Performance Comparative Analysis of Monocrystalline and Polycrystalline Single Diode Solar Panel Models using the Five Parameters Method

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Abstract

The use of renewable energy as a source of electrical energy increases every year. Unfortunately, Indonesia does not have many power plants that utilize renewable energy sources. The most potential renewable energy in Indonesia is the sunlight with the help of solar panels that converts solar energy into electrical energy. However, the environment could affect the solar panel module and in turn, affect the performance of solar panels or the generated electric energy. This research calculated the performance of solar panels with a single-diode model using the Five Parameters method that required solar panel module specification data, the total radiation absorbed by the solar panel module, and the temperature of the environment. The Five Parameters method is a method modeled after solar panel module performance in the form of the single-diode equivalent circuit. The Five Parameters method is reliable in predicting the energy produced by the solar panels when the input data is limited. The results for using the Five Parameters in monocrystalline solar panels were I_{sc} = 1.827 A, I_{mp} = 0.662 A, V_{oc} = 18.221 V, V_{mp} = 15.019 V, P_{mp} = 9.955 W. And the results in polycrystalline solar panels were I_{sc} = 1.926 A, I_{mp} = 0.686 A, V_{oc} = 17.594 V, V_{mp} = 14.166 V, P_{mp} = 9.722 W. Based on the results; it was concluded that the most efficient and optimised types of solar panels on natural conditions in Sendang Biru Beach was the monocrystalline solar panel because it produced electrical output power of 9.955 W. Therefore, there could be a manufacturer of solar energy power plants to reduce the cost of electricity in the coastal area, such as in Sendang Biru Beach.

Keywords
Photovoltaics, Solar Energy, Five Parameters Model, Monocrystalline, Polycrystalline

1. Introduction

Solar energy is one of the accessible renewable energy sources. It has a high potential to be utilized as a renewable energy source. The reason behind is its availability every day year-round with no adverse effect on the environment. The solar energy is trapped using a solar panel and converted into electrical energy to be utilized by the people in daily life. There are many sites with high solar energy, for example, the coastal areas [1]–[4].

Solar energy can be converted into electrical energy using a solar panel. The solar panel consists of several components: photovoltaic (PV) module to trap the photon energy from the sun, inverter module to convert the DC into AC and to set the AC output that will be used by consumers, and off-grid PV generation system that the storage battery usually used to store the energy and provides constant electrical energy, and charge controller to set the current input and output in the battery and to prevent battery overcharging and completely discharging. Each component in the PV generation system has its characteristics [5]–[9].

The making of the solar power plant requires a calculation of system model performance to determine the type, capacity, and total component to get a precise and optimal system. There are several model performance calculations such as the Five Parameters model. Each method has different assumptions and parameters so it is vital to know the required data by observing the component specification or direct measure in the field. The model performance calculation was used to determine the PV module type to be used according to nature and climate conditions in Sendang Biru Beach for the optimal system [5].

2. Main Theory

A. Solar Energy

Solar energy is obtained through trapping the sunlight through particular devices and then turned into an energy source in another form. Solar energy is a renewable energy source, along with water, steam, wind, and others. AC Becquerel first utilized solar energy in 1839, where he used silicon crystal to convert solar radiation into a voltage or electric current [10]–[13]. This phenomenon is also called the photovoltaic effect. The sun is a star closest to the Earth with an average distance of 149,600,000 km (92.96 miles) from the Earth. The Sun's distance from the Earth is known as an astronomical unit and usually rounded off to 150 million km (Mutiara Sani, 2013). Sunlight can be used directly to produce electricity or heating and even cooling. To date, solar energy is utilized around the world. When correctly exploited, this energy has the potential to provide the world's electrical energy consumption in the long run. Solar energy means directly converting the sunlight into heat or electrical energy. The trapped solar energy is in the form of photon energy (E) that the magnitude is inversely proportional to the wavelength of light (λ).

B. Sun Radiation

The sun emits light radiation with various wavelengths, ranging from ultraviolet, visible light, to infrared from the electromagnetic spectrum. These radiations occur due to the high temperature of the sun above the surface that reached around 2800°K or 5500°C so that the spectrums emitted by the sun are similar to the spectrums of a blackbody with the same temperature. A blackbody is defined as an object that entirely absorbed all electromagnetic radiations and could emit radiation in distributed energy depending on the temperature.

C. Photovoltaic

The solar cell, or photovoltaic cell, was first known in the 19th century. The solar cell is a series of semiconductors that absorb photon energy and convert it into electrical energy. According to Einstein, besides having wavelength characteristics, sunlight also comprises of photon groups' energy. When the sunlight reaches the solar cell surface, the photon is absorbed by the molecules inside the solar cell then converted into electrical energy. In the process, the semiconductor is a vital material for the solar cell to function well. During the process, the required first thing is material that absorbs the light, which causes electrons to move to a higher energy state [14], [15]. Then, the electrons move from the solar cell to the external circuit. The electrons then dissipated in the external circuit, leaving energy, and back to the solar cell. There are many types of material and processes that meet the requirement in solar energy conversion, but in practice, almost all conversions use semiconductors in the form of the p-n junction. The solar cell from the semiconductor is processed to produce DC/direct current. To use it, a collection of solar cells is connected, parallel or series, depending on their use to produce energy with the combination of the desired current and voltage.

