EXPERIMENTAL AND NUMERICAL STUDY OF THE EFFECT OF DUST ACCUMULATION ON PHOTOVOLTAIC PANELS

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ABSTRACT

In this study, experimental and numerical investigation of the performance of the conventional photovoltaic panel, concentrated photovoltaic (CPV) system and water-cooled CPV system were performed, where the practical study was implemented at Al-Kitab University on the effect of the climate (dust and high temperatures) on the output of the solar cell (efficiency - maximum energy and output). In the practical aspect, solar panels with similar specifications were used, one of the panels is clean and the other is dirty with dust, the same used dust that was collected from the roof of the building that was brought by storms. Four cases of dust weights were studied (later using dust layers and dealing with thickness) during the period from 9:00 am until 5:00 pm during July and August. The results showed that the temperature of the cell increased in direct proportion to the thickness of the deposited dust layer, which caused the cell power and output current to decrease compared with the clean cell. The energy was reduced by 60% when the dust layer was at the level (dust 4) and the output current lost about 0.6 amperes under the same conditions. The cell occupancy was simulated using practical data and synthesized in a MATLAB/Simulink environment. The agreement of the experimental results with the simulation results demonstrated the deterioration of the performance of the solar cell at different levels of cell temperatures due to dust deposited on it.

Keywords: PV system, accumulation of dust, power, efficiency, Pulsed-spray.

1. INTRODUCTION

Energy production in the world is increasing dramatically as a result of increasing energy consumption by humans. Most of the electricity produced is generated in thermal power plants. These stations cause environmental damage in addition to emissions into the atmosphere and consumption of natural resources. The increase in demand for energy resources causes an increase in their prices. Leaders from throughout the world recognized this serious issue and urged turning to alternative technologies to acquire reliable and secure energy. The usage of renewable energy was one choice [1].

However, photovoltaic solar systems were the most widely used solutions, assuring energy production with minimal environmental impact [2]. Over the past few decades, the production of photovoltaic solar modules has started. Baker (1839) discovered the photoelectric effect near the end of the nineteenth century, and Alexander Shulitov made the first photovoltaic cell based on an external photoelectric effect. In American facilities in New Jersey and Bell, crystalline silicon's photoelectric characteristics were found in 1941. In 1954, crystalline silicon was used to create the photovoltaic cell, which had a 6% efficiency [3]. Globally, the production and consumption of solar energy have grown quickly, and nations like Japan, the United States, Germany, China, and Italy have emerged as global leaders. According to [4] between 2012 and 2017, the average yearly capacity growth for solar photovoltaic facilities was over 60%. More than 100 Giga watts of solar energy capacity existed globally in 2012.

There are several parameters, which impact on PVT collector performance, for sample, the intenseness of solar radiation, solar cell panel angle and increase the surface temperature of the cell. The last factor, the surface temperature of the cell, focuses on the fundamental issue causing the solar cell efficiency to decline. The lifetime and overall effectiveness of PVT are both increased by chilling the cell surface. [5]. There are two types of cooling methods for PVT cells: passive cooling and active cooling. PCM (phase change material, such as paraffin wax) and natural water/air cooling are both components of passive cooling. Forced water/air cooling, nanofluid cooling, and refrigerant cooling are all types of active cooling. Most commonly used cooling techniques for PV panels, water and air are used as the working fluids. Air cooling requires less energy as related with water cooling, while, cooling power of water is more than the cooling power of air. [6] Centered on the solar panel's direct-contact fluid film cooling technique. Using this method, they kept the average solar panel temperature below 80°C. [7] Used the water as the coolant in the PV panel. They placed the water channels behind a PV panel. As a result, in the present study, a pulsed-spray water cooling system is built and tested to lower the PV panel's cooling requirements and use less water in the cooling process. Two cooling systems have their electrical efficiency, I-V characteristic curves, cell temperatures, and water consumption during the cooling process measured. The results of the PV panel with the pulsed-flow spray cooling system are related with the steady-spray water cooling system and the uncooled PV panel. Finally, to ascertain the financial advantages of using the new cooling systems for the photovoltaic panels, a cost study is set up.

Despite all these benefits, Limited efficiency is a PV system's principal flaw, which ranges between 12% and 20% [8] .Overall exergy efficiency and total thermal efficiency can be increased by using optimization process [9] . The primary variables that have a significant impact on how much energy the solar PV system produces are temperature and solar radiation. Environmental factors include ambient temperature, solar radiation, wind speed, kind of installation configuration, and type of PV technology affect how hot a PV module or solar cell will get. [10].

