Jurnal Ilmiah Teknik Elektro Komputer dan Informatika (JITEKI)
Vol. 9, No. 3, September 2023, pp. 585-595
ISSN: 2338-3070, DOI: 10.26555/jiteki.v9i3.26440

Photovoltaic Generator Approach Model for Characteristic Estimation I-V

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ARTICLE INFO

Article history:

Received June 14, 2023
Revised July 10, 2023
Published July 14, 2023

Keywords:

Approach Models;
Photovoltaics;
Estimation of Characteristics I-V

ABSTRACT

Modeling of the photovoltaic (PV) approach is generally described by nonlinear equations with solving the equation using the steps iteratively. However, this proposed research discusses the monocrystal type PV module approach model to estimate the characteristics of a photovoltaic generator, because it has the advantage that it is good enough to operate in Indonesia. This approach model takes into account the relationship between power, energy, and current to obtain the performance characteristics of the PV generator. This PV generator approach model is compared with PV generator manufacturer data and analyzed to validate the proposed approach model. Approach model with simulation hope this helps to find out IV characteristics according to the data recorded on the PV module and can save time or reduce the time to measurement results. The simulation results obtained the amount of power, energy, and current, 200.475W, 133.65 W/m^2, and 7.9 Amperes, respectively with a simulation time of about 1.5 milliseconds. In addition to the above results, a comparison between the current and the power of the PV modules under study is also given and it gives the result that at a certain current the power level will no longer increase, but the power will decrease drastically due to heat from the PV panel module, because the module has the ability to receive heat from outside.

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1. INTRODUCTION

The choice of the monocrystalline type in this study is because it has the best efficiency, generally the PV module is in the form of a layer of SiN (N-type silicon) which functions as an electron donor and provides solutions for rural and even urban electricity for electrical energy saving solutions and applications in Solar Home Systems, Solar PJU, Solar Water Pumps or for Centralized Solar Power Generation, and ideal for battery charging applications [1]. It is proven that high-temperature performance and robust design make the product durable in the field and easy to install [2]. Monocrystalline solar panels or mono solar panels, are solar panels that use the purest silicon material [3].

Monocrystal has advantages (https://www.renewableenergyhub.co.uk/main/solar-panels/monocrystalline-solar-panels) including; 1) the efficiency of converting sunlight into electrical energy is between 15% -20%, 2) monocrystalline solar panels require a smaller space compared to other types, 3) have a long service life and many manufacturers of monocrystalline solar panels provide guarantees up to 25 years of service life, 4) monocrystalline solar panels have better performance so they are very appropriate when used in areas that are often cloudy/rainy, and with drawbacks including; 1) monocrystalline solar panels are the most expensive type of solar panels so the investment costs for making solar power bigger, 2) performance may decrease during extremely hot weather.

Testing the estimation of a simple PV model that can predict the characteristics of PV modules operating in various atmospheric conditions and the continuous least squares approach is applied to simple PV behavior [4]. Installation of PV systems requires a large investment at the beginning of production, so the estimation of the PV generator characteristic model is needed before being applied in the actual system [5], [6]. The PV generator works under conditions according to manufacturing data so that does not damage the PV itself, such as paying attention to standard test conditions (STC), maximum power (P_{max}), maximum peak voltage (V_{mp}), open state voltage (V_{oc}) and short circuit current (I_{sc}) [7]. For STC, P_{max} , V_{mp}, V_{oc}, and I_{sc} is a parameter of the solar panel that shows the performance of the PV module being operated (https://www.electronicsforu.com/market-verticals/solar/difference-nominal-voltage-voc -vmp-isc-imp-solar-panels).

The use of PV energy to generate electricity is more environmentally friendly and does not use fossil fuels, to minimize exhaust emissions [8]. PV generators are expected not only to produce electricity with low operating costs in the long run but also to contribute to maintaining a balance between utilization and environmental and social preservation [9], [10]. The initial challenge in channeling credit to the PV energy sector is the need to prioritize handling and the lack of information about PV projects for banks in Indonesia [11]. Banks must adhere to the principle of prudence in extending credit. Based on the PV panel module information on the manufacturer's data sheet and taking into account the I-V characteristics of the irradiation conditions at varying temperatures, it provides the best accuracy to obtain the lowest RMSE value for various test conditions [12]. Modified algorithms and optimization algorithms will give the best results at the lowest execution compared to some of the best meta-heuristic optimization algorithms [13].