D. Types of PV

Various types of PV depend on the required energy to be supplied to the load. The standard type is made from 32 or 36 crystalline silicon. These cells have the same dimensions, connected in a circuit, and encased in glass and plastic materials and using polymer resin (EVA) as a thermal insulator. The surface is around 0.1–0.5 m^2. The solar panel usually has two electricity contacts, one positive and one negative. PV usually made from silicon and is divided into two types: crystalline silicon and thin-film silicon. The solar cell comprises of several types:

a. Single-Crystalline Cell (Monocrystalline)

It is a crystal with one type. In development, this type produces high efficiency. The types of single-crystalline, among others, are Gallium Arsenide Cell and Cadmium Sulfide Cell.

b. Polycrystalline Cell

It consists of various crystals. It is composed of silicon crystal with 10–12% efficiency. The advantage of this type is a lower price than a single crystalline cell.

c. Amorphous Silicon Cell

Amorphous means non-crystal. It uses thin film with 4–6% efficiency.

d. Copper Indium Diselenide (CIS) Cell

The active semiconductor material in CIS solar cells is copper indium diselenide. CIS compound is often a mix of gallium and sulfur with 9–11% efficiency.

e. Cadmium Telluride (CdTe) Cell

The CdTe solar cell is produced in a glass substrate with a transparent TCO conductor layer. Usually made from indium tin oxide (ITO) as the front contact with 1–8.5% efficiency.

f. Dye Sensitized Cell

Its principle is to absorb light in organic color, similar to the way plants use chlorophyll to trap the solar energy in photosynthesis.

E. Work Principle

The conventional solar cell uses the p-n junction principle. It is a junction between p-type and n-type semiconductors. This semiconductor consists of atomic bonds with the electron as the basic compiler. The n-type semiconductor has surplus electrons (negative) whereas the p-type semiconductor has surplus holes (positive) in their atomic structure. The surplus electrons and holes are occurred by doping the material with a dopant atom. The role of the p-n junction is to form an electric field so that electrons (and holes) can be extracted by the contact material to produce electricity. When the p-type and n-type semiconductors are in contact, the surplus electrons move from the n-type to the p-type semiconductor and form a positive pole on the n-type semiconductor and negative pole on the p-type semiconductor. The results from these movements form an electrical field where the sunlight reaches the p-n junction and pushes the electron to move from the semiconductor to the negative contact and utilized as the electrical energy. Meanwhile, the holes move to the positive contact, waiting for the electrons.

F. PV Efficiency

The PV efficiency is a ratio between the generated energy of the PV system and total solar radiation that is absorbed by the PV surface. Other parameters such as ambient temperature, PV cell temperature, chemical potential component, and heat capacity are not calculated. The amount of the current that is produced by the PV from the photon at a specific temperature is influenced by:

a. The intensity of the incoming light

Increasing intensity means more absorbed photon and increasing the gap between photon energy and bandgap energy. Thus, it increases the produced current.

b. The wavelength of the incoming light

G. The Five Parameters Performance Model

The five parameters performance model is a PV performance calculation method that was developed by De Soto (2004) at the University of Wisconsin-Madison. The inputs are output parameter values (I_{SC0}, V_{OC0}, I_{mp0}, V_{mp0}), PV characteristic curve during STC, and climate data such as solar radiation and ambient temperature. Thus, this method is reliable at predicting the energy created by PV with limited data.

Generally, the five parameters method model the PV performance equivalent to in the form of the single-diode circuit. This circuit then generates five parameters: I_L (Light Current), I_0 (Diode Reverse Saturation Current), a (Diode Ideality Factor), R_s (Series Resistance), and R_{sh} (Shunt Resistance).

I_L or lighting excitation current is the current that appears in PV module due to solar light in the PV surface. The value is usually close to the short-circuit current characteristic of the PV ($I_L \approx I_{sc}$). The value of I_O or diode reverse saturation current is usually small, around 10^{-10} or 10^{-9}. R_S and R_{sh} usually called parasitic resistance and are the resistance in the PV as the results of connection material between cells and PV cell material resistance. In the PV model, the desired R_S is small while R_{sh} is large. Figure 1 shows the single-diode equivalent circuit with its components.

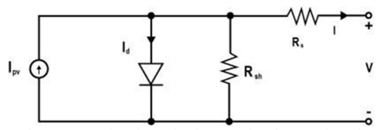

Figure 1. Single-Diode Equivalent Circuit

3. Five Parameters Method Calculation Method

PV performance calculation using the five parameters method is a method that modeled the performance of PV module in a single-diode equivalent circuit, where the analysis of this circuit will create five parameters (a, I_L, I_o, R_s, R_{sh}) that are the components of the single-diode equivalent circuit. The values also determine the results of PV module outputs (I_{sc}, V_{oc}, I_{mp}, V_{mp}, P_{mp}) and its characteristic curve. The calculation using five parameters input required is the PV module specification data during reference, total radiation absorbed by the module, and cell temperature. Then, the input at reference condition, including its characteristic curve was processed using the equivalent circuit modeling equation of the PV module to determine the five parameters at the reference condition. After those are obtained, this research determined the five parameters in particular operating condition. Next, the values at operation were substituted into the equivalent circuit modeling equation of the PV module to determine the I–V characteristic module at operation point. From the curve, this research received the I_{sc}, V_{oc}, I_{mp}, V_{mp}, and P_{mp} at operation point.