2. FACTORS AFFECT THE DUST DEPOSITION

The majority of solar cell system research publications concentrated on system design, operation tactics, and the provision of solar radiation [11, 12], The impact of dust, its elements, and its quantity on solar system performance were not given much consideration. Since solar plants are affected by various environmental and atmospheric conditions, which include dust, bird droppings, and air pollutants from industrial establishments, dust is a complex phenomenon.

2.1. Environmental conditions

In this paper, the effect of ambient temperature (cell temperature) and dust accumulation on solar cells was highlighted, and the pilot study was conducted at Al-Kitab University, north of Kirkuk governorate. The latitude and longitude of the site (35.28°- 25.44°, altitude 331 meters above sea level). The biggest barriers to solar energy expenditures are overheating and the impacts of dust, as clouds and shading from fog and smoke rising from homes and factories reduce the intensity of sunlight and the energy of the solar energy system, respectively. [11,12].

2.2. Geographical location and climatic conditions

Due to its location in the global solar belt, Iraq has excellent potential for solar energy throughout the year [14], According to estimates, solar panels across Iraq's western and southern deserts can provide energy equivalent to 30 million tons of oil per year, which might provide a solution to the country's energy shortfall. Figure 1 shows the typical direct natural radiation for the location where the tests described in this research were conducted [14, 15].

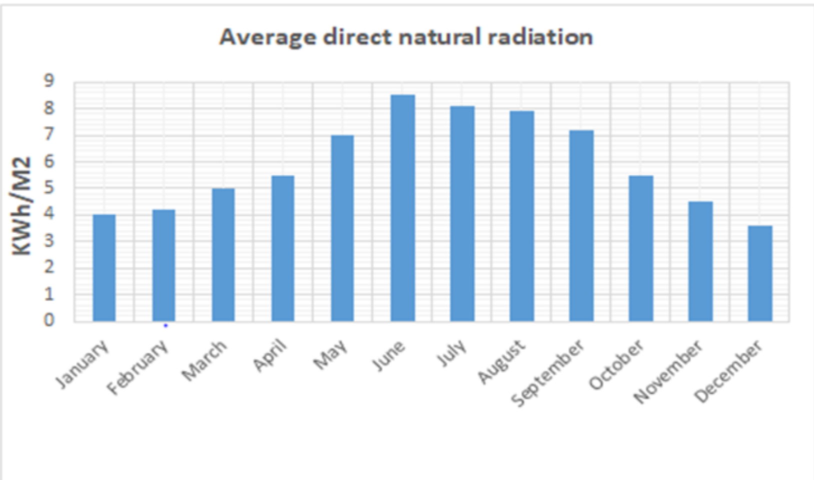

Figure 1. The typical monthly direct natural radiation in Kirkuk Governorate, Iraq, throughout the year.

3. METHODOLOGY

Because the characteristics of solar cells depend mainly on the absorbed thermal energy, which is controlled by several factors: The nominal intensity of solar radiation (W/m^2), Solar panel emission factor, and solar area (m^2). In addition to the technical characteristics of short circuit current (Isc) and open circuit voltage (Voc).

The research method included: the practical side, several solar panels with similar specifications were used. One is clean and the other is dirty, that is, its surface is covered with dust (the characteristics of cells are known). Four fish from the dust were used for each daily experiment. Data registration starts from nine in the morning until five in the afternoon. To measure the temperature of the solar panel, 3 sensors were installed on the surface of the panel. Data are recorded every hour of the experiment.

Recording data: light intensity, the temperature of the panels, ie each panel separately, current and voltage for each panel. All these data were recorded for the four cases of dust thickness. Through practical data, relationships were formed through diagrams that describe the performance of the cell for each case. The other side of the research included the adoption of common mathematical equations to describe the work of the cell and its synthesis to the Simulink program to form subsystems that facilitates the control of the inputs of each subsystem. Parameters used when simulating subsystems were either fixed (manufacturer specifications) or variable depending on the work environment. Simulation results were compared with practical results to verify the stability of the results on the one hand and the extent of deviation of the outputs from STC.

