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Efficiency and performance ratio of photovoltaics on a 50 kWp Universitas Pamulang Viktor rooftop solar power plant

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ABSTRACT

To overcome the fossil energy crisis due to the increasing need for electrical energy, new renewable energy sources are needed. Due to technological developments in the fields of transportation, industry, household, and commercial use. Indonesia's geography has the potential to apply new renewable energy, more specifically photovoltaic (PV). However, it is greatly influenced by environmental factors such as solar radiation, voltage, which have an impact on the output power efficiency and performance. So, it is necessary to test both measurements and calculations to see the optimization of output power and PV efficiency. From previous research, it has not been carried out, especially in the experimental method Universitas Pamulang: measurement and empirical and for a sufficiently high capacity with the aim of optimal output power. Methods of measuring sunlight intensity, voltage and current, the calculation of converting sunlight intensity to solar constellation, power, efficiency, and performance ratio (PR). The average value being 721 W/m^2 an efficiency value of 19.9% and a value PR is obtained of 0.967 or 96.7% is still realistic. So that the system is declared optimal.

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1. INTRODUCTION

The need for electrical energy continues to increase, making the supply of fossil energy reserves dwindling, it is necessary to use alternative energy using new renewable energy sources so that it can overcome the current fossil energy crisis [1]–[3]. The use of electrical energy that is currently being used as final energy for electric power in the coming years will continue to increase, due to technological developments in the fields of transportation, industry, household and commercial use electrical energy [4], [5]. Indonesia's geography has the potential to turn solar energy into a source of electrical energy or better known as new renewable energy [6]. This the territory of Indonesia, there has been a lot of utilization, more specifically regarding the utilization of electrical energy from photovoltaic (PV) [7], [8]. However, the design and design of PV modules and installations are greatly influenced by environmental factors such as solar radiation a voltage, which have an impact on the efficiency of the output power and performance [9]–[11]. Under these conditions, it is necessary to carry out a test both measurement and calculation to see the level of PV efficiency so that it can also be seen that the output power is optimal [12].

Abubakar *et al*. [13] located in Pakistan using data sources from Quaid-e-Azam solar park (QASP) on machine learning: ARIMA model with the Python program, using 225 Wp PV resulting in a performance ratio (PR) of 73%, this research is still predictive. Windarta *et al*. [14] located in Indonesia using data sources from simulation on PVsyst 7.2, using PV 100 to 400 Wp resulting in a PR of 84%, this research is still based on simulation results. Apribowo *et al*. [15] located in Indonesia using data sources from simulation on simulators, using PV 330 Wp resulting in a PR of 83.1%, this research is still based on simulation results. Dhimish [16] located in England, Ireland, and Scotland using an experiment with the measurement and empirical method, using a 220 Wp PV resulting in a PR in England of 88.91%, in Ireland 88.78 and in Scotland 88.57%, this research still uses a small PV capacity. While this research is located in South Tangerang, Banten Indonesia using the experiment with the measurement and empirical method, using a 485 Wp PV resulting in a PR in England of 96.7%, this research has the advantages of the experimental method: measurement and empirical as well as for a fairly high capacity with was first conducted at Universitas Pamulang, South Tangerang, Banten, Indonesia.

The purpose of this study is to determine the output power value of the currently installed design and can actually provide optimal output power. Measurement methods are used to measure sunlight intensity, open circuit voltage (Voc), short circuit current (Isc) and calculation methods to convert sunlight intensity to solar constellations, input power and output power, efficiency and PR. Furthermore, the results of measurements and calculations are analyzed to find out what the performance level of the PV is installed on the 50 kWp on-grid roof power generation system on the Viktor Campus, Universitas Pamulang.

2. METHOD

2.1. Process

Figure 1 shows the stages of the research carried out. From start: data collecting, measurements method, data validation, empirical methods, efficiency and performance analysis, and data validation. The last is data analysis.

