Theoretical and Experimental Analysis of Photovoltaic Module under Clouds Effects

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Highlights
- Output power losses of PV module during irradiance transitions were studied.
- The maximum output power loss of PV module was around 62.26%.
- Experimental results were compared with theoretical results.

Abstract
Photovoltaic (PV) module is one of the most useful, sustainable and non-harmful products in the field of renewable energy therefore, it increased rapidly. Photovoltaic performance affected inversely by Partial shading which occurs due to clouds, birds, buildings, trees and dust deposition etc. This paper investigates the performance of monocrystalline photovoltaic module under cloud effect theoretically and experimentally. The experiments are conducted in Baghdad during November, December and January in 2018 and 2019. PV parameters are simulated by using MATLAB to determine this effect. The measured and simulated data are compared to verify the effectiveness and robustness of the proposed approach. The results show that the cloud has a significant impact on the performance of photovoltaic module. The clouds decrease the amount of direct radiation reaching to the surface of PV module. Therefore, output power of PV module in cloudy days is less than the power output in sunny days. The power output in the sunny days was 69.7W, and by comparing this value with measured values in (November, December and January), it is found that the measured values are reduced by 15.5, 59.65 and 62.26% respectively.

Keywords: PV module, Cloud effect, solar radiation, efficiency.

1. Introduction
As the world is confronting the issue of global warming, energy deficit and deterioration of environment and energy sources, there is a requirement for an alternative energy resource for generation power instead of using fossil fuels. An exciting alternative to diminish these negative effects is an expansion of the renewable energy utilisations, energy from the sun is the best option for electricity generation amonge renewable energy[3] because of it is clean [4], available and inexhaustible [5]. Solar energy can be employed in various applications; such as, thermal field or electricity generation through solar Photovoltaic (PV) cells [6]. The great advantages such as freedom from environmental pollution, absence of moving or rotating parts and low maintenance cost represent the important reasons to increase attention about the Photovoltaic (PV) system over the last decade[7], [8]. A PV cell is basically a semiconductor diode with a large barrier layer when expose to light portion of the energy in the light photons arriving at the cell is convert directly to DC electrical power [9]. The electrical energy produced by PV panels can be affected by relative humidity high, angle of irradiance [10], temperature, excessive radiation, shading and dust [11].

In Iraq, the fluctuation of oil prices and their decline, air pollution due to emissions of greenhouse gases from diesel and gasoline, the difficulty of exploring the oil and gas sites on the one hand, and the aging of the electrical grid and lack of equipment lead to a small production of electrical energy. The severe shortage of energy forced the Iraqi citizen to rely on the private generators, which are drivers the diesel and gasoline. The emission results from excessive use of fossil fuels reflected on the Iraqi environment in addition to pollution from generators and motor vehicles [15-19]. Therefore, one of the rest solutions to reduce the risk of pollution of the environment is to find environmentally friendly sources. Solar energy represents the most important alternative source of energy in Iraq. This energy is free, has high power to be used by photovoltaic and in CPC station, available during the year [17], [18]. There are many application of solar cell such as generating electricity in remote area and it can operate communication towers in this region. In addition, it can be used for outdoor street lighting, reducing the load on electricity grid in cities by...
converting part of parking lights, health clinic energies to the use of PV modules [19]. P. Chrobak1 and et al (2016) [20]: Studied the impact of cloud on the electrical power produced by 9 photovoltaic panels for the months of October, November, December, and January in year 2015 and 2016, respectively. The results showed that the average amount of the electrical power were 3.601, 2.652, 1.006 and 1.370 kWh, while the average amount of solar radiation were 80.73, 52.14, 23.27 and 30.12 W/m² for the four months mentioned above. M. H. Ali1 and A. I. Gaya (2016) [21]: Studied the impact of cloud on the electrical power produced by 9 photovoltaic panels for the months of October, November, December, and January in year 2015 and 2016, respectively. The results showed that the average amount of the electrical power were 3.601, 2.652, 1.006 and 1.370 kWh, while the average amount of solar radiation were 80.73, 52.14, 23.27 and 30.12 W/m² for the four months mentioned above. M. H. Ali1 and A. I. Gaya (2016) [21]: Studied the impact of cloud on the performance of the PV panel at three different locations. The results showed that the reduction in the performance of the PV panel was 0.96% at central Mosque, 1.68% at Nana Hall and 3.77% at PG Common Room. A. Bonkaney and et al (2017) [22]: Studied the effect of dust and cloud on the performance of PV module in Niamy for the months from May to August (2015). The cloud prevents the direct component of solar radiation reaching the module’s surface resulting in minimum output power. Therefore, the power producing in cloudy day is lower comparing to sunny days. Kari Lappalainen and Seppo Valkealhti [23]: Studied the mismatch losses of PV arrays with various layouts and electrical configurations during around 27,000 irradiance transitions identified in measured irradiance data. The overall effect of the mismatch losses caused by moving clouds on the energy production of PV plants was also studied. The study was conducted using a mathematical model of irradiance transitions and an experimentally verified MATLAB/ Simulink model of a PV module. The relative mismatch losses during the identified irradiance transitions ranged from 1.4% to 4.0% depending on the electrical configuration and layout of the PV array. The overall effect of the mismatch losses caused by moving clouds on the total electricity production of PV arrays was about 0.5% for the PV array with strings of 28 PV modules and substantially smaller for arrays with shorter strings.