4. THEORETICAL DESCRIPTION AND MATHEMATICAL MODELING

In this section, electrical modeling is achieved by using MATLAB/Simulink software to calculate the output characteristics of the PV module at various environmental factors. The single diode model and the two diode model are the two major types of PV cell modeling. The single diode is simple and accurate therefore, it is used in this study. Using the equations for the PV module and the reference's data sheet, Simulink modeling is created. (monocrystalline PV module) under standard test conditions (25 ◦C and 1000 W/m^2). The block diagrams for the following PV model equations are then combined to create the PV panel's Simulink model.

Photocurrent Equation

$$I_{sat=}\frac{G}{Gn}[I_{1+}K_i(T-T_n)] \quad (1)$$

where Isat is the photo current, G is Irradiance, Gn is Nominal Irradiance, I_l is the short circuit current, Ki is the coefficient of the current temperature, T is the absolute temperature in Kelvin and Tn is the reference temperature (298 K).

Diode Current Equation

$$I_d = I_o \left(\frac{Tn}{T}\right)^3 exp\left(\frac{q*Ego}{B*K}\left\{\frac{1}{Tn} - \frac{1}{T}\right\}\right) \quad (2)$$

where Id is the saturation current and Ego is the material band gap energy.

Reverse Current Equation

$$I_o = \frac{I_{sc}}{exp\left(\frac{V_{oc}}{a+V_t}\right)^{-1}} \quad (3)$$

Where Io is the reverse saturation current, Voc is the open circuit voltage, Vt thermal voltage, and α is the ideality factor .

Load Current Equation

$$I_{ph} = I_{sta} - I_d - I_{sh} \quad (4)$$

Where Iph is the output current of the PV panel

Thermal Voltage Equation

$$V_t = \frac{(T*K*N_S)}{q} \quad (5)$$

Where Vt thermal voltage, Ns is the number of cells in series, K is the Boltzman constant, and q is the electronic charge. Eq. (1-5) represent the mathematical behavior of the cell. The modeling of equations in the environment of (MATLAB-Simulink) depends on the theoretical analysis of the physical processes that occur during the operation of the cell. Mathematical models that define the system's attributes have been created and converted into subsystem components as a result of the theoretical study for use in the simulation process.[16].

5. EXPERIMENTAL SETUP

In a series of experiments carried out over the summer, a layer of dust was applied to one of the plates, also used as a control plate was the other clean plate. The experiment lasted for six hours a day, according to the following steps: -

1- Solar panel specifications are in Table 1, shown in Figure 2.

Figure 2. Structure of the experimental setup

2- The panels are set up on the roof of the 23-meter-high Al-Kitab University building.
3- The clean panel serves as a true control element for comparison with the other plate, which depicts the many scenarios in which dust could accumulate on its surface.
4- The experiment was carried out at one-hour intervals between nine in the morning and five in the afternoon.
5- The panels are installed on a stand at an angle of inclination of (30 °C).
6- The temperature of the solar panels was measured through thermal sensors (type K), The sensors were distributed on the surface of the solar cell (3 sensors). As for measuring the intensity of solar radiation (G), a device (G) was used type device (SM 206.2),
7- Measurements were taken on a daily and weekly basis. Using four weights of sedimentary dust.
8- Additionally, the sort of dust that is deposited on the surface of the solar panels is the same as that deposited on the building's roof since the solar panels are exposed to atmospheric conditions, the environment, and the open atmosphere (the site where the experiments were conducted).

Dust was collected from the roof of the building because the roof of the building is affected by the same conditions as solar panels. The surface areas of the building were determined equal to the area of the plate. The deposits accumulated on the roof of the building were divided into four time periods, that is, an accumulation period of 2-4-6-8 months, after taking the accumulation rates for each of them over a while, the dust was weighed and its density was calculated.

Dust weights were transformed into layers of different thicknesses. Table 1 shows the thickness of the dust layers used in the study. Dust handling was limited on a quantity basis without delving into the physical and chemical components. Practical readings during the daily experiment period: the (first) reading, measuring the temperatures of the panels, the (second) reading, measuring the output voltage, and the (third) measuring the output current.

Table 1. thickness of the dust layers.

dust	Thickness dust
dust 1	**$7.7e^{-2}$ mm**
dust 2	**$1.1e^{-2}$ mm**
dust 3	**$15e^{-2}$ mm**
dust 4	**$18.79e^{-2}$ mm**

6. RESULTS AND DISCUSSIONS

6.1 Numerical Analysis

In this subsection, electrical modeling is used to numerically analyze electrical performance. in Equation 1. Simulated I-V and P-V characteristics of a module are shown in Figure 3. and Figure 4. The simulation is run at 1000 W/m^2 (STC), 800 W/m^2, 600 W/m^2, 400 W/m^2, and 900 W/m^2 irradiation intensities. Results from the simulation downward standard test conditions are given at a temperature of 298 K and 1000 W/m^2, which precisely match the manufacturer's specifications. The module's effectiveness is one of the performance measures included in these simulated test results. It is found that maximum output power is significantly influenced by irradiation. The open circuit voltage does, however, only slightly rise as the irradiation changes.