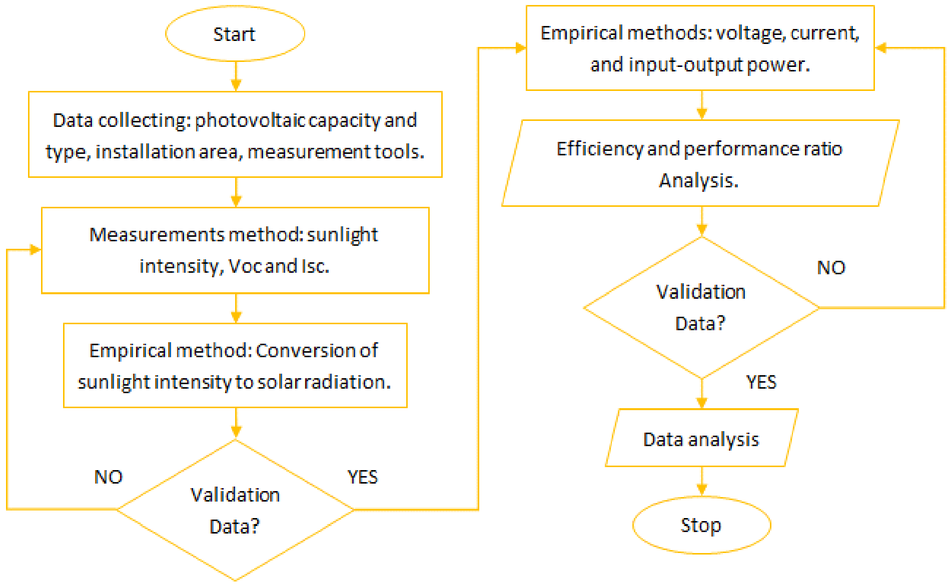

Figure 1. Research process

2.2. Material and measurements

2.2.1. Specification of photovoltaic

The amount of light reflected from the surface of the PV is about 30% of the incident light. Reducing the amount of reflected light can increase efficiency. Then a PV is needed which is coated with anti-reflection in dark blue or black so that it can reduce reflections [17]. Table 1 shows the specification for the PV installed in Universitas Pamulang Viktor's 50 kWp on-grid rooftop solar power plant is mono-clystalline 485 Wp which has a black color and fits these criteria.

Table 1. Specification of PV [18]

Electrical data | STC*		Mechanical data	
CS3Y	485 MS	Specification	Data
Nominal max. power (Pmax)	485 W	Cell type	Mono-crystalline
Operating voltage (Vmp)	44.4 V	Cell arrangement	156 [2×(13×6)]
Operating current (Imp)	10.94 A	Dimensions	2,252×1048×35 mm
Voc	53.1 V	Weight	25.7 kg (56.7 lbs)
Isc	11.62 A	Front cover	3.2 mm tempered glass
Module efficiency	20.6%	Frame	Anodized aluminium alloy
Operating temperature	-45 °C ~ +85 °C	J-box	IP68, 3 bypass diodes
Max. system voltage	1,500 V or 1,000 V	Cable	4 mm^2 (IEC), 12 AWG (UL)
Module fire performance	TYPE 1 or TYPE 2	Cable length	500 mm/350 mm
Series fuse rating	20 A	Connector	4 series or H4 UTX or MC4-EVO2
Application classification	Class A	Per pallet	30 pieces
Power tolerance	0 ~ +10 W	Per container	600 pieces

The surface area of the PV used is 2.36 m^2 with a total of 108 modules currently installed. So that it can be calculated that the total PV capacity installed is approximately 50 kWp. PVs have characteristic parameters based on standard test conditions (STC) which are defined as solar radiation 1,000 W/m^2, temperature of module 25 °C [19].

2.2.2. Measurement of solar radiation

The digital Lux meter AS823 is used to measure the intensity of sunlight in units (Lux). Then the measurement results are converted to solar radiation in units (W/m^2). Table 2 shows the specification data of the digital Lux meter AS823.

