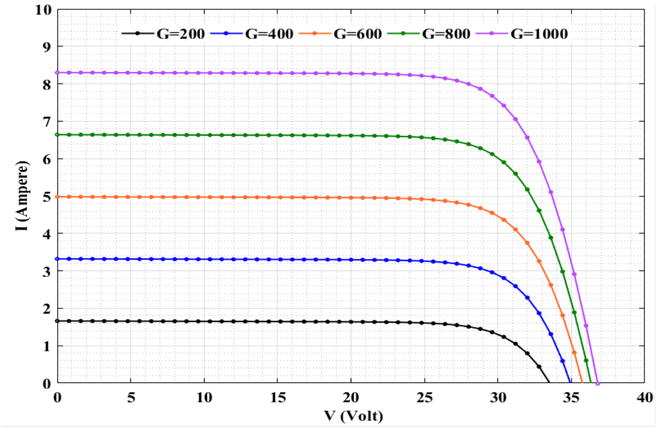

Figure 2. The I-V characteristics for different solar radiation.

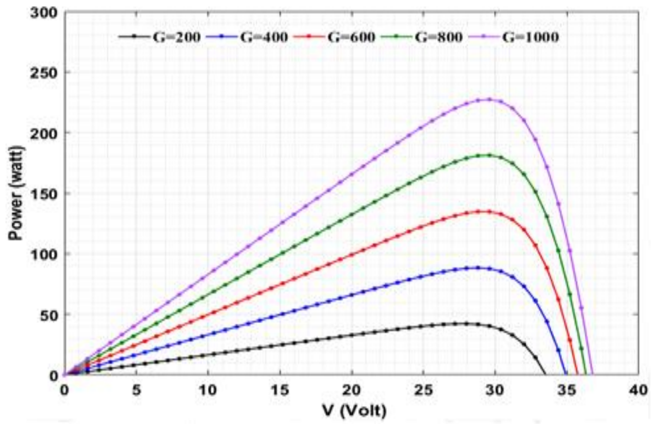

Figure 3. The P-V characteristics for different solar radiation.

3.2. The Solar Cell Temperature Effect

The cell temperature can be represented by Equation 3 [Kumar, M., Kumar, N., & Chandel, S.S., 2015]. When $T_{Nominal}$ is the nominal operating cell temperature.

$$T_{Cell} = T_{ref} + \left(\frac{T_{Nominal} - 20}{0.8}\right)G \quad (3)$$

Figure 4 and Figure 5 show the simulation results for 60 cells at different temperatures (0, 25, 36, 45, 50 and 75) C° under constant radiation 1000 W/m².

Figure 4 shows when the cell temperature is low the PV current decreases but PV voltage boosts when the cell temperature increases as shown in Figure 5.

3.3. The Series Resistance (Rs) Effect

The arrangement of the solar cell with single-diode and series resistance is shown in Figure 1. The major action of series resistance is to minify the fill factor (F.F), given in Equation 4 [Salmi, T., Bouzguenda, M., Gastli, A., & Masmoudi, A., 2012].

$$F.F = \frac{P_{Maximum}}{V_{O.c} * I_{S.c}} \quad (4)$$

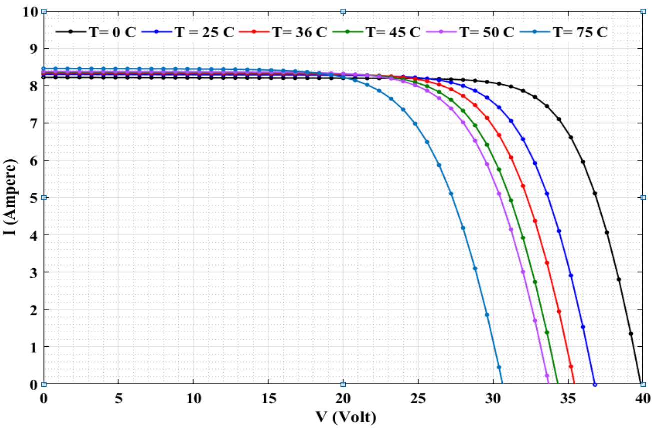

Figure 4. The I-V characteristics of the PV module with different temperatures.