Hardware and software simulation tools for PV module systems have been developed to model the proper PV modules and estimate the internal electrical parameters with the lowest execution time without other parameters in the optimization process [12]. Testing a simple PV model approximation that can take into account the performance of PV Modules operating in various atmospheric conditions. The continuous least squares approach is applied to PV behavior in a simple way [4]. The mathematical approach is easier and does not rely on iterative procedures to find solutions. The accuracy of the model is evaluated through simulation with current according to experimental data [14]. Integration of energy optimization of future PV modules in real-time will focus on this forecasting model [15], [16].

PV system performance by utilizing Excel facilities can be used for design and analysis. Model approach. This is expected to be useful in the development of solar cell simulators, analysis, and development of MPP (maximum power point) tracking algorithms, with few steps and only a millisecond execution time with a notebook [17]. This approach can be used as a tool to simplify the design of PV module power converters and the development of circuit simulators. This Excel spreadsheet model approach can be used for modeling PV modules and can be implemented in an optimization toolbox with the help of Visual Basic and provides a practical method for power electronics engineers and designers [18]. The PV approach model and its characteristic estimation have been carried out by [19], [20], [21], [22], [23], [24].

The analytical and iterative methodologies for determining the parameters of the PV panel model with the four-parameter model show that the model has negligible errors, this is caused by behavior that is closely related to radiation. Therefore, the parameters are variable to obtain a more accurate model, with RMSE and RRMSE statistics, showing that this methodology can accurately estimate the unknown model from a single diode model and estimate the power generated by the PV system [25]. The PV module parameter approach in optimization to find the right pattern by considering photo current, saturation current, resistance, parallel resistance and idealistic factor with dual diode test and validation model will show its performance, where this model is very interesting to be developed in the future as an estimation tool [26].

The problem of previous researchers is that no one has stated that the generator of the PV module is stated clearly and straightforwardly in selecting and determining the characteristics of the PV module, so the researcher provides an alternative in determining the characteristics of the PV module by providing suggestions for observing the power, energy, and current of the module. the PVs. The contribution to this paper is to improve the PV module model in its estimation simple but accurate with the aim to overcome the limitations in PV module characteristics. PV module performance with an approach that allows engineers to predict the current with a closed model and use the applicable mathematical model to determine the parameters and characteristics of the PV module generator.

2. METHODS

This paper discusses PV module modeling, and PV model estimation, with these two discussions to get the PV model equation in estimating the characteristics of the analyzed PV module using a valid mathematical model. The proposed research methodology is shown in the schematic in Fig. 1.

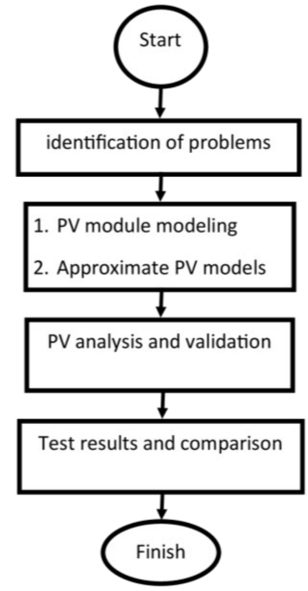

Fig. 1. Research flowchart

The research diagram in Fig. 1 illustrates the observation and analysis process to obtain the expected research results. Problem identification aims to identify problems with existing PV module generators so that the performance of the PV module can be improved. PV generator modeling and approach to obtain observed parameters to be evaluated and analyzed so that they can be identified and compared with existing data from current manufacturers, and finally conclusions can be drawn from the evaluation and analysis of the observed PV generator conditions. The steps are as follows:

1. first, select the problems that exist in the solar panel module practically or theoretically.
2. determine the problems raised in this study by taking into account the shortcomings of previous researchers to improve the existing system.
3. make a model of the solar panel module to be studied including the type of solar panel.
4. create a model to simulate the model of the PV module under study.
5. analysis and validation of the simulation results on the rail data from the PV module, to obtain a comparison between the rail data and the simulation.
6. make conclusions from the results of comparing PV module parameters between rail data and simulation results.