Table 2. Specification of AS823 digital Lux meter [20]

Description	Value
Model number	AS823
Description	Lux meter
Serial number	6027370
Date of manufacture	2021-12-30
Measuring range	1 to 100,000 Lux
Sampling rate	1.5 times/sec
Measurement repeatability	± 2%

The AS823 digital Lux meter measuring instrument must have a good level of accuracy and measurement quality, so it must be calibrated. Calibration aims to determine the accuracy and quality of the measurements displayed [21]. Table 3 shows the calibration result data from the digital Lux meter AS823.

Table 3. Certificate of calibration AS823 digital Lux meter [20]

Reference document	Temperature	RH
JJG245-2005	23~27 °C	50~75%
Normalized value (Lux)	Actual value (Lux)	Permissible error (Lux)
100	99	-1.0
150	153	3.0
200	202	2.0
500	489	-2.0
1,000	998	-2.0
1,500	1,503	3.0
2,000	1,996	-4.0
3,000	3,006	6.0

2.2.3. Measurement of voltage and current

Measurement of sunlight intensity using the AS823 digital Lux meter and measurements of Voc. Isc of PVs using the seaward PV200 tester are carried out simultaneously. The specifications for the seaward PV200 tester are shown in Table 4.

Table 4. Electrical specifications of PV200 PV tester [22]

Description	Value
Display range (open circuit voltage)	0.0–1,000 VDC
Measuring range resolution	5.0–1,000 VDC
Accuracy enunciators	0.1 VDC maximum
Display range	± (0.5%+2 digits)
Measuring range resolution	DC voltage polarity correct or reversed
Display range (short circuit current)	0.00–15.00 ADC
Measuring range	0.50–15.00 ADC
Maximum power	10 kW
Resolution	0.01 ADC maximum
Accuracy	± (1% + 2 digits)
Maximum power rating	10 kW

2.3. Empirical

2.3.1. Efficiency of photovoltaics

Power, current, and voltage are generated in the adsorption of solar energy to the PV voltage and current can produce power which can be calculated using (1) [23]. In (1) is a calculation to find out the magnitude of the PV output voltage:

$$Output\ power\ (Pout) = Voc \times Isc \times FF \times number\ of\ modules \tag{1}$$

Where Pin is the light power incident on the device. Fill factor (FF) is expressed by (2) [24]. In (2) is the result of (Vmp×Imp) divided by (Voc×Isc):

$$Fill\ factor\ (FF) = \frac{V_{mp} \times I_{mp}}{V_{oc} \times I_{sc}} \tag{2}$$

While the input power (Pin) is the amount of solar radiation in units (W/m^2) multiplied by the surface area of the PV in units (m^2) [25], as shown by (3):

$$Output\ power\ (Pin) = S\text{olar radiation} \times \text{Surface area} \times number\ of\ modules \tag{3}$$

The equation for determining the efficiency (η) of a PV depends on the ratio of power output (Pout) divided by Pin, Pin is equal to multiplying the surface area of the panel (A) and the intensity of solar radiation (ε), for Pout the equation is equal to the multiple of the resulting voltage (V) and the amperage current consumed by the source (I) [26]. This can use (4):

$$Efficiency\ (\eta) = Power\ output\ (\text{Pout}) / Power\ available\ (\text{Pin}) \tag{4}$$

2.3.2. Performance ratio of photovoltaics

The solar radiation values measured at the location yielded an average value for the entire analysis period of 721 W/m^2 using the AS823 digital Lux meter [20]. This solar radiation value is extrapolated to the PV generator modular area as (5) [27]. In (5) can be used to determine energy potential:

$$Energy\ potential = Irradiation\ value\ in\ (W/m^2) \times Plant\ area\ in\ (m^2) \tag{5}$$

Efficiency factor of the PV modules is 20.6% [18]. To further calculate the nominal generator output, the solar radiation value for the PV generator is multiplied by the efficiency factor. Meanwhile, to find out the amount of nominal plant output, you can use (6):

$$Nominal\ plant\ output = Energy\ potential \times Efficiency\ factor\ of\ the\ solar\ PV\ modules \tag{6}$$

The actual electrical energy exported by the generator to the network is 13,140 kWh. The formula for calculating the performance ratio of PVs. The PR is obtained by dividing the electrical energy actually by the modular efficiency.