This method used a poly-crystalline PV type, but the calculation of the other two PVs using the same method was still displayed. Table 1 shows the input parameters to obtain the value of α_{ref}, $I_{L,ref}$, $I_{o,ref}$, $R_{s,ref}$, $R_{sh,ref}$. Attachment 1 provides complete data input.

TABLE 1 DATA INPUT TO SEARCH FIVE PARAMETERS VALUES

Parameter	**Value**
Isc_0	2.97
Imp_0	2.78
Voc_0	21.8
Vmp_0	18
αIsc	0.05%
EPOA	442.27
Eo	1000
Tc	25
To	25
N	1.026
Ns	36
K	1.38066×10^{-23}
Q	1.60218×10^{-19}

4. Result

This research conducted the PV performance calculation using the five parameters model. The purpose was to predict the created energy of a PV module at a specific natural condition without conducting a direct test. The result from the climate data and electrical data processing at STC conditions were in the form of PV output at operation conditions. The values were analyzed and compared between each PV module type; they were mono-crystalline (SPM050-M) and poly-crystalline (SPM050-P).

A. The Five Parameters Method

The output parameters from the calculation of PV performance using the five parameters method are not directly affected by climatology conditions. However, this climatology condition influences the value of five parameters obtained from the results of the PV equivalent circuit model. The climate data that was used in this method was not much; only the absorbed solar radiation and cell temperature. The result from this method was not only output parameters but also current characteristics for each load voltage that can be seen in Table 1. Five parameters method only required little data input so that we could calculate the PV performance at limited data. The required data input is only the PV output parameter at STC and its characteristics and climate data such as total solar radiation and cell temperature. Although the required data input was little, the calculation and data processing was quite tricky and required higher accuracy because the calculation needed to know the five parameters at STC and operation. The most challenging part was determining the values of the parameters at the suitable reference by deriving the equation (2.48) or the single-diode equivalent circuit model equation and considering the five conditions known from the PV characteristic curve. Besides, equation (2.48) should be derived using Lambert's W function to determine the current value on each PV voltage due to the rank exponent so that it was difficult to determine the PV current. The values of five parameters in STC and operation conditions on each PV module can be seen each in Table II and III.

TABLE II. THE VALUES OF FIVE PARAMETERS AT REFERENCE CONDITION

PV Type	a_{ref}	$R_s$ref	Io,ref	IL,ref	Rsh,ref
Mono crystalline	0,9 57	0,148	1,698E-10	2,972	152,513
Poly- crystalline	0,948	0,235	3,028E-10	2,973	209,408

TABLE III. THE VALUES OF FIVE PARAMETERS ON OPERATION CONDITION

PV Type	a	Rs	Io	IL	Rsh
Mono- crystalline	0,080	0,148	3,592E-10	1,316	344,841
Poly-crystalline	0,079	0,235	6,444E-10	1,316	473,485

From the above tables, the calculations followed the theories. It can be seen from the results where I_{Lref} and I_L at operation condition each are nearing the values of I_{sc0} and I_{sc} at operation condition. Then, the value of I_0, in reference to or operation conditions, is small, around the order of 10^{-6}–10^{-10}. Lastly, the value of R_s is quite small, whereas the values of R_{shref} and R_{sh} at operation conditions are quite high. These values were following the PV ideal condition, where it requires the smallest R_s possible and the broadest R_{sh} possible.

B. Comparison from Both PV Module Types

As explained, the calculation resulted in the PV output parameters at operation conditions. Both results can be seen in Table IV.

TABLE IV. THE VALUES OF FIVE PARAMETERS OF PV OUTPUT

PV brand	Isc	Imp	Voc	Vmp	Pmp
Mono-Crystalline	1,817	0,661	18,545	15,543	10,288
Poly Crystalline	1,817	0,664	17,808	14,860	9,871

5. Conclusion

The calculation results of solar panel performance using the five parameters model method was affected by the values of five parameters from the single-diode equivalent circuit model, where the values were also influenced by the solar radiation that was absorbed by the PV surface and its cell temperature at operation condition. The calculation also gave the PV output current value on each PV output voltage value to facilitate us making precise characteristic curves (I–V) at operation conditions. From several methods to find the PV performance, five parameters were the most efficient and optimal because it required little data input but gave maximum or the best output. From two types of PV, the most efficient and optimal to be used in Sendang Biru Beach was mono-crystalline because it could produce tremendous electrical power along with the increase of total solar radiation and had little impact on the temperature change in Sendang Biru Beach.

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