2.1. PV module modeling

Photovoltaic is a device for converting solar radiation into electrical energy directly [27], besides that this module is formed by several cells into a single unit that is connected in series and parallel to get the voltage and current values determined based on the photovoltaic effect [28]. The PV cell is a semiconductor consisting of a pn junction diode, which when exposed to sunlight (photons) will produce electrical energy, this conversion process is called photoelectric. Solar cells began to be used commercially recently, apart from the depletion of fossil energy reserves and the issue of global warming, the energy produced is also very cheap due to solar energy obtained for free [28]. A solar cell consisting of monocrystalline silicon pn junctions (solar panels have a junction between two thin layers made of semiconductor material, each of which is known as a "p" (positive) type semiconductor due to an excess of holes and an "n" (negative) type semiconductor due to an excess of electrons) or also called monocrystalline photovoltaic, has a high purity of 99.999% [29], [30]. Things that affect the amount of power generated by the PV are the irradiance and temperature of the PV module itself [31] shown in Fig. 2.

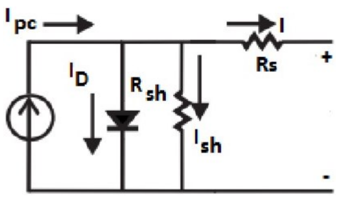

Fig. 2. PV module generator model

The efficiency of monocrystalline silicon photovoltaic cells has a fairly high conversion efficiency of around 15 to 20%. As a result, sunlight is protected, but this type of panel does not work properly and results in a decrease in efficiency [30]. In addition to the weaknesses above, this panel will also leave a lot of space because solar cells like this are hexagonal or round in shape, so they have a low density level. Generally, manufacturers make square shapes with a cutting process, but the losses in the production process are of course greater and make the price more expensive.

Irradiation from the sun received by the earth is distributed over several wavelengths, ranging from 3 nm to 4 microns. Some of the radiation is reflected in the atmosphere (diffuse radiation) and the rest reaches the earth's surface [32], [33]. The important units to measure are the special irradiance ($I\lambda$) the power received by one unit area in the form of a differential wavelength $d\lambda$, the unit W/m^2 um, the integral irradiance of the irradiance spectrum for the entire wavelength, the unit W/m^2, the time integral radiance of irradiance for a certain period of time, therefore, the units are the same as energy units, i.e. J/m^2–days, J/m^2 months or J/m^2 years (https://www.pveducation.org/pvcdrom/properties-of-sunlight/spectral-irradiance). In the analysis, W/m^2 will be used because it is commonly used in data sheets. Irradiance is a source of energy for solar cells, so the output is very dependent on changes in irradiance [34].

2.2. Approximate PV Models

The potential for solar power in Indonesia is quite high (as a tropical country) with an intensity of 4.8 kWh/m² per day. The intensity of solar radiation is influenced by the time of the earth's rotation cycle, weather conditions including the quality and quantity of clouds, the change of seasons, and latitude position [35]. Solar energy production in an area can be calculated as (1).

$$E = I \times A \tag{1}$$

where, E is the solar energy generated (W), A is area (m²), and I is the isolation/intensity of average solar radiation received for one hour (W/m^2).

In general, PV modules are electric power generated depending on weather conditions and have nonlinear current and voltage (I-V) relationship characteristics. I-V characteristics have a point where the maximum power for certain irradiation conditions. The main problem with using photovoltaic modules is their low efficiency, especially in conditions of low solar radiation. The sunlight that the PV module receives depends on the weather and the position of the sun. The output power generated by the PV module is not constant with an efficiency of around 9-17% [36]. The mathematical model of the PV module is the short circuit current (I_{sc}) of the PV panel shown in Fig. 3.

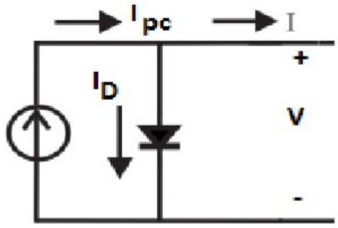

Fig. 3. PV module approach without shunt and series resistance

The short circuit current is affected by the function of solar radiation (S) and open circuit voltage (V_{oc}) [37], [38], expressed as in (2).

$$I = n_p I_{ph} - n_p I_0 \left[e \frac{q\left(\frac{V}{n_g} + IR_S\right)}{nkT} - 1 \right] \tag{2}$$

where n_p is the number of units in parallel, n_s is the number of units connected in series, k is the Boltzmann constant, q is the velocity of the electrons (Coulumb), R_s is the series resistance (Ohm), R_{SH} is the parallel resistance (Ohm), T is the temperature surface (degrees Celsius) of the PV module is shown in Fig. 4.

