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Performance Analysis and Comparison of a 93.6 kW Grid-Connected Rooftop Photovoltaic System in South Tangerang

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Abstract: System performance analysis and comparison are necessities for ensuring the optimal operation of a photovoltaic (PV) power plant system. The primary metric that affects the PV system's productivity, dependability, profitability, ecological footprint, and grid compatibility are called Key Performance Indicators (KPIs). This study analyzes the KPIs of a 93.6 kW grid-connected rooftop PV system in South Tangerang and then compares them with the previous studies. Solar irradiation and output power data are collected. Then a modified extrapolation approach is used to fill in data gaps before proceeding with the performance parameter calculation. The performance indicator analysis refers to the IEC 61724-1 standard, including performance ratio (PR), final energy yield, system efficiency, system losses, and capacity factor. The results indicate that the PR, final energy yield, system efficiency, losses ratio, and average daily capacity factor varied from 82.0% to 91.6%, 2.94 to 3.70, 13.7% to 15.7%, 8.4% to 18.0%, and 12.12% to 15.67%, respectively. Compared to other studies, the PR values are much higher than expected. All of the other parameters, however, are normal. As a result, it shows that the PV system is working correctly.

Keywords: PV performance indicator; performance ratio; energy yield; system losses, system efficiency, capacity factor, data gap

1. Introduction

Solar energy has emerged as the most widely used in many countries. With roughly 3.1% of the world's power generated by solar energy in 2019 and predicted capacity growth of over 8% or an increase of almost 320 GW in 2022, solar energy with solar module photovoltaic (PV) continues to rank third among all renewable energy sources[1),2)]. Though Indonesia has the technical potential for solar energy up to 207 GW, the solar PV installed capacity by the end of 2020 was just 181.2 MW[3)]. Solar energy's simplicity as a stand-alone system, on-grid (rooftop PV, solar farm field), and hybrid with other energy sources with/without batteries is another reason developing countries choose this technology to minimize emissions[4–6)]. PV systems can also be implemented in the household sector[6)], which supports the prosumer to maintain the balance of its electricity demand and supply using an energy management system (EMS)[7)].

A good quality PV system is essential for the owner or utilities to ensure the power output and energy production conform to the PV module datasheet. Furthermore, PV modules and inverters represent the central part of the PV system and affect the system's CAPEX and return on investment (ROI), so performance and quality assessment should be done. PV systems' KPIs are the primary metrics that affect their performance, reliability, profitability, environmental impact, and grid integration.[8)]. KPIs are essential because they can give a comprehensive insight into the reliability of solar modules and inverters. It is crucial for long-term finance, especially for the investor[9)]. The PV power plant's performance depends on PV module type, power converter, installation, system configuration, and climate. Therefore, evaluating the PV power plant's performance is essential, as many countries have recently investigated[10–19)].

A PV power plant's performance evaluation requires operational data over a specific period. Therefore, a PV system typically includes a monitoring system capable of recording and displaying data while the system is in operation, such as Supervisory Control and Data Acquisition (SCADA) or a low-cost Internet of Things-based monitoring system[20–22)]. However, the monitoring system sometimes experiences problems that cause data did not record. This condition causes data gaps on certain days. To the best of our knowledge, there has not been any literature that explicitly describes data processing methods for PV system performance analysis.

This study uses a modified data processing method for the KPI parameter of the 93.6 kWp rooftop PV system in South Tangerang. The work aims to evaluate the performance of the 93.6 kWp rooftop PV power plant and compare it with other studies. Analyzing and assessing the PV power plant's performance appropriately is crucial because it can show the actual performance of a PV power plant. The excellent performance will encourage investment growth in PV systems.

2. PV System Description

In 2018, the 93.6 kWp rooftop PV system was installed at Building 625 Puspiptek, Serpong. There is no energy storage system between the PV array and the utility grid. The 93.6 kWp rooftop PV system comprised 288 units of polycrystalline solar modules with a nominal power of 325 Wp. The system is divided into 18 strings with 16 solar modules per string. A PV string's operating voltage (Vmpp) was 37.5 V_{DC}, so each string's operating voltage equals 600 V_{DC}. Every six strings were connected in parallel to form a PV array, so there were three PV arrays in this PV system. The PV array was installed with a slope of 15° and azimuth 0 in the north direction. Each PV array was connected to a PV inverter with 36 kW (2 units) and 33 kW (1 unit) capacity. This system has used the solar modules CS6U-325P and three solar inverters, SUN2000-36KTL (2 units) and SUN2000-33KTL (1 unit). The system's configuration can be observed in **Fig. 1**, while the actual view of the 93.6 kWp rooftop PV system is shown in **Fig. 2**.