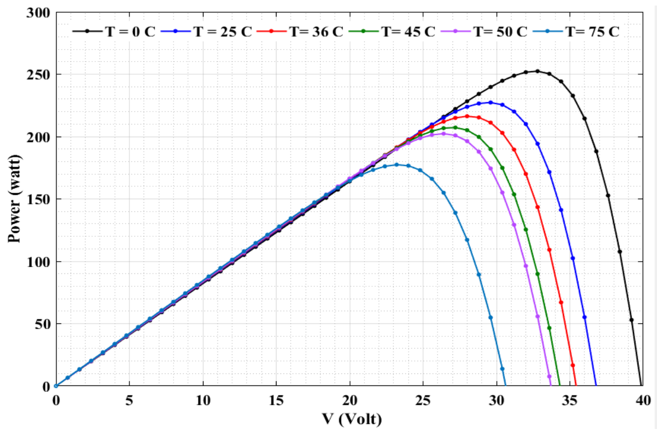

Figure 5. The P-V characteristics of the PV module with different temperatures.

Where $P_{Maximum}$ is the maximum power and $V_{O.C}$ is the open circuit voltage. The Matlab simulink for different series resistance which are displayed in Figure 6 and 7 under various value of R_s (0.1, 0.2, 0.3, and 0.35) **Ω** with constant temperature and irradiance are 25 C^o and 1000W/m^2 respectively for 60 cells. Hence the open circuit voltage not influenced by changing of series resistance value, but near the open circuit voltage region, the I-V curve is hardly influenced by R_s resistance, additionally raising the series resistance so the output power is minimized as exhibited in Figure 7.

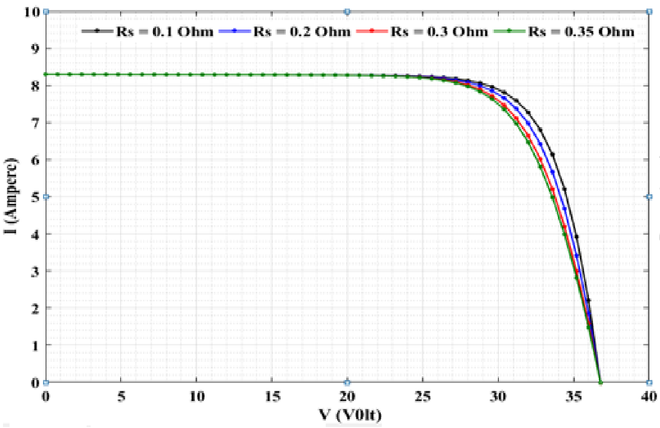

Figure 6. The I-V characteristics of the PV module with different series resistance.

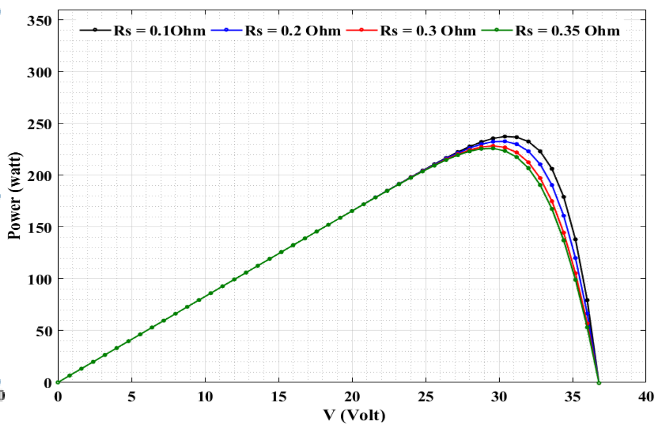

Figure 7. The P-V characteristics of the PV module with different series resistance.

3.4. The Shunt Resistance (Rsh) Effect

The presence of the resistance in the PV leads to power loss. When the value of shunt resistance is less than rated, the power losses are increased in solar cells by providing an alternate current path for the light-engendered current. These results can be seen in Figures 8 and 9, for 60 cells, under reference atmosphere condition with different value of shunt resistance at (50, 100, 500, and 1500) **Ω**. The results in both Figure 8 and 9, show that as the value of shunt resistance decreases it has less of an effect on the open circuit voltage region but the short circuit current region will reduce because of less light-engendered current. Thisalso has an impact on the output power as it is reduced.