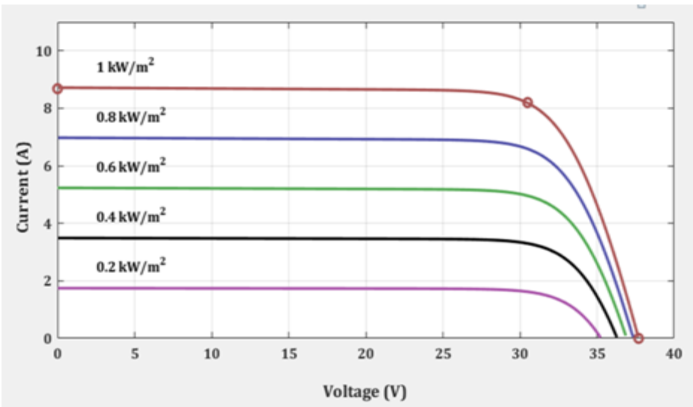

Figure 3. I-V characteristics for different solar irradiation conditions.

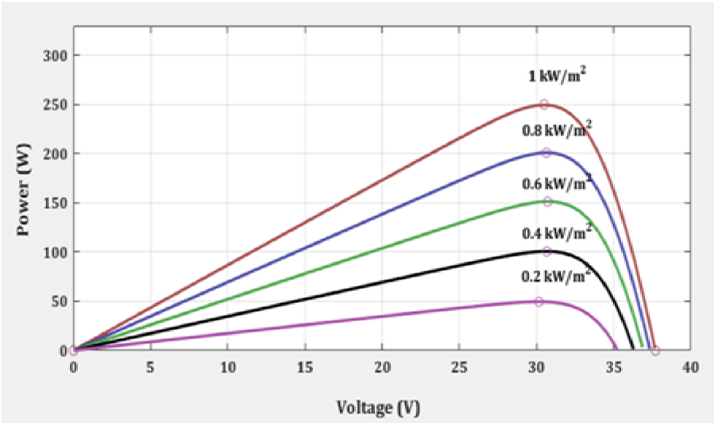

Figure 4. Numerical power output of the four cases.

6.2 Experimental Analysis

The experimental results are presented and analyzed in this article the test is conducted on a sunny day of 9th August of this year. The readings are recorded between 9:00 am and 5:00 pm. The lower value of the solar radiation was 421 W/m² and the maximum value was 977 W/m² during the day of the experiment, while the ambient temperature was in the range of 41–55.1 ◦C.). According to the findings, water cooling directly impacts the panel's temperature, as presented in Figure 5. The water-cooled CPV system's average panel temperature was 34.3 ◦C, compared to 64.1 ◦C for the CPV system and 57.5 ◦C for the standard PV panel. The average drop in the panel temperature of the CPV system was 29.8 ◦C by using the water-cooling system.

The electrical efficiency of the four different dust weights during the experimental day is shown in Figure 6. The practical tests showed a decrease in the maximum energy values compared to the clean plate (169.36 W/m² for the clean plate, while it was 56.47

W/m² for the dust 4). The output current was also affected the readings for the clean plate were 7.3 amperes, while for the dirty plate it was 6.5 amperes. As for the efficiency of the cell, which is an important parameter that reflects an evaluation of the product design and a criterion for the economic feasibility of the solar system, it recorded a significant decrease for the dirty panel, as the efficiency reached 37% when the efficiency of the clean panel was close to 100%.