The PV system is equipped with SCADA, which allows for actual monitoring of PV system production. SCADA recorded the solar radiation and the inverter output power for further analysis. The onsite solar radiation is measured using a pyranometer. Solar radiation data was measured by Davis Vantage Pro 2 Plus weather station installed beside the PV system on the rooftop. The weather station system is equipped with Modbus Gateway, so the Ethernet port of the weather system is directly integrated into SCADA. Meanwhile, the PV inverters have RS-485 communication ports integrated into the communication system with the addition of a Modbus Gateway and Ethernet Switch. The output data of the PV inverter is sent to the SCADA monitoring system using an ethernet cable. A detailed schematic diagram of the data monitoring system showed in **Fig. 3**

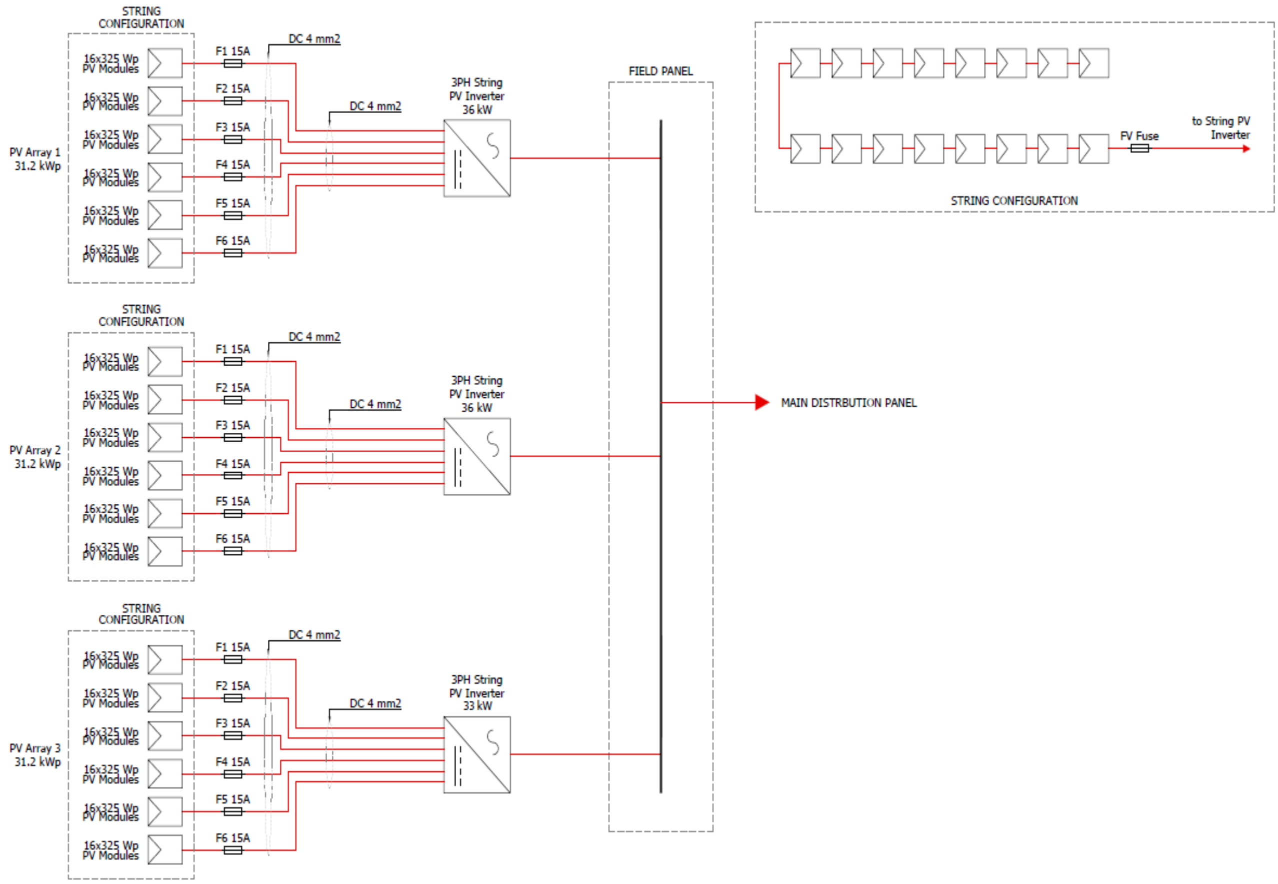

Fig. 1: The configuration of the 93.6 kWp grid-connected rooftop PV system at Building 625, Puspiptek, Serpong

Fig. 2: View of 93.6 kWp rooftop PV system at Building 625, Puspiptek, Serpong, South Tangerang

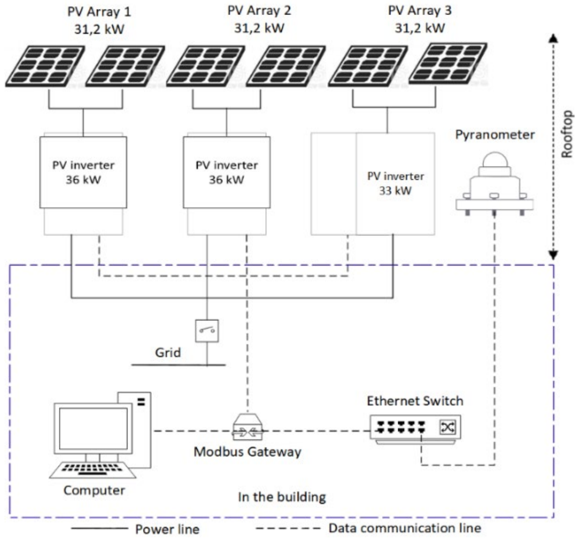

Fig. 3: Schematic diagram of data monitoring system

3. Data and Method

The research methodology steps are shown in **Fig. 4**. The initial step is collecting the solar radiation and the PV inverter's output power data for 2021. After the data was completed, the data were identified and calculated to obtain performance parameters. Lastly, the PV power plant performance was examined by analyzing the calculation results based on the IEC61724-1 standard.