For saturation current expressed by (3).

$$I_{rs} = I_{rr} \left(\frac{T}{T_r}\right)^3 e \left[\frac{qE_G}{KA}\left(\frac{1}{T_r} - \frac{1}{T}\right)\right] \tag{3}$$

where, $q = 1.6022 \times 10^{-19}$ Coul is the electron charging constant, T_r is the reference battery temperature, I_{rr} is the reflux saturation under T_r conditions, $K = 1.3807 \times 10^{-23} JK^{-1}$ is the Boltzmann constant, EG is the energy unit (Joule) used in the width of the semiconductor interruption, while the photo current (I_{ph} in Amperes) which depends on solar radiation and temperature is shown in (4).

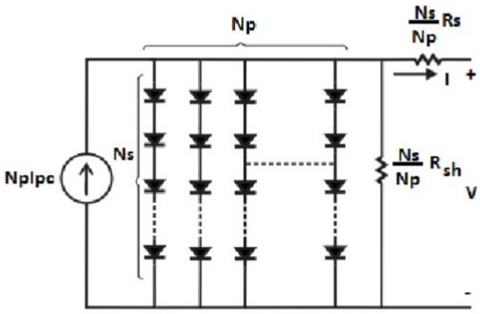

Fig. 4. The equivalent circuit of the PV module model

$$I_{ph} = \left[I_{SC} + k_i (T - T_r) \frac{S}{1000} \right] \tag{4}$$

where I_{SC} is the photovoltaic short circuit current, k_i is the temperature coefficient of the short circuit current, S is the level of solar radiation, and T is the air temperature, so the output power of the PV module is the product of the multiplication of the terminal voltage V and the output current I_0 [39] as (5).

$$P = VxI = n_p V I_{ph} - n_p V I_0 \left[e \frac{q\left(\frac{V}{n_g} + IR_S\right)}{nkT} - 1 \right] \tag{5}$$

Changes in these two variables result in changes in the characteristics of the power to voltage (PV) and the characteristics of the current to voltage (IV). The electrical specifications for the PV module used have been provided by the manufacturer with standard solar radiation (1000 W/m^2) and a temperature of 25^{0}C [40], as Table 1.

Table 1. PV module specifications

No	Specification	Information
1	Max. Power(Pmax)	100W
2	Max. PowerVoltage(Vmp)	18.4V
3	Max. Power Current (Imp)	5.68A
4	Open Circuit Voltage (Voc)	22V
5	Short Circuit Current (Isc)	6,33A
6	Nominal Operating Cell Temp (NOCT)	45±2°C
7	Max. System Voltage (Vmax)	1000Vdc
8	Max. Series Fuse	16A
9	Weight	8.3 Kg
10	Dimensions	±1005 x 670 x 35mm

Table 1 description as, P_{max} is the maximum power output value of the panel module which is the combination of voltage (volts) and current (amps) that produces the highest wattage (volts x amps = watts). Design Controller and Maximum Power Point Tracking periodically to measure solar panel voltage with various load matched panel inputs to balance voltage and current maximizing power output during mass charging. Watts on a solar panel is listed as P_{max}, where $P_{max} = V_{mp} \times I_{mp}$ at standard test conditions.

The voltage at maximum power (V_{mp}) is the voltage at highest power output, when connected to the Maximum Power Point Design and Tracking controllers under standard test conditions, with actual V_{mp} for one day depending on conditions, temperature, shadows, dust and dirt adhering to the surface of the panel. This voltage is measured with a multimeter at the solar input terminal of the Maximum Power Point Design and Tracking controller during mass charging mode [41]. I_{mp} is the actual amperage when connected to the Design and Maximum Power Point Tracking controller under standard test conditions at the greatest power output current.