3.5. The Diode Reverse Saturation Current Effect

The Simulink model equation for calculating the diode reverses saturation current at the reference temperature is given in Equation 5.

$$I_o = \frac{I_{S.c,k} + \kappa\, \Delta T}{\exp\left(\frac{V_{o.c,k} + \kappa_V \Delta T}{\alpha\, a}\right) - 1} \quad (5)$$

Where k is for nominal symbolic cases, κ_v is the voltage coefficient, $\Delta T = T_{ref} - T_{Cell}$. In a solar cell, the inversion saturation current because of diffusive flow of minority electrons from the p-side to the n- side and the minority holes from the n-side to p-side, firstly dependent on the cell temperature [Messenger, A.R., & Ventre, J., 2004; Francisco, M.,

& Longatt, G., 2005]. In these scenarios, the values of the reverse saturation current are ($8.7e^{-8}$, $3.5e^{-7}$, $2.14e^{-7}$ and $1.3e^{-7}$). At reference atmosphere state, the simulation results for 60 cells is displayed in Figure 10 and 11.

The merits of I-V and P-V are insignificant when the value of the inversion saturation current increased so the open circuit voltage decreased as in Figure 10 and the maximum power point distributed by the solar cell is reduced as shown in Figure 11.

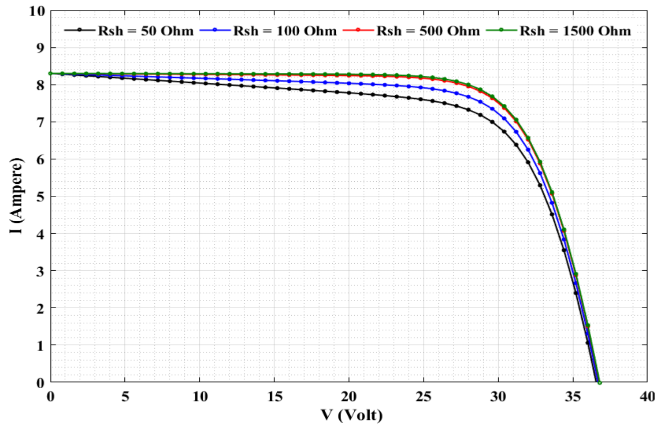

Figure 8. The I-V characteristics of the PV module with different shunt resistance.

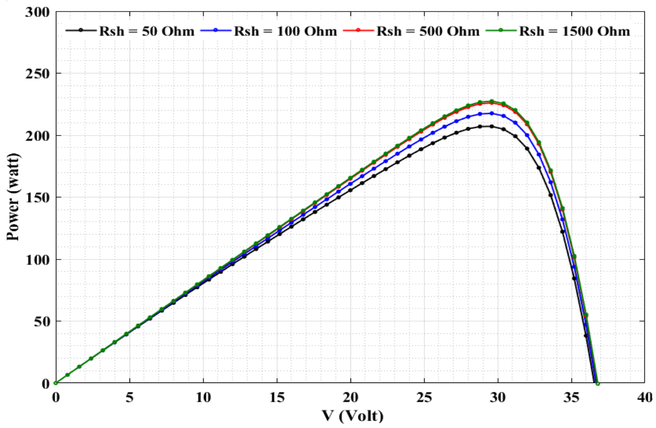

Figure 9. The P-V characteristics of the PV module with different shunt resistance.

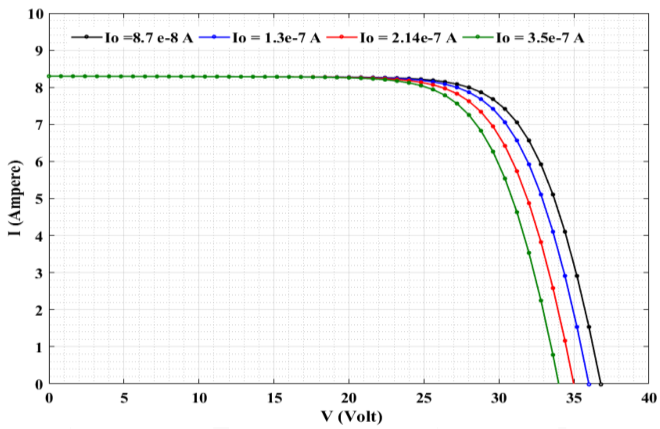

Figure 10. The effect of saturation current on I-V characteristics.