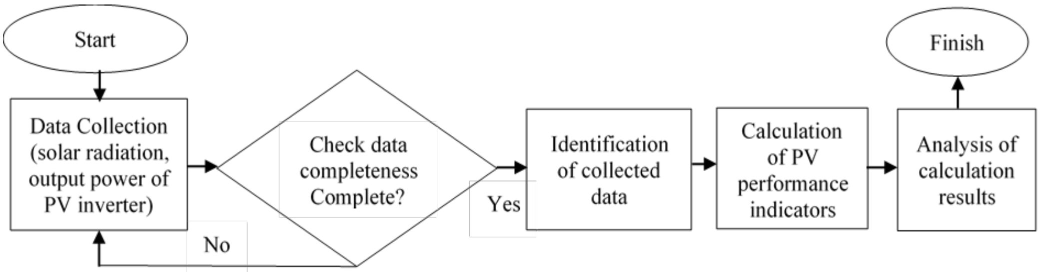

Fig. 4: Flowchart of step-by-step research methodology

3.1.Data Processing

The 93.6 kWp rooftop PV system at Building 625 Puspiptek, Serpong, has a monitoring system that enables data recording. In recording data, the monitoring system sometimes experiences problems that cause data did not record. This condition causes data gaps on certain days. This study had several data gaps, especially solar radiation data. At certain hours, the absence of solar radiation data is accompanied by a lack of PV power data. In this case, analysis cannot be carried out on the PV system. Another hand, PV power production data was recorded in one day, but solar radiation data did not record at certain hours. In this case, data processing was done to fill the solar radiation data gap. This data processing is performed by extrapolating available PV power data. Other gap-filling methods have also been recognized by other researchers[23,24]. However, our study can't use these methods because they also need data on Diffuse Horizontal Irradiance (DHI) and Direct Normal Irradiance (DNI).

Precisely, we followed these procedures during our study's data processing phase. First, determine the trendline of the PV power data chart. The trendline used was a second-order polynomial. Furthermore, the equation of the trendline uses to determine solar radiation (as the y variable) using PV power data (as the x variable). This polynomial equation determines the solar radiation pattern because the distinctive pattern of solar radiation is identical to the pattern of the PV power graph. A similar gap-filling method was also introduced by other researchers, which determined the gap data using the polynomial function estimated from the neighborhood data[25] and the solar radiation data gap-filling using polynomial fitting[26,27]. In general, the polynomial equation of the trendline of the PV power graph for calculating solar radiation is as follows.

$$y = ax^2 + bx + c \quad (1)$$

y is the calculated solar radiation, x is the PV power, while a, b, and c are constants in the polynomial equation.

In reality, PV power and solar radiation data have the same pattern but have very different values. This requires an additional formula that states a discrepancy between

PV output and solar radiation measurements. This difference did not calculate using a polynomial, but it calculates using the ratio formula between PV power and solar radiation. Thus, we develop the equation for determining solar radiation data that combines the polynomial and the additional formula, expressed by the following equation:

$$y = ax^2 + bx + c + \left(\frac{y_1 - x_1}{x_1} x\right) \qquad (2)$$

Where x_1 is PV power data, and y_1 is known solar radiation data at the same time as x_1 on the same day. Furthermore, this equation calculates the absence of solar radiation data.

3.2.PV Performance Evaluation

The processed PV power and solar radiation data determine the PV power plant's performance metrics like energy yield, performance ratio (PR), capacity factor (CF), energy efficiency, and system losses.

Yields

Energy yield is the energy taken from solar panels, considering external factors like heat, dirt, and shade, which is the most crucial determinant of PV performance. It is defined as the function representing energy transfer from the sun to the electrical grid, consisting of three parameters: reference, array, and final yield, as shown in **Fig. 5**. These parameters are measured in kilowatt-hours per kilowatt-peak (kWh/kWp) during a specific period.

Reference yield (Y_r) is the potential energy harvested from the sun at a given location and time. It is the ratio of the total irradiation in the tilted surface of the PV array (H_t) and the reference irradiance (H_R). It is similar to the total amount of daylight hours required to generate 1000 W/m^2 of electricity from solar radiation and is expressed as follows :

$$Y_r = \frac{H_t}{H_R} \qquad (3)$$

The array yield contains the array capture losses associated with temperature, partial shading, soiling, reflection, and others[28]. In comparison, the final energy yield (Y_f) is part of a loss system in which the loss of DC to AC conversion is included. It becomes an ideal parameter for normalizing the generated energy depending on the system size and is calculated as follows:

$$Y_f = \frac{E_{AC}}{P_{PV,rated}} \qquad (4)$$

Where; E_{AC} is the output energy of the PV system delivered to the network in Alternating Current (AC), and $P_{PV,rated}$ is the nominal power of the PV system in Direct Current (DC).