V_{oc} is the maximum voltage generated by the solar panel without load and is measured with a multimeter through the cable attached to the solar panel. The highest voltage generally occurs in the morning because the sun rises quickly and the temperature of the solar panels is still quite low. The V_{oc}+ value must not exceed the allowable voltage by the solar charge controller (SCC) which functions to regulate the charger/charging current to the battery. The actual current varies depending on how well the light hits the solar panel. It should be noted that the current that the pulse width modulation controller will accept is slightly higher than the Imp value under standard test conditions.

It is the amount of current that flows out of the panel when the positive and negative cables are connected. $I_{sc} + 20\%$ to determine the required current handling capacity of a compatible solar charge controller (SCC) and is the highest current the solar panel will produce under standard test conditions. Short circuit current (I_{sc}) is the current through the solar cell when the voltage on the solar cell is zero ($V_{oc} = 0$).

NOCT provides a lower power rating than actual specifications but is more realistic. Generally listed as a 1000W/m^2 rating, NOCT uses 800W/m^2 rating, close to a moderately clear day with scattered clouds. This condition describes an air temperature of 20°C, not the temperature of the solar cells, and takes into account the 1m/s wind that cools the back of the tilted solar panels. The maximum system voltage ($V_{max} = 1000V_{dc}$) means that the solar panel can be supplied with 1000V direct voltage, and still work normally.

2.3. Description 100 Wp Monocrystalline Module

Monocrystalline is a panel with the best efficiency that uses a layer of *SiN* (silicon type 'N'), which is a solution to rural and even urban electricity needs for electricity savings and other applications such as Solar Home Systems, Solar Public Street Lighting, Solar Water Pumps or centralized PV generators. The 100Wp PV modules offer increased efficiency, making them ideal for high-temperature battery charging applications and the rugged design makes the product durable in the field and easy to install. It is proven high-temperature performance and robust design make the product durable in the field and easy to install. Monocrystalline solar panels or commonly called mono solar panels are solar panels that use the purest silicon material. With these materials, Monocrystalline solar panels can convert sunlight energy into electrical energy with the highest level of efficiency. Here are the advantages and disadvantages of monocrystalline solar panels.

The first type of solar panel that we will discuss is the monocrystalline silicon solar panel. This type of solar cell component is the most widely used type because of the advantages it has. This solar cell is made of thinly sliced silicon using a machine. Slices can be thinner and also have identical characteristics due to the use of this cutting machine. For its advantages, this type of solar cell can be called one of the most efficient solar cells to use. This is because its cross-section can absorb sunlight more efficiently than other solar cell materials.

The efficiency of converting sunlight into electricity which is owned by this solar cell material is around 15%. This amount is a fairly large amount when compared to other solar cell constituent materials even though they have the same cross-sectional size. This solar panel is also one of the most widely used because it is most suitable for daily needs. The use of solar cells in various electrical equipment including Submersible Pumps with these solar panels, but this type of solar panel will require very bright light when operating. It will experience a reduction in efficiency if it is in cloudy and overcast weather. For the characteristics of this monocrystalline silicon solar panel, it has a black color and also a thin shape.

3. RESULTS AND DISCUSSION

3.1. Results

The power curve characteristics of the PV module used to depend on radiation and temperature with the following data: For annual temperature data simulation, minimum (V_{min}), average (V_{avg}), and maximum (V_{max}) wind speed with an area of 20 m^2 PV module and generator efficiency PV module 75%, as follows: $V_{min} = 0.53\ m/s$; $V_{avg} = 2.57\ m/s$; $V_{max} = 3.50\ m/s$; $A = 20m^2$; efficiency=0.75;

Based on the simulation results of the research data above, the power characteristics are obtained with the software to generate power minimum, average, and maximum shown in Fig. 5 and energy next in Fig. 6.

The magnitude of the short circuit current and no-load voltage with changes in ambient temperature of 1000W/m^2, 1200W/m^2, and 1400W/m^2 is shown in Fig. 7 and Fig. 8. Observation of current and power when observing changes in ambient temperature, as shown in Fig. 9, where changes in ambient temperature result in a linear change in current up to a certain power and will decrease to a certain power as well, this is due to the material used having a certain saturation power.