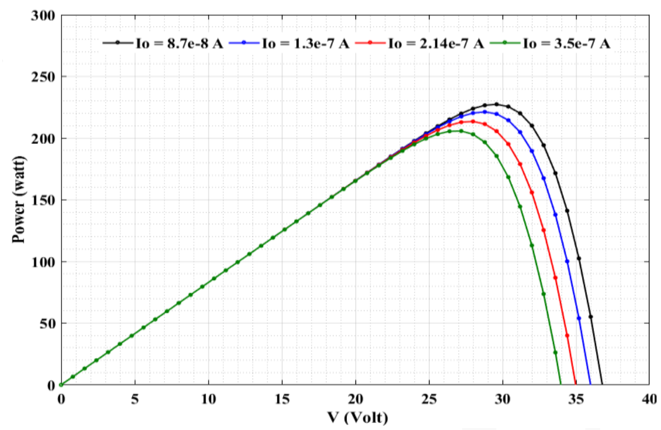

Figure 11. The effect of saturation current on P-V characteristics.

Expremental set up and results

4.1. I-V and P-V Behavior

The experiments were performed in outdoor conditions in Erbil city using Mono-crystal PV – panels with variable conditions including resistance, irradiance meter, temperature sensor and digital multi-meters. Figure 12 presents actual photos of the system under tests with the various environmental conditions.

The datasheet parameters of the PV panels used in the study are listed in Table 1. The IV characteristic was obtained by changing a variable resistor (as a load) and recording both voltage and current in regular steps. The experiment and simulation data results for solar radiation of 724 W/m2, are shown in Figure 13 and Figure 14.

Table 1. Manufacturer data sheet of Mono-type at reference conditions [MECREA Lab, College of Eng. Salahaddin University-Erbil].

Parameter	Value
Rated maximum power	225 W
Open circuit voltage	36.8 V
Rated voltage	29.5 V
Short circuit current	8.30 A
Rated current	7.64 A

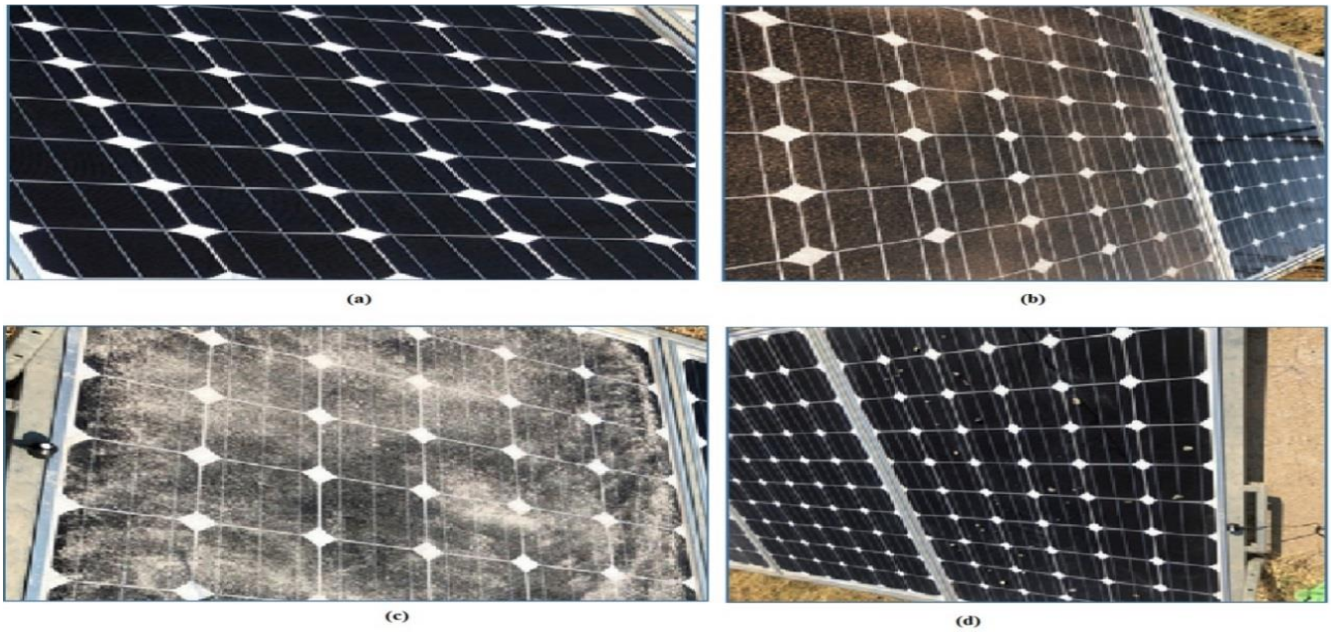

Figure 12. Actual photos for the present PV system with the different environmental states: (a) The reference case (clean PV Panel), (b) dust collection, (c) chalk powder, (d) bird droppings.