This paper presents an experimental study that evaluates the effects of clouds on the performance of monocrystalline solar module during November, December and January (2018-2019) in Baghdad. Moreover, Matlab/Simulink is used for investigating this effect and compared theoretical results with the experimental results.

2. Modeling of photovoltaic module

PV module is the basic unit of power PV generation system. PV module has non-linear characteristics which depend on solar radiation and cell temperature. In this investigation, PV module with 36 series connected solar cell is chosen. Fig. (2). Shows the photovoltaic module model. The environmental data; such as, irradiance (G) and temperature (T) in addition to the electrical characteristics parameter of PV module such as, open circuit voltage (Voc), short circuit current (Isc), etc. It is having 23.42V, 5.192A and 1.5 as open circuit voltage (Voc), short circuit current and ideality factor respectively, while series resistance value (Rs) is 0 ohm. Different cases are carried out using Matlab/ Simulink to determine I-V and P-V characteristics. To develop the model of PV module, Solar cell block from SimElectronics block set is employed. The parameter of solar cell is defined in (1) and (2) [24].

\[
I = I_{ph} - I_{rs} \left[ \exp \left( \frac{V + IR_s}{A V_T} \right) - 1 \right] \tag{1}
\]

Where:

\[
V_T = \frac{N_s k T_e}{q} \tag{2}
\]

\[I, I_{ph} \text{ and } I_{rs} \text{ are the output, photo-generated and the diode saturation currents respectively, } V \text{ is the output voltage, } R_s \text{ is the series resistance, } N_s \text{ is the number of cells, } V_T \text{ is the junction thermal voltage, } A \text{ is the ideality factor, } k \text{ is the Boltzman constant (1.3806503 \times 10^{-23} J/K), } T \text{ is the cell temperature and } q \text{ is the electron charge (1.6021765 \times 10^{-19} C). Figure 1. Shows photovoltaic module model with three bypass diodes configuration which used to investigate the cloud effect on the PV module.}

The same module of PV module employed to study different cases of random irradiance level as illustrated in Table (2). It can be notice that the module divided to three groups connected with three bypass diodes, each group consist of 12 cells and resaved random irradiation levels.

Table (1). The level of radiation on PV module.
3. Experimental set up

In order to obtain the I-V and P-V characteristics of PV panel under clouds effect, this requires current and voltage measurement. Solar radiation and ambient temperature affected on these characteristics therefore, it is necessary to measure these parameters. At environmental conditions, the change in atmospheric condition may lead to rapid change in the solar radiation therefore; the data must be recorded quickly in short time as possible.

The experimental set up as shown in figure 2. It was installed in Baghdad city (33.33° N latitude and 44.39° E longitude) for collecting the required data and consisted of Monocrystalline PV panel with 36 cell connected in series, each 12 cell connected to one bypass diode. The panel placed on a mobile metallic holder and installed to face the south with an inclination of 31.2°.

Table 1 explain the electrical characteristics of the PV panel under standard test condition. The required data are radiation intensity, ambient and module

| Case study | Solar Cell Irradiance (W/m²) | Unshaded group A (12 cells) | Shaded group B (12 cells) | Shaded group C (12 cells) |
|------------|-----------------------------|-----------------------------|---------------------------|---------------------------|
| Case 1     | 1000                        | 1000                        | 1000                      |                           |
| Case 2     | 1000                        | 900                         | 800                       |                           |
| Case 3     | 1000                        | 800                         | 600                       |                           |
| Case 4     | 700                         | 600                         | 200                       |                           |
| Case 5     | 800                         | 950                         | 300                       |                           |
| Case 6     | 300                         | 500                         | 700                       |                           |
| Case 7     | 300                         | 200                         | 400                       |                           |
| Case 8     | 200                         | 200                         | 200                       |                           |

Fig. 1. Photovoltaic module model (36 cells with three bypass diodes)
temperatures, wind speed and relative humidity therefore, two digital multi-meter to measure current and voltage. Thermocouple type k was used to obtain the panels temperature using a digital data recorder. Relative humidity and ambient temperatures were measured by using UNI-T UT332 digital Thermohygrometer devise. The measurement of wind speed has been obtained using wind gage type Kaindl Windmaster 2.