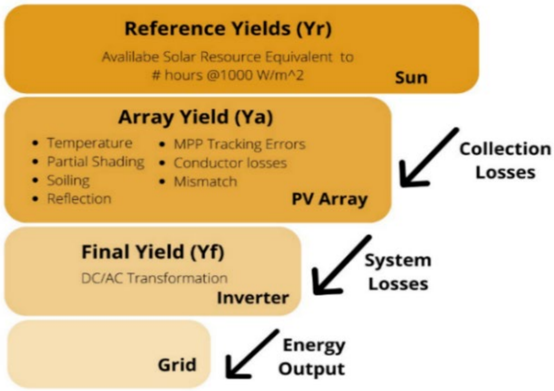

Fig. 5: The concepts of energy yield

Performance Ratio (PR)

A PV power plant's success or failure over a specific time frame may be gauged by its PR number. PV power plant systems with a higher PR value are more effective at transforming solar irradiation into usable electricity. Commonly, it has a value varying from 0.6 to 0.8. PR is calculated on a monthly and annual basis, taking the whole system's loss into account, and is regardless of the size of the system. Smaller PR calculations interval, such as weekly or daily, may be used to examine the frequency of component failures in large-scale commercial systems[29]. PR equation is obtained from the equation below[11,30]:

$$PR = \frac{Y_f}{Y_r} \, x \, 100\% \qquad (5)$$

The PR value relies on selecting solar radiation data that can be obtained from pyranometers, silicon reference cells, or satellite-based solar models. According to several observations, the pyranometer provides the most accurate radiation measurement by paying close attention to factors such as the precision of the sensors, maintenance, and calibration[8]. In terms of solar radiation measurements, there are varying opinions on what constitutes the most reliable data. Some partnerships consider that pyranometers obtain the best accuracy when high-accuracy sensors are used, well-cleaned, maintained, and calibrated.

Total Losses

The overall losses are the combination of collection losses (L_c) and system losses (L_s). The collection losses are attributable to the losses on the PV array, while system losses are related to the transformation from DC to AC via inverter[11], also known as inverter losses. The equation of collection losses and system losses is shown below:

$$L_c = Y_r - Y_a \qquad (6)$$

$$L_s = Y_a - Y_f \qquad (7)$$

Based on equations (5) and (6) above, the equation of total losses (L_{total}) can be determined by the calculation below:

$$L_{total} = L_c + L_s = Y_r - Y_a + Y_a - Y_f \quad (8)$$
$$= Y_r - Y_f$$

Total losses are usually expressed in normalized form, called total losses ratio, which is calculated using the formula below:

$$Ratio\ L_{total} = \frac{L_{total}}{Y_r} \quad (9)$$

The total losses ratio complements PR, so their sum equals 1. This is the proportion of available solar energy lost during the conversion process.

Capacity Factor (CF)

The capacity factor is not a standard parameter. This is determined by the proportion of the actual energy produced to the energy generated by a power plant continually operating at total capacity. It is expressed in % occasionally in hours/year. The occasional capacity factor can be calculated using the equations below:

$$CF_d = \frac{E_{AC,d}}{P_{PV,rated}\ x\ 24} \quad (10)$$

$$CF_m = \frac{E_{AC,m}}{P_{PV,rated}\ x\ 24\ x\ D} \quad (11)$$

$E_{AC,d}$ is the daily energy production and $E_{AC,m}$ is the monthly energy production of a specific month, while D is the total days in the particular month. The average yearly CF ranges from 0.1 - 0.2 [8]. This value cannot be higher since the length of daylight inhibits the PV power plant's production at its maximum capacity.

System Efficiency (ηsys)

The system efficiency represents the whole efficiency of the components used in the PV systems [12]. It can be calculated daily, monthly, or yearly. In this study, the authors estimated the value of the monthly system efficiency. It can be determined using the equation below

$$\eta_{sys} = \frac{E_{AC,m}}{H_t\ x\ S} \quad (12)$$

S is the entire area of the module surface (m²), and H_t is the total radiation reaching the surface of the modules (kWh/m²).

4. Results and Discussion

4.1. Data Analysis

The KPI of the 93.6 kWp rooftop PV system was evaluated based on annual data in 2021. The analysis was based on the data of inverter output power and solar radiation recorded on the monitoring system. These data were not fully available in one year, but some were not recorded for several reasons: 1) the system does not operate when the grid is off; 2) the system was operating but has yet to deliver electricity. This 93.6 kWp PV system can not form islanding when the grid is out and can not connect to the electricity grid automatically after the grid is out; 3) the system operates, but there is a problem with the communication system, so the data was not recorded. At the time when the data is not available, the PV system is considered inoperative. In this case, in April, November, and December, the PV system was deemed not to produce any energy because there was a problem with the communication system, so the data was not recorded correctly. On the other hand, some solar radiation data are not recorded for technical reasons. Extrapolation has been done using linear regression to determine the missing radiation data. The pyranometer in this PV system was installed in 2017, and until the data recording in this study, neither the pyranometer nor the PV system was cleaned.

The images below show an example of data processing on July 16th, 2021. **Fig. 6** shows the PV power and solar radiation data on July 16th, 2021. The figure shows that the solar radiation data were not recorded at certain times, while the PV power data was recorded entirely. In this case, solar radiation data will be determined by extrapolation utilizing the trendline of PV power data. **Fig. 7** shows the trendline, and the gap-filling calculation uses its equation. Then, solar radiation data determine by using PV power and solar radiation data when both were available. This process was resulting solar radiation data, as shown in the red graph in **Fig. 7**. Thus, PV power and solar radiation data were complete and can be used for further analysis of PV system performance parameters.