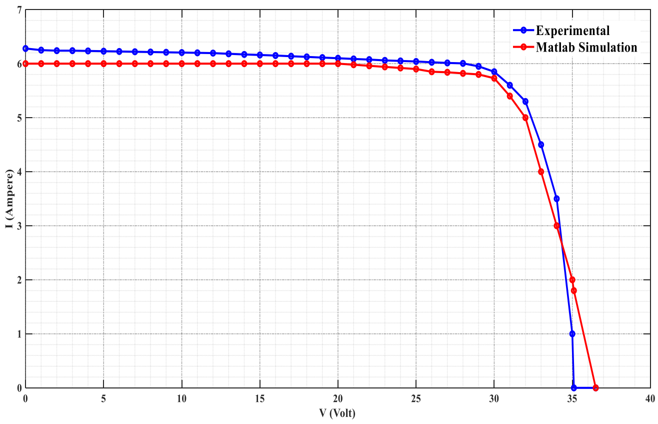

Figure 13. The I-V characteristics for both the practical experimental and Matlab simulations.

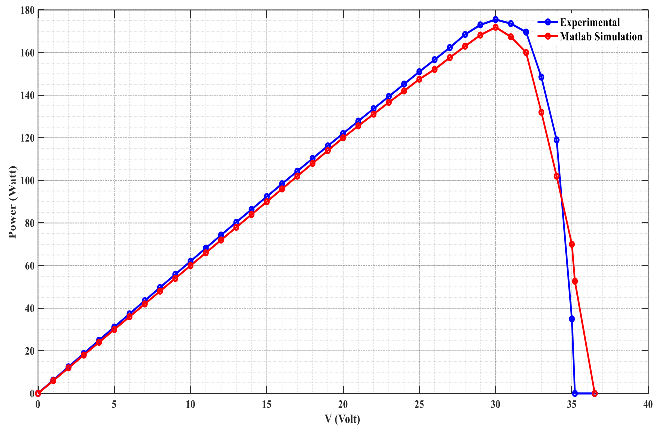

Figure 14. The P-V characteristics for both practical experimental and Matlab simulations.

4.2. Effect of Clouds on PV Panel Behavior

There are ten major kinds of clouds namely, cirrus, cirrocumulus, cirrostratus, altocumulus, altostratus, nimbostratus, stratocumulus, stratus, cumulus, and cumulonimbus, which are classified according to height as high, middle, and low clouds [Ahrens, 2009]. When clouds cover the sun, light levels are reduced, the impacts of clouds on a solar panels might then produce peaks at or above 50% more than its direct-sun output. The results of the experiment for the Altostratus cloud type are given in Table 2 with a solar radiation of 446 W/m^2. The results of the second case when the cloud type was stratocumulus with a solar radiation of (210) W/m^2 are shown in Figure 15.. The results of the third case where conditions were sunny weather and the solar irradiance was 781 W/m^2 are shown in Table 3. Table 4 shows the characteristics of solar panels, according to the tests comparing sunny conditions and cloudy conditions.

Table 2. Experimental results for Altostratus cloud type- Erbil City [MECREA Lab, College of Eng. Salahaddin University].

SOLAR PANEL DATA					
V(voltage)	I(Ampere)	P(watt)	V(voltage)	I(Ampere)	P(watt)
0	4.01	0	35	0.85	29.75
6	3.9	23.4	35	0.78	27.3

14	3.5	49	35.2	0.59	20.768
30	2.7	81	35.3	0.28	9.884
33.4	1.63	54.442	35.4	0.21	7.434
33.8	1.44	48.672	35.5	0.17	6.035
33.9	1.33	45.087	35.6	0.13	4.628
34.1	1.29	43.989	35.7	0.12	4.284
34.4	1.17	40.248	35.9	0.11	3.949
34.5	1	34.5	35.8	0.08	2.864
34.8	0.93	32.364	36.2	0	0

Table 3. Experimental results for solar panel exposed to sunny weather - Erbil city [MECREA Lab, College of Eng. Salahaddin University-Erbil].