Solar radiation was measured by solar meter pyranometer type TES 1333R and rheostat (100W, 10Ω) used as load to measure the maximum current and maximum voltage. Experimental has been carried in November, December and January (2018-2019).

| Table 2. Electrical Characteristic of Monocrystalline solar panel |
|---------------------------------------------------------------|
| Maximum power (P max)                                        | 88 W |
| Open circuit voltage (VOC)                                   | 23.42 V |
| Short circuit current (ISC)                                  | 5.192 A |
| Voltage at maximum power (Vmp)                              | 18.33 V |
| Current at maximum power (Imp)                               | 4.801 A |
| Voltage temperature coefficient (Kv)                        | -2.10 mV/cell/℃ |
| Current temperature coefficient (Ki)                         | 15 micro A/cm2/℃ |
| No. of cells connected in series (NS)                        | 36 |

4. Results and discussion

4.1 Theoretical results

When the irradiance on the module was non uniform irradiance as illustrated in Table (1), multi steps in the I-V characteristics and multiple peaks in the P-V characteristics curves are observed. Figure (3) shows the simulation results of the cases study in Table (3). The same figure appeared that the short circuit current negatively affected with decreasing the irradiance levels which lead to decreasing the maximum current and consequently, the maximum power decreasing. While the open circuit voltage less affected in compared with short circuit current under these conditions. The maximum power values for these cases were 88, 76, 56.9, 33, 44.3, 29, 16.1 and 15W for first, second, third, fourth, fifth, sixth, seventh, eighth case respectively.
4.2 Experimental results
Corresponding to the conditions at which the experiments were conducted, the I-V and P-V curves of 36 cell (3 group each one with 12 cells) under environmental condition with variable cell temperature and irradiance are analyzed. However, in Iraq, the clouds are abundant in the autumn and winter seasons (usually in October, November, December, January and February). The clouds are of little thickness at the beginning of autumn while, they are thicker in the cloudy winter days, especially in the months of December and January. Fig. 4. Shows the I-V and P-V curves of monocrystalline solar module on separate plot during different days of years (2018-2019). From the figure, it can be notice that the current is affected by cloud significantly. It drop from 4.39A at 2nd June to 3.83, 1.93 and 1.82A in 2nd November, December and January respectively. From the other hand, it can be noticed that power at 2nd June was 69.7W; while, the power at
2nd November, December and January were 58.9, 28.26 and 25.74 respectively. This means that the power is decreasing by 15.5, 59.65 and 62.26% respectively. So, the amount of energy produced by photovoltaic solar module negatively affected with thickness of the cloud layer.

It is worth noting that the clouds are randomly appeared during the day. For the purpose of studying their effect, the characteristics of the solar module were carried out on different months, days and times as shown in figs 5, 6 and 7. It can be noticed that the short circuit current decreases in cloudy day which cause reduction in the output power and consequently decrease the performance of the PV module.

Fig. 4. Recorded characteristics of PV panel I-V and P-V through different months

Fig5. I-V and P-V curves of PV module in the 2nd of November
The above figures show that the currents value in November is higher than its value in December and January. The corresponding power also decreases in month of December and January due to increases thickness of clouds.

Table 3. Values obtained from experiment for the three different days.

| Time    | 2nd November | 2nd December | 2nd January |
|---------|--------------|--------------|-------------|
|         | P (W)        | G (W/m²)     | η (%)       | P (W) | G (W/m²) | η (%) |
| 8:30 AM | 9.64         | 133          | 10.81       | 2.84  | 135      | 3.14  |
| 10:30 AM| 46.57        | 620          | 11.21       | 5.12  | 150      | 5.1   |
| 12:30 AM| 58.9         | 765          | 11.5        | 28.26 | 410      | 10.28 |
Figs. 8, 9 and 10. Shows both the simulated (red lines) and measured (blue lines) IV curves are plotted in the same figure for each experimental day at 12:30 am. The corresponding power also plotted in the separate figures. In general, the graphs appeared good agreement between the simulated and measured results.

Fig. 8. Electrical Characteristics obtained from simulation and experimental study on the day of 2nd November 2018 at 12:30, solar radiation= 765W/m².

Fig. 9. Electrical Characteristics obtained from simulation and experimental study on the day of 2nd December 2018 at 12:30, Solar radiation = 410W/m².
Fig.10. Electrical Characteristics obtained from simulation and experimental study on the day of 2nd January 2019 at 12:30, Solar radiation= 368W/m².

Conclusion
The electrical characteristics of monocrystalline solar module are evaluated under different cloudy days in Baghdad, Iraq. The I-V and corresponding P-V curves are plotted in separate figures for different days and times of years 2018 and 2019. At 12:30, the power output dropped by 15.5, 59.65 and 62.26% for 2nd November, December and January in comparing with its value at 2nd June. Besides, the simulations of parameters of the PV module are conducted using MATLAB to determine this impact, random irradiance levels have been applied. Furthermore the results reveal that there is a considerable agreement between the experimental and simulated results. The results show that the reduction in irradiance reaching to the surface of solar module under cloudy days leads to decrease the output power and efficiency significantly.

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