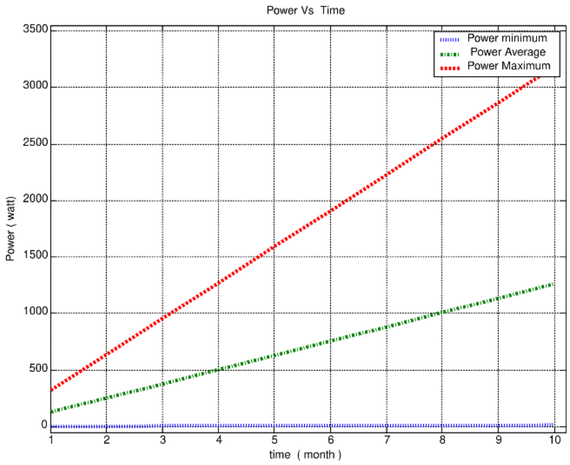

Fig. 5. Power over time (monthly)

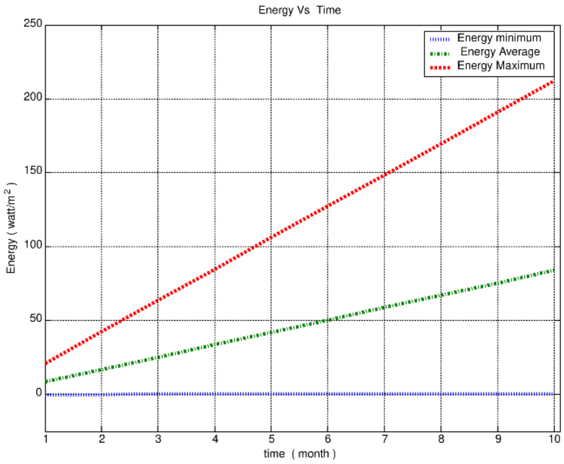

Fig. 6. Energy over time (monthly)