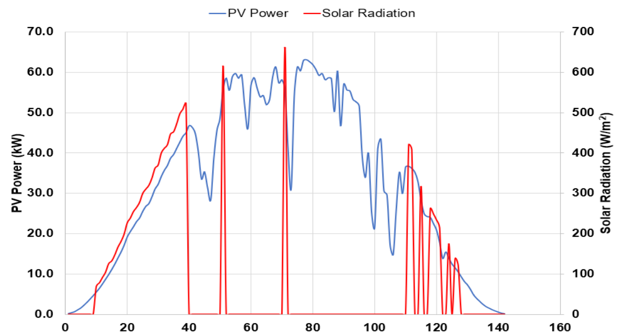

Fig. 6: Real data of PV Power and Solar Radiation on July 16th, 2021

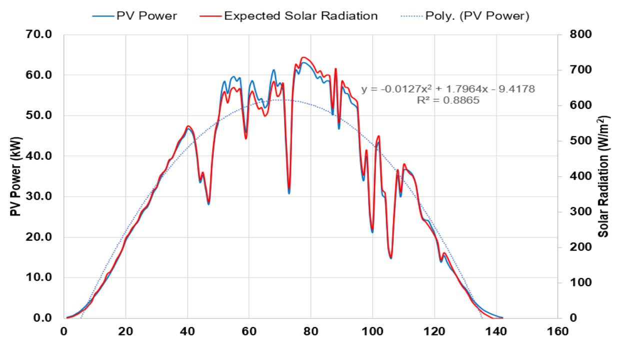

Fig. 7: Graph of PV power and expected solar radiation on July 16th, 2021 as the result of the calculation

Several KPI parameters were evaluated to understand the performance of the 93.6 kWp rooftop PV system, such as yields, performance ratio, total losses, losses ratio, energy production, capacity factor, and system efficiency. The calculation result of these parameters is shown in Table 1. This table shows the daily average value of each parameter mentioned above. There were no calculation results in April, November, and December because no data was available throughout the months. At the end of this research, the results of these parameters will be compared with those of previous research in other countries.

Table 1. Calculation results of several KPI parameters of 93.6 kWp rooftop PV system in Serpong, South Tangerang

Month	**Number day-on (days)**	**Average Daily Reference Yield (kWh/kWp-day)**	**Average Daily Final Yield (kWh/kWp-day)**	**Average Daily PR (%)**	**Average Daily Total Losses (kWh/kWp-day)**	**Average Daily Losses Ratio (%)**	**Energy Production (MWh)**	**Average Daily CF (%)**	**System Efficiency (%)**
Jan	23	3.38	3.08	91.6%	0.31	8.4%	6.09	12.12%	15.2%
Feb	26	3.46	3.14	90.7%	0.33	9.3%	7.08	13.21%	15.5%
Mar	31	4.14	3.70	89.6%	0.44	10.4%	10.16	15.41%	15.7%
Apr	-	-	-	-	-	-	-	-	-
May	12	3.74	3.40	91.2%	0.34	8.8%	3.62	15.45%	15.2%
June	13	3.24	2.94	90.7%	0.30	9.3%	2.66	13.51%	15.2%
July	30	4.04	3.66	90.1%	0.40	9.9%	8.56	15.67%	14.5%
Aug	31	4.06	3.65	89.4%	0.44	10.6%	10.54	15.13%	14.6%
Sept	20	4.20	3.66	87.5%	0.55	12.5%	6.84	15.23%	14.5%
Oct	3	4.32	3.55	82.0%	0.78	18.0%	1.00	14.78%	13.7%
Nov	-	-	-	-	-	-	-	-	-
Dec	-	-	-	-	-	-	-	-	-

4.2.Yields and Energy Production

This section only focused on the reference and final energy yield parameters to investigate the 93.6 kWp rooftop PV system. Table 1 shows that the maximum reference yield was 4.32 kWh/kWp-day, reached in October. In contrast, the minimum reference yield was achieved in June at 3.24 kWh/kWp-day. The highest final yield reached 3.70 kWh/kWp-day in March, and the lowest was 2.94 kWh/kWp-day in June. Based on this analysis, it can be seen that the highest reference yield in October resulting a lower final yield than other months that have lower reference yields.

The values of daily yields in October showed in Table 2 below. The number of days-on in this month was only three days. The reference yield on these days is relatively high, with the daily average above the daily average during the monitoring period. In contrast, the final yields give results relatively low than other months. This is likely caused by the increase in module temperature due to the high value of reference yield. This increase in module temperature can elevate the energy losses produced, resulting in a lower final yield[31)]. However, this needs further evaluation based on module temperature data, which was not measured in this study.