SOLAR PANEL DATA					
V(voltage)	I(Ampere)	P(watt)	V(voltage)	I(Ampere)	P(watt)
0	6.7	0	30	4.5	135
5	6.5	32.5	31.5	3.45	108.7
10	6.4	64	32	2.9	92.8
15	6.25	93.75	32.5	2.4	78
20	6.05	121	33	1.5	49.5
25	5.9	147.5	33. 5	1.1	36.85
27	5.88	158.75	34	0.4	13.6
27.5	5.85	160.87	34.25	0.2	6.85
28	5.8	162.5	34.35	0.1	3.44
29	5.6	162.4	34.5	0	0
29	0.93	32.364			

Table 4. The comparison between sunny and cloudy cases.

Type cases	Irradiation (w/m²)	$I_{s.c}$ (A)	$V_{o.c}$(V)	I_{max} (A)	V_{max} (V)	Efficiency %
Sunny	781	6.77	34.8	5.77	28.1	13.84%
Cloudy type (Altostratus)	446	4.01	36.2	2.7	30	12.10%
Cloudy type (Stratocumulus)	210	1.5	32	0.83	27	7.11%

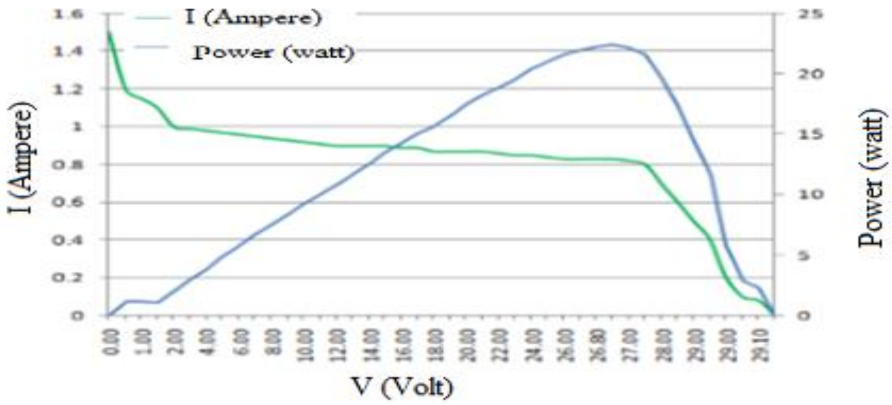

Figure 15. The I-V and P-V characteristics for solar panels exposed to cloudy weather - Erbil City.

4.3. Effect of Dust on PV Panel Behavior

The dust accumulation on the surface of the PV panel decreases the irradiance transmittance. The experiments were performed at outdoor conditions in Erbil city by using two Mono-crystal PV panels. The datasheet parameters of PV panels used in the study are listed in Table 1. The impact of dust can be investigated by comparison between a dirty panel and a clean panel. The study was carried out using different dust samples with different weights.

The outside panels were under outdoor weather conditions, and a collection of different types of dust were spilled manually on the PV surface with fraction rates of 20 grams of dust, 5 grams of chalk powder and fly ash. The influence of dust was found by comparing the output parameters of clean and dirty panels. The weight of dust was determined using a digital weight meter. The tilde angle of the solar panel was kept at 0^o during the study. The weather status was normal as most days were sunny without wind.

A comparative study of dust, chalk powder and fly ash patterns was carried out, and the results are listed in Tables 5, 6 and 7 for the different irradiation cases. Also, bird droppings may minimize the performance of solar panels due to reducing the transmittance of the glass cover on the PV panel. The tilde angles of the solar panels was kept at 0^o during the research. The weather conditions were normal as most days were sunny. The experiment data results for solar radiation under the effect of fly drops are given in Table 8.

Table 5. The Parameters of Difference of Dust Accumulation.

Dust Weight(g)		**G(w/m²)**	**$I_{s.c}$(A)**	**$V_{o.c}$(V)**	**$P_{Maximum}$(W)**	**Efficiency %**	**$\frac{I_{S.c(Dirty)}}{I_{S.c(Clean)}}$ %**
Panel-1	**20**	460	4.75	34.3	83.62	12.11%	98.54
Panel-2	**0**		4.82	34.4	85.2	12.34%	
Panel-1	**40**	506	4.57	34.2	87.52	11.53%	93.26
Panel-2	**0**		4.9	34.3	94.76	12.48%	
Panel-1	**60**	510	4.51	34.2	86.37	11.29%	90.2
Panel-2	**0**		5	34.3	96.04	12.55%	
Panel-1	**80**	502	4.22	34.1	80.58	10.70%	83.73
Panel-2	**0**		5.04	34.2	93.52	12.41%	
Panel-1	**100**	512	4.3	34.0	79.12	10.30%	80.37
Panel-2	**0**		5.35	34.2	97.85	12.74%	

Table 6. The Parameters of Difference of Chalk Powder Accumulation.