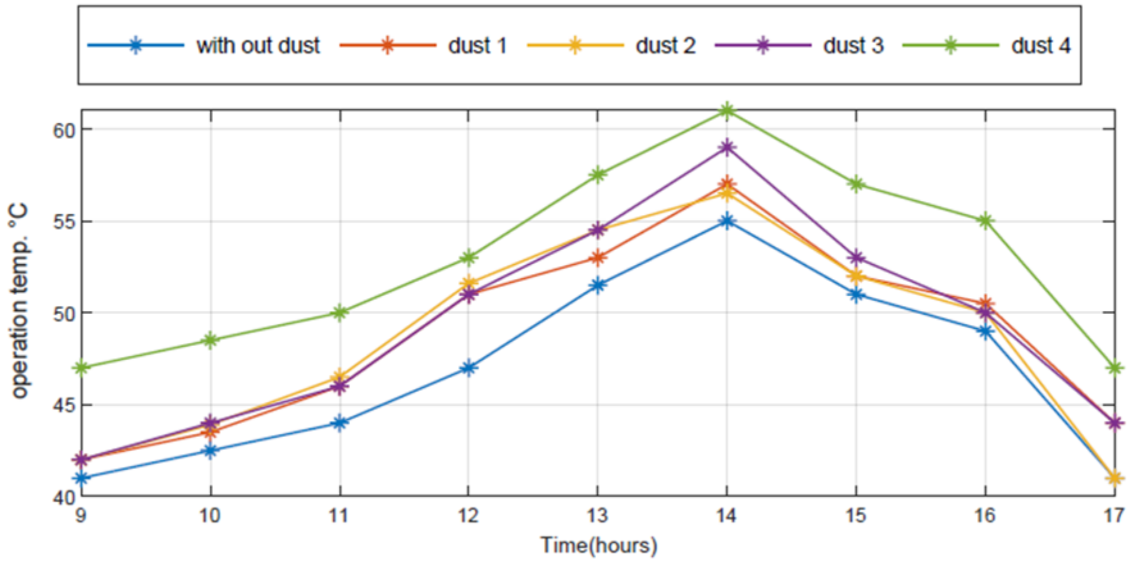

Figure 5. Temperature characteristics with varying dust.

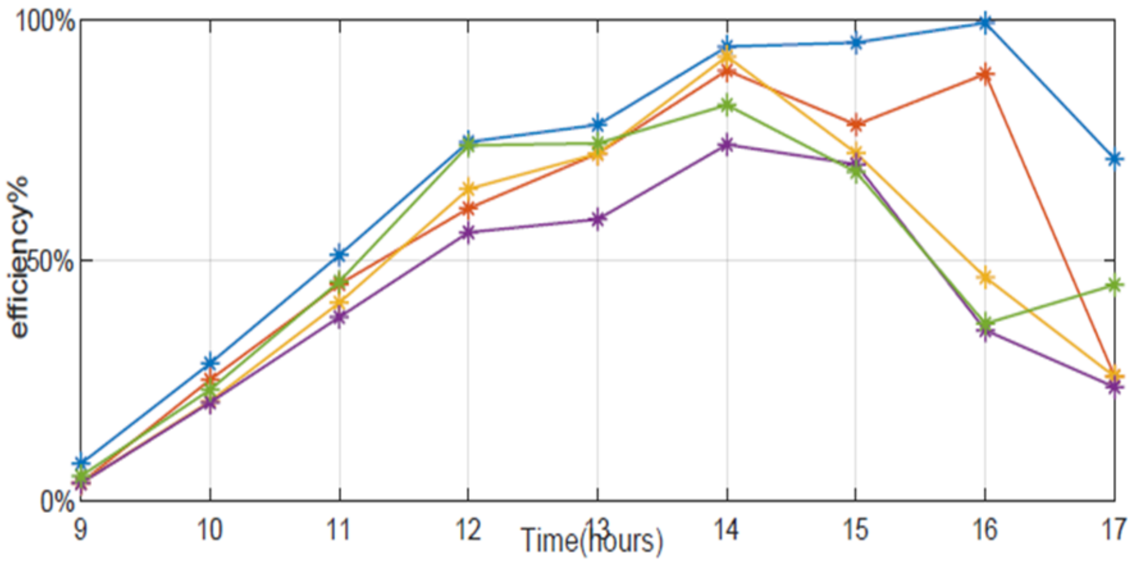

Figure 6. Efficiency characteristics with varying dust.

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4. CONCLUSIONS

In this paper numerical and experimental investigations have been studied were used to determine the performance of the photovoltaic panel by using a water cooling and cleaning system by nozzle, under the climatic conditions of the city of Kirkuk/ Iraq. Due to Iraq's extensive solar energy resources, the severe lack of power produced, the influence of the economy on energy imports, and the need to discover alternatives that reduce the pollutants produced by both large and small industrial units (civil), the environment must be kept clean. All these factors were encouraging for the use of solar energy and harnessing it for domestic uses in Kirkuk Governorate (it is located in northern Iraq and at 45 longitudes and 32 latitudes, the maximum temperature is (49.2) ◦C in July and the minimum temperature is (4.5) ◦C in January).