The reference yield and final yield comparison are shown in **Fig. 8**. The reference yield and final yield vary from 3.24 to 4.32 kWh/kWp-day and 2.94 to 3.70 kWh/kWp-day, respectively. Compared to the previous study in Butwal, Nepal, the reference yield and final yield vary from 3.87 to 6.20 kWh/kWp-day and 2.33 to 3.80 kWh/kWp-day, respectively[11)]. While the average daily reference yield and final yield in Baghdad, Iraq, were 6.07 kWh/kWp-day and 3.991 kWh/kWp-day, respectively[13)]. This study also compared the reference yield with the previous research at the exact location in 2020. The last study showed that the reference yield ranged from 3.17 kWh/kWp-day in February 2020 to 4.87 kWh/kWp-day in November 2019, and the final yield ranged from 2.60 kWh/kWp-day in January 2020 to 3.92 kWh/kWp-day in September 2019[10)].

Table 2. Energy yields during days-on in October 2021

Date	**Reference Yield (kWh/kWp-day)**	**Final Yield (kWh/kWp-day)**
Oct, 29th	4.49	3.78
Oct, 30th	4.71	3.83
Oct, 31th	3.77	3.03
The daily average in Oct 2021	4.32	3.55
The daily average during the monitoring period (Jan – Dec 2021)	3.90	3.49

Fig. 9 shows the daily energy production of the PV system in August, with the entire operation in one month. August's highest daily energy production was 453 kWh, and the lowest was 182 kWh. Moreover, the minimum monthly energy production was 1 MWh with 3 days of operation in one month, and the maximum energy production was 10.54 MWh with the entire operation in one month. The total energy production during this experimental study was 56.54 MWh. **Fig. 10** shows the energy production for each month and the number day-on as well. The figure also tells that the months with the entire

operation were March and August. The total day-on was 189 days during the experimental study, so the average daily energy production was 299 kWh/day.

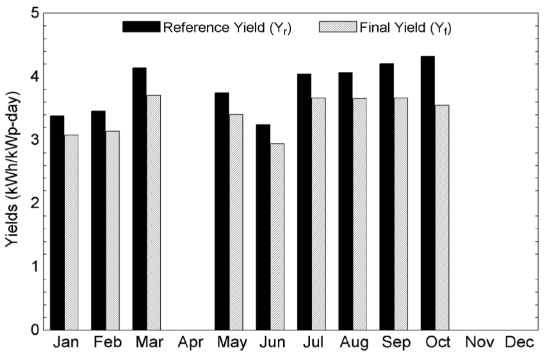

Fig. 8: Graph of reference yield and final yield of the 93.6 kWp rooftop PV system at Building 625 Puspiptek

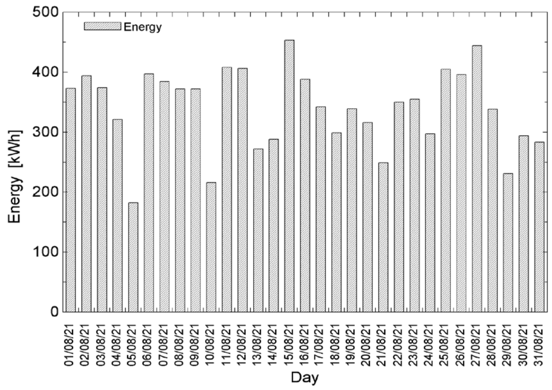

Fig. 9: Graph of energy production of the 93.6 kWp rooftop PV system at Building 625 Puspiptek

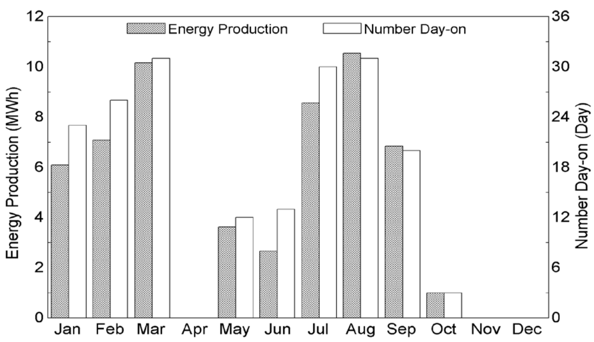

Fig. 10: Graph of energy production and number day-on of each month

4.3.Performance Ratio (PR) and Total Losses

Table 1 shows that the average PV power plant daily PR value varied from 82% to 91.6%, with the annual PR value being 89.0%. This value is relatively higher than the PV system's PR average value. This case must be attention for further evaluation. The average performance ratio value ranged from 25% to 70% before 1995, 65% to 80% from 1995-2010, and 75% to 90% after 2010[32]. The uncleaned and uncalibrated pyranometer may cause a higher PR in this research. So, the pyranometer gives the lower measurement result of radiation data that caused the lower reference yield, and the implication will generate the higher PR. The inaccurate measurement of the pyranometer also affects the reference yield and loss analysis. In contrast, October's PR is substantially lower compared to previous months. According to the investigation, there was no shading surrounding the plant's location. The probable cause is the module's high temperature, which results in significant PV array losses.

Other studies also found a high PR value above 90%. The PR of PV systems in Morocco ranged from 58% in December to 98% on January[33], while PR in Lucknow, India, ranged from 55.7% to 93.14 %[34]. The studies were conducted in 2016 and 2020. Results from prior research conducted in the same area but using a different PV system were compared with those from the present study. The previous study showed that the PR value varied from 79.45% to 87.58% and was conducted in 2019-2020, using the same pyranometer[10]. Another study in Morocco shows that the PR value of the Poli-Si PV system is 68.61% - 79.26%[12].