$$Performance\ ratio\ (PR) = Electrical\ energy\ actually / The\ modular\ efficiency \tag{7}$$

3. RESULTS AND DISCUSSION

3.1. Conversion of sunlight intensity to solar radiation

The measurement of sunlight intensity was carried out from 9:00 am to 4:00 pm using the AS823 digital Lux meter. The following is the result of converting the intensity of sunlight to solar radiation with 120 Lux=1 W/m^2=0.0083 [28] as shown by Table 5. The average result of measuring the intensity of sunlight is 86,915 Lux. After being converted to solar radiation, the average value is 721 W/m^2. Simultaneously with the measurement of the intensity of sunlight, measurements of the Voc and Isc were also carried out using the PV200 tester [29].

Table 5. Convert sunlight intensity to solar radiation

No.	Time	Sunlight intensity (Lux)	Solar radiation (W/m^2)
1	9:00 AM	76,610	636
2	10:00 AM	97,270	807
3	11:00 AM	97,500	809
4	12:00 PM	92,860	771
5	1:00 PM	94,380	783
6	2:00 PM	87,380	725
7	3:00 PM	77,530	643
8	4:00 PM	71,790	596

3.2. Measurement of open circuit voltage and short circuit current

Figure 2 shows the average Voc is 47.58 V and the average Isc is 9.05. This shows that with a solar radiation level of 72% and an increase in the temperature of the PV by 59% from STC. With an average (Voc) value of 89.6% from (Voc) module of 53.1 V and 77.9% from (Isc) module of 11.62 A.

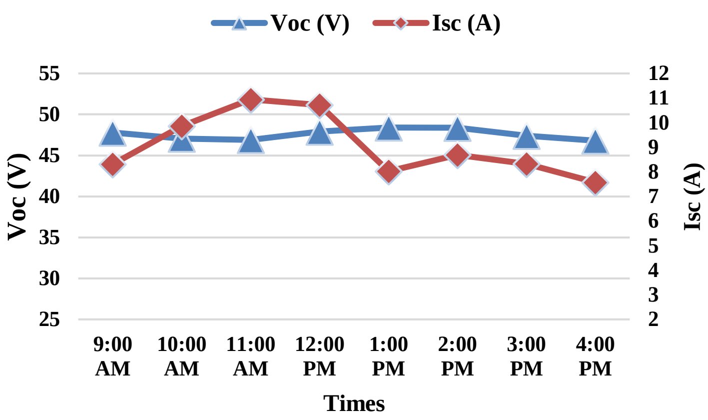

Figure 2. Voc and Isc measurement

The condition of the open circuit voltage (Voc) with the lowest value is 46.8 V and the highest value is 48.4 V so that there is a difference of 1.6 V. This change is influenced by changes in solar radiation during measurement. While the current condition of the short circuit (Isc) with the lowest value is 7.57 A and the highest value is 10.94 A so there is a difference of 3.37 A. This occurs due to a decrease in voltage, especially at 10:00 AM to 11 AM with the solar radiation level being at on 800 W/m^2.

3.3. Calculation of output power

After the Voc and Isc values are known. Then calculate the amount of Pout by multiplying the Voc generated by the PV in units (V) and the Isc consumed by the source in units (I). The result is as shown in Figure 3.

The highest output power produced by the PV of 43.66 kW occurred at 11:00 AM. The output power of the PV has a difference in value of 13.52 kW from the lowest value of 30.13 kW and the highest value of 43.66 kW. Thus, the output power value is an average of 36.61 kW or only 29.61% of the maximum power (Pmax) of the PV. The Pout can be said to be stable close to the Voc value of the PV.