This work describes the behavior of solar cells using practical data and modeling them through the use of MATLAB/Simulink. The simulation was designed based on constructing a fixed number of control variables. The practical part of the paper the results of the analysis were related to the effect of different sediments on the cell surface on the output. The practical results showed the sensitivity of the outputs of the solar cell to changes in temperature due to sedimentation when used to determine the basic parameters (cell current - output voltage - maximum power - efficiency) under local conditions and in the way of comparison between the solar panels used for the experiment. The simulation showed that the results matched the practical results to determine the outputs. It should be noted that the deposits cause the heating of the solar cell, which leads to a decrease in performance.

REFERENCES

[1] KARMOUCH, Rachid, et al. Solar cells performance reduction under the effect of dust in Jazan Region. J. Fundam. Renew. Energy Appl, 2017, 7.2: 1-4

[2] RAJPUT, Dayal Singh; SUDHAKAR, K. Effect of dust on the performance of solar PV panel. International Journal of ChemTech Research, 2013, 5.2: 1083-1086

[3] CHAPIN, Daryl M.; FULLER, Calvin S.; PEARSON, Gerald L. A new silicon p-n junction photocell for converting solar radiation into electrical power. Journal of applied physics, 1954, 25.5: 676-677.

[4] KOZYUKOV, Dmitry Alexandrovich; Tsygankov, Boris Konstantinovich. Modeling the characteristics of photovoltaic modules in Matlab/Simulink. Polythematic network electronic scientific journal of the Kuban State Agrarian University , 2015, 112: 1577-1593

[5] Teo HG, Lee PS, Hawlader MNA. 2012, An active cooling system for photovoltaic modules. Applied Energy; 90(1):309–315

[6] Wang, Y. Wang, X. Shi, Q. Huang, Y. Cui, X. Kang, Experimental study on directcontact liquid film cooling simulated dense-array solar cells in high concentrating photovoltaic system, Energy Convers. Manag. 135 (2017) 55e62.

[7] S. Jakhar, M.S. Soni, N. Gakkhar, An integrated photovoltaic thermal solar (IPVTS) system with earth water heat exchanger cooling: energy and exergy analysis, Sol. Energy 157 (2017) 81e93.

[8] Razykov, T. M., Ferekides, C. S., Morel, D., Stefanakos, E., Ullal, H. S., & Upadhyaya, H. M. (2011). Solar photovoltaic electricity: Current status and future prospects. Solar energy, 85(8), 1580-1608.

[9] Singh, S., Agarwal, S., Tiwari, G. N., & Chauhan, D. (2015). Application of genetic algorithm with multi-objective function to improve the efficiency of glazed photovoltaic thermal system for New Delhi (India) climatic condition. Solar Energy, 117, 153-166.

[10] Rajput, P., Sastry, O. S., & Tiwari, G. N. (2017). Effect of irradiance, temperature exposure and an Arrhenius approach to estimating weathering acceleration factor of Glass, EVA and Tedlar in a composite climate of India. Solar Energy, 144, 267-277.

[11] SISSAKIAN, Varoujan; AL-ANSARI, Nadhir; KNUTSSON, Sven. Sand and dust storm events in Iraq. Journal of Natural Science, 2013, 5.10: 1084-1094.

[12] RAI, Ujjwala. Modeling of solar PV system under partial shading using particle swarm optimization based MPPT. International Research Journal of Engineering and Technology (IRJET), 2017.

[13] KUMARI, JSurya; BABU, Ch Sai. Mathematical modeling and simulation of photovoltaic cell using matlab-simulink environment. International Journal of Electrical and Computer Engineering, 2012, 2.1: 26.

[14] Khalid, Ibrahim Ahmed. Analysis of schemes of solar power plants operating in Iraq. News of higher educational institutions. North Caucasian region. Engineering Sciences , 2015, 2 (183): 107-108.

[15] ISTEPANIAN, Harry H. Iraq solar energy: from dawn to dusk. Friedrich-Ebert-Stiftung Jordan et Iraq, 2020.

[16] SHARMA, Chandani; JAIN, Anamika. Simulink Based Multi Variable Solar Panel Modeling. TELKOMNIKA Indonesian Journal of Electrical Engineering, 2014, 12.8: 5784-5792.