The PV system's total losses resulted from the conversion process by various components, such as PV modules, inverters, and cables[33]. The value of average daily total losses in this research ranged from 0.30 kWh/kWp/day to 0.78 kWh/kWp/day, as shown in Table 1. The table also gives information about the daily total losses ratio ranging from 8.4% to 18%. The average daily PR and total losses value are shown in **Fig. 11**.

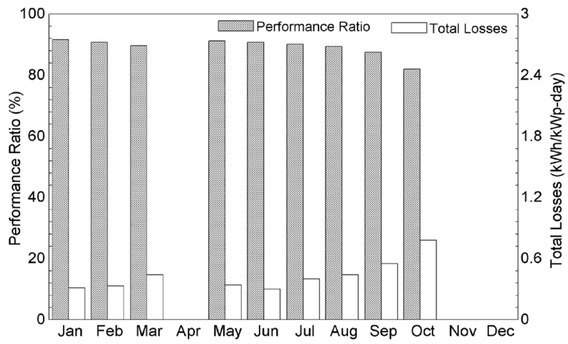

Fig. 11: Graph of average daily PR and total losses of the 93.6 kWp rooftop PV system at Building 625 Puspiptek Serpong

The total losses are complementary to the performance ratio, so the sum of PR and the percentage of total losses must be 100%. The complementary relation between daily PR and the ratio of total losses is shown in **Fig. 12**. Total losses represent the proportion of reference yield that cannot be turned into electricity. In contrast, the final yield represents the portion of the reference yield converted to energy. So, the sum of the final yield and total losses is the reference yield. This relation represents in **Fig. 13**.

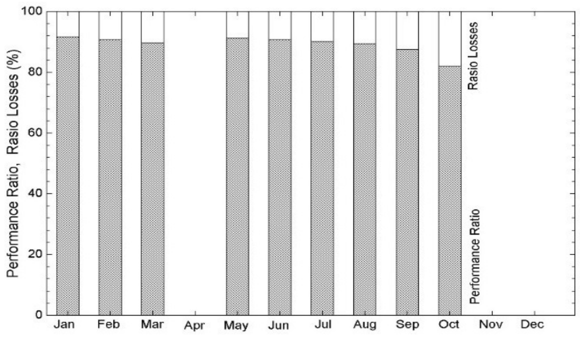

Fig. 12: Complementary of average daily PR and ratio losses of the 93.6 kWp rooftop PV system at Building 625 Puspiptek Serpong

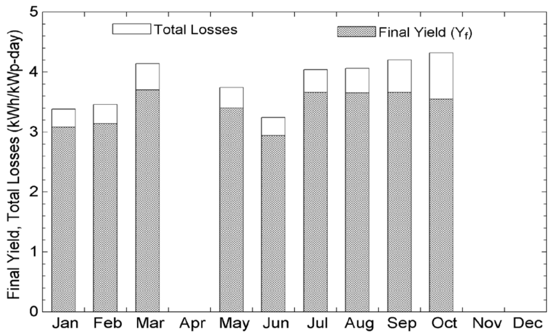

Fig. 13: Average daily final yield with corresponding daily total losses of the 93.6 kWp rooftop PV system at Building 625 Puspiptek Serpong

4.4.Capacity Factor (CF)

This research calculated the daily capacity factor (CF_d). The result of the daily CF of the 93.6 kWp rooftop PV system in Building 625 is mentioned in Table 1. The table informed that the lowest average daily CF of the PV system was 12.12% in January, and the highest average was 15.67% in July. The daily CF describes how long the PV system operates daily at its total capacity, which is strongly related to energy production. The result shows that the average daily CF ranges from 12.12% to 15.67%. The PV system was operated on average for 2.9 to 3.8 hours daily at its total capacity. The graph of average daily CF is shown in **Fig. 14**.

The comparison of daily CF and energy production during August is shown in **Fig. 15**. The graph shows that daily CF and energy production have a strong relation. The CF value shows the quantity of energy production and is highly influenced by the PV system site condition. In August, the lowest daily CF was 8.12%, with an energy production of 182 kWh, and the highest daily CF was 20.16%, with an energy production of 453 kWh. The average daily CF in August ranged from 8.12% to 20.16%, so the PV system worked at its total capacity for 1.95 to 4.8 hours daily. Usually, the CF value ranges from 10 to 35%[8]. In this study, the daily CF of the PV system shows an expected value.

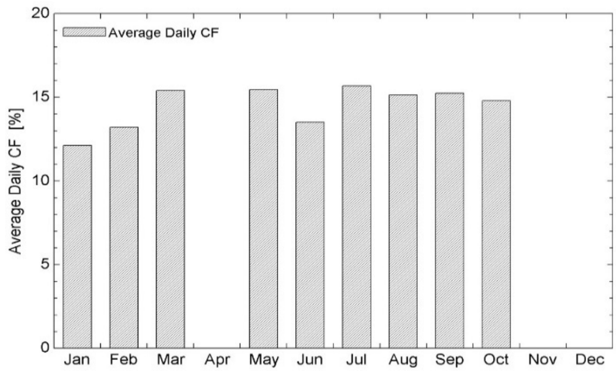

Fig. 14: Average daily CF of the 93.6 kWp rooftop PV system at Building 625 Puspiptek, Serpong