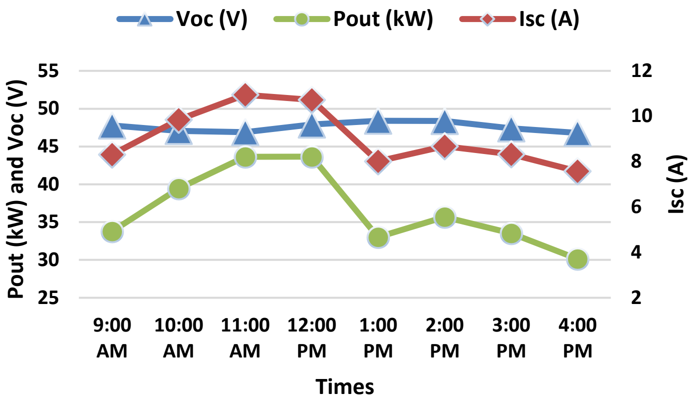

Figure 3. Photovoltaic output power calculation

3.4. Calculation of efficiency

The efficiency value of the PV is obtained by calculating the value of the Pout using (1). The Pout is 36.6 kW, where the FF according to (2) is 0.79 and 108 for the number of PVs. Then calculate the input power value of the PV using (3), where the solar radiation is 721 W/m^2 multiplied by a surface area of 2.36 m^2 and 108 number of modules to get a Pin of 83.8 kW. Complete results can be seen in Figure 4.

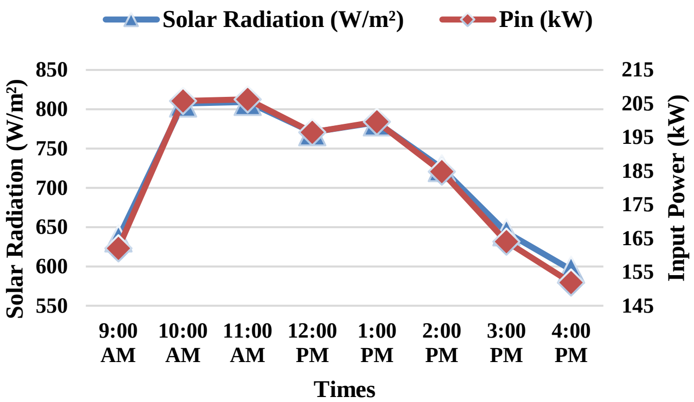

Figure 4. Photovoltaic input power calculation

The Pin of the PV has a difference of 54.39 kW from the lowest value of 151.88 kW and the highest value of 206.27 kW. This is influenced by the large value of solar radiation captured by the PV. Furthermore, to find out the efficiency value of the PV by calculating it using (4). Where the amount of Pout is 36.6 kW divided by the amount of Pin of 183.8 kW so that an efficiency value of 19.9% is obtained. This shows that the resulting efficiency value is better than the module efficiency value of 20.6%.

3.5. Calculation of performance ratio

Before calculating the performance ratio, it is necessary to know the energy potential using (5), where the solar radiation in units (W/m^2) is multiplied by the surface area of the PV module in units (m^2). With a solar radiation value of 721 W/m^2 multiplied by the number of days in a year 365 days a year's solar radiation value is 263.3 kWh/m^2 with a total surface area of the PV of 254.89 m^2. So that the energy potential is 67,115 kWh. Next, calculate the nominal plant output using (6), where the energy potential is 67,115 kWh multiplied by the efficiency factor of the PVs of 20.6%. So that the nominal value of the plant output is 13,826 kWh. Lastly, calculate the performance ratio using (7) with the actual electrical energy in a year of 13,140 kWh, then divide it by the nominal plant output of 13,826 to get a value PR of 0.967% or 96.7%, PR above 90% is still realistic [30]. Based on these results, this system is suitable for installation in transit-oriented development (TOD) areas and the choice of implementation is based on the resources available at the location [31].

4. CONCLUSION

Conversion of sunlight intensity to solar radiation can be done with a conversion factor of 120 Lux=1 W/m^2=0.0083 there is a voltage drop, especially at 10:00 AM to 11 AM with the solar radiation level being at 800 W/m^2. The output voltage can be said to be stable close to the Voc value of the PV. The input voltage is greatly influenced by the large value of solar radiation captured by the PV so that an efficiency value of 19.9% is obtained and a value PR is obtained of 0.967 or 96.7%. With these results, it can be concluded that the on-grid rooftop solar power plant Universitas Pamulang Viktor is feasible for operation because the installation system can produce optimal energy.

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