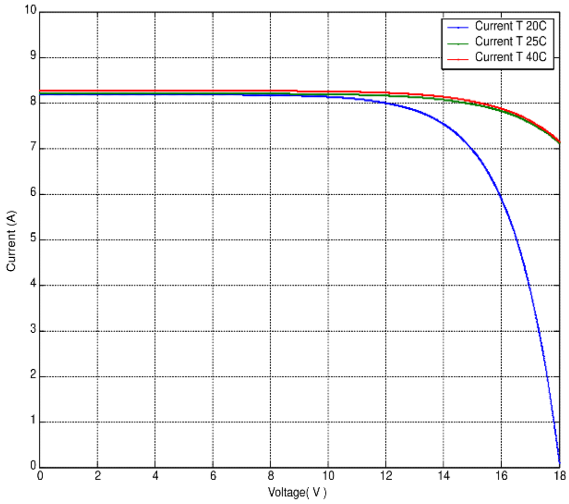

Fig. 7. Current Vs Voltage with changes in ambient temperature

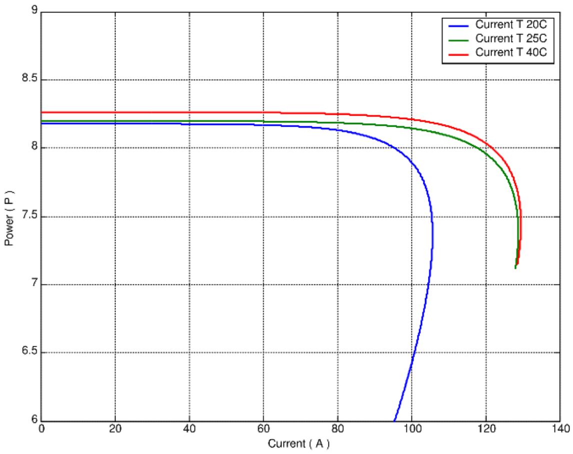

Fig. 8. Relationship of power and current with changes in ambient temperature

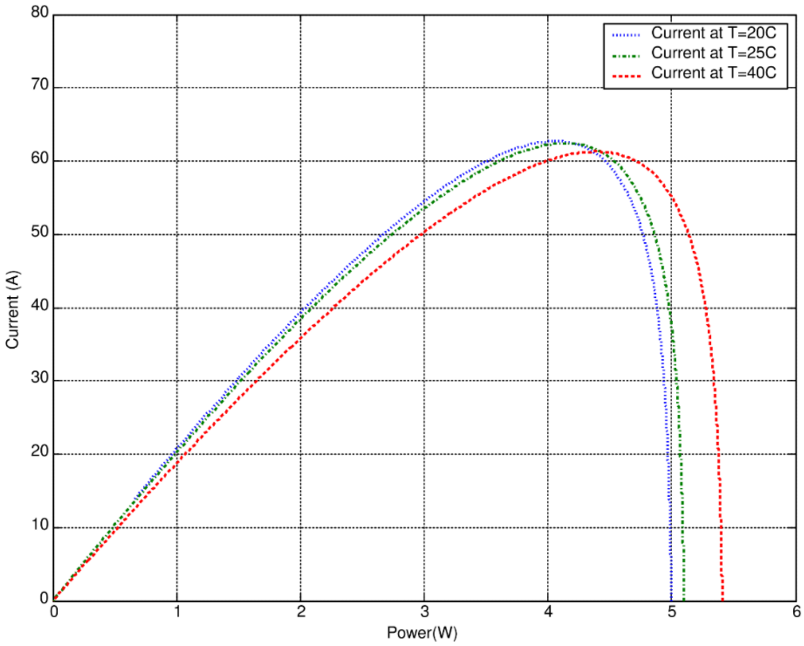

Fig. 9. Current and power at temperature changes

3.2. Discussion

The simulation results using the software for various environmental temperature conditions, for power, energy, and current are shown in Fig. 5, Fig. 6, Fig. 7, and Fig. 8 so that they are obtained as follows:

Fig. 5 shows that the amount of power will continue to increase with a certain change in time. The simulation results obtained the minimum, average and maximum power, namely $P_m = 1.1054W$, $P_{avg} = 126.0364W$, $P_{max} = 200.4750W$. Fig. 6 shows that the magnitude of the energy will increase continuously until a certain time and result in simulation with the amount of energy in the PV generator, namely: $E_{min} = 0.7369\ W/m^2$, $E_{avg} = 84.0242W/m^2$, $E_{max} = 133.6500W/m^2$, respectively, These results are in Accordance with research conducted by Mohammad Reza Maghamu et al., [42].

Fig. 7 shows the magnitude of the current versus voltage with changes in ambient temperature, where the magnitude of the short circuit current will decrease with a greater change in voltage until there is no change in a certain voltage [15]. The magnitude of the short circuit current (I_{sc}) increases with changes in ambient temperature of 20^{0}C, 25^{0}C, and 40^{0}C, respectively, but will decrease with increasing voltage, this is due to the ability of the PV module to accept a certain voltage. This is Accordance with what was found by Asif Javed [43].

Fig. 8 shows the amount of power to current with changes in ambient temperature, where the amount of power will decrease with changes in current with increasing magnitude for changes in ambient temperature of 20^{0}C, 25^{0}C, and 40^{0}C, respectively. This is in accordance with research put forward by Munipally Bhavani et al., [44]. and Koffi et al., [45].

Fig. 9 shows the amount of current versus power caused by changes in the surrounding temperature, where the current changes linearly up to a certain power and will decrease drastically for constant power, this is in accordance with the results of research from Ivan Ratkovic and friends [46].

4. CONCLUSION

Several factors determine the ideal output of a PV module including the environment. This paper has researched the relationship between power, energy, and current. The results show that the power and energy will be affected by the operating time of the PV module. However, for a certain voltage change it will result in a decrease in current, because the module has certain capabilities even though the voltage continues to be applied, while the amount of power will decrease at a certain amount of current, this is as studied by Singh with the design of commercial PV power plants [29]. Evaluation through simulation with current according to experimental data produces reliable accuracy [14]. As long as the PV module is not protected by a solar radiation receiver, there will be a voltage drop generated by the PV module. It is recommended that the performance can increase its efficiency [47], [48], [49]. This paper also observes the influence of sunlight intensity on the performance of PV module power through photovoltaic solar cells by analyzing the acceptable electrical performance parameters of PV modules. The maximum output power increases with high light intensity to solve traditional research problems. Increasing light intensity will also enhance the efficiency of PV power generation, and with certain assistance and available supporting data for further research, as well as for future applications and development of PV cells [50].

Acknowledgments

Acknowledgments to the Chancellor of Universitas Muhammadiyah Sumatera Utara, who has provided support for this research, so that it can finish writing journal manuscripts, hopefully, it will be useful for all parties.

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