Chalk Powder (g)		**G(w/m²)**	**$I_{s.c}$(A)**	**$V_{o.c}$(V)**	**$P_{Maximum}$(W)**	**Efficiency %**	**$\frac{I_{S.c(Dirty)}}{I_{S.c(Clean)}}$ %**
Panel-1	**5**	520	5.22	34.0	99.15	12.71%	97.57
Panel-2	**0**		5.35	34.1	99.84	12.80%	
Panel-1	**10**	525	5.56	34.1	98.97	12.56%	97.37
Panel-2	**0**		5.71	34.2	101.50	12.89%	
Panel-1	**15**	529	5.83	34.1	97.69	12.31%	96.36
Panel-2	**0**		6.05	34.2	102.52	12.92%	
Panel-1	**20**	533	5.8	34.0	96.01	12.00%	93.24
Panel-2	**0**		6.22	34.2	103.50	12.94%	

Table 7. The Parameters of Difference of Fly Ashes Accumulation.

Fly Ash (g)		**G(w/m²)**	**$I_{s.c}$(A)**	**$V_{o.c}$(V)**	**$P_{Maximum}$(W)**	**Efficiency %**	**$\frac{I_{S.c(Dirty)}}{I_{S.c(Clean)}}$ %**
Panel-1	**5**	460	4.2	34.2	81.43	11.80%	87.5
Panel-2	**0**		4.8	34.3	85.07	12.33%	
Panel-1	**10**	453	3.77	34.1	73.27	10.84%	83.77
Panel-2	**0**		4.5	34.2	84.56	12.44%	
Panel-1	**15**	445	3.17	34.0	60.45	9.05%	79.29
Panel-2	**0**		4.0	34.2	79.70	11.94%	
Panel-1	**20**	448	3.09	34.0	58.5	8.70%	75.0
Panel-2	**0**		4.12	34.1	79.94	11.89%	

Table 8. The Parameters with and without bird droppings for solar PV panel.

Cases	G(w/m²)	$I_{s.c}$(A)	$V_{o.c}$(V)	$P_{Maximum}$(W)	Efficiency %	$\frac{I_{S.c(Dirty)}}{I_{S.c(Clean)}}$ %
Panel-1 with bird dropping	456	4.54	34.1	**81.4**	11.90%	98.48
Panel-2 without bird dropping		4.61	34.2	**84.2**	12.30%	

4. Conclusions

The following conclusions were obtained from the results of the study:

1. In this study, multi parameter models like (saturation current, temperature, irradiance, series and shunt resistance) influences on PV cell characteristics were investigated.
2. Temperature is a parameter that has major influence in the behavior of PV characteristics as it adjusts the system efficiency and output energy.
3. With the irradiance variation from (200 to 1000) W/m², cell parameters such asthe light engendered current is proportional to the flux of photon consequently $I_{S.C}$ increased leads to a small boost in open circuit voltage, as a result there is more power generated and vice versa.
4. Series and shunt resistance have a large effect on PV cell characteristics when the value of both resistance is chosen randomly the efficiency of the cell is reduced because the range of resistance depends on the area of cell.
5. Series resistance does not affect open circuit voltage, but near open circuit voltage, the I-V curve is robustly affected by Rs, and large values may lessen the short circuit current. In addition, power is minimized.
6. Solar panels are designed to work in sunny conditions, but they can still work in cloudy conditions when a type of cloud blocks the sunlight from hitting the solar panel directly much less power and efficiency is generated.
7. Simulation results validate the experiment results and are compared. The accuracy of analytical and experimental results show that this model is based in realty.
8. Cloudy weather conditions reduce the short circuit current, and upper output power as well as the efficiency of the PV panel.
9. Any accumulation of dust, fly ash and/or chalk powder have an influence of reducing output power and module efficiencies, as it reduces the short circuit currents.
10. Fly ash had a greater influence on module performance.
11. Bird droppings most likely created shade, which blocked the sun light from hitting the PV panel cell.

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