4.5.System Efficiency (μ_{sys})

Based on the information in Table 1, the system efficiency of the 93.6 kWp rooftop PV system varied from 13.7 % to 15.7 %. The polycrystalline PV modules have efficiencies between 15% to 17%[35]. The value of system efficiency depends on the technology of the PV module used in the PV system and is influenced by the temperature of the PV module. Polycrystalline PV modules have a higher temperature coefficient. When the temperature rises, it will enhance the losses of free carriers, so polycrystalline modules will lose more efficiency[36]. Otherwise, the PV system's efficiency was not influenced by energy production. The graph of the system efficiency and energy production shown in **Fig. 16** informs no correlation between system efficiency and energy production.

The KPI parameters calculated in this research compared to other studies in various countries. The summary of the comparison is shown in Table 3. Typically, the performance of the PV system is calculated every year. Nevertheless, figuring for a shorter period, maybe daily or weekly, will be beneficial to determine the component failures[37]. Besides, the experimental period shorter than one year has advantages, such as adequate accuracy and providing earlier results to enhance the system performance[38]. Other researchers also conducted calculations during a period shorter than one year, such as one month[13] and three months[39].

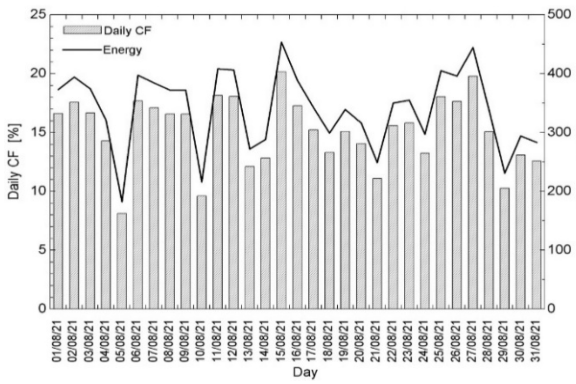

Fig. 15: Daily CF and energy production of 93.6 kWp rooftop PV system in August 2021

Table 3. PV performance comparison of other countries

No	PV System Capacity	Location	Data Collection Period	PR (%)	Final Yield / Y_f (h/day)	CF (%)	System Efficiency/ η_{syst} (%)	Reff.
1	10.6 kWp grid-connected	South Tangerang, Indonesia	8 months	79.45 - 87.58	2.60 - 3.92	10.84 - 16.35	14.24 - 15.69	10)
2	8.5 MWp grid-connected	Butwal, Nepal	12 months	54 - 77	2.33 - 3.80	9.7 - 15.8	-	11)
3	2.04 kWp grid-connected	Casablanca, Morocco	12 months	76.7	3.63 - 5.33	18.86	11.7	12)
4	2.04 kWp grid-connected		12 months	75.6	3.45 - 5.36	18.64	11.4	
5	1.86 kWp grid-connected		12 months	73.1	3.21 - 5.14	18.05	7.21	
6	5 kWp hybrid PV system	Diyala, Iraq	1 month	65.4	3.991	-	-	13)
7	5 kWp grid-connected	Tangier, Morocco	12 months	58 - 98	1.96 to 6.42	14.84	11.41 - 12.93	14)
8	467.2 kWp grid-connected	Lucknow, India	3 years	55.7 - 93.14	-	11.25 - 17.60	-	15)
9	23 MWp grid-connected	Diass, Senegal	12 months	77.3 - 78.8	3.42 - 4.55	14 - 19	-	16)
10	6 MWp grid-connected	Zaouiet Kounta, Algeria	12 months	62.27 - 84.89	4.88 - 5.62	20.32 - 23.4	9.54 - 12.88	17)
11	4.2 kWp grid-connected (1)	Tsukuba, Japan	12 months	80.51	4.05	-	10.69	40)
12	4.2 kWp grid-connected (2)		12 months	86.50	3.85	-	10.24	
13	2.2 kWp grid-connected (1)		12 months	76.06	3.95	-	10.17	
14	2.2 kWp grid-connected (2)		12 months	74.69	3.90	-	9.93	
15	2.2 kWp grid-connected	Fortaleza, Brazil	12 months	82.9	4.6	19.2	12.6	18)
16	4 kWp grid-connected	Kumasi, Ghana	12 months	70.8	3.08	12.8	-	41)
17	4 kWp grid-connected		12 months	48.8	2.12	8.8	-	
18	4 kWp grid-connected		12 months	69.8	3.07	12.6	-	
19	4 kWp grid-connected		12 months	63.4	2.8	11.47	-	
20	4 kWp grid-connected		12 months	71.3	3.10	12.9	-	
21	15 kWp grid-connected	Baghdad, Iraq	12 months	66.5 - 83.81	4.4	14.93 - 20.3	11.74 - 14.8	19)
22	48 kWp grid-connected	Nouakchott, Mauritania	12 months	69.69 - 89.35	3.91 - 5.09	16.31 - 21.25	8.52 - 10.92	42)
23	93.6 kWp grid-connected	South Tangerang, Indonesia	9 months	82.0 – 91.6	2.94 – 3.70	12.12 – 15.67	13.7 – 15.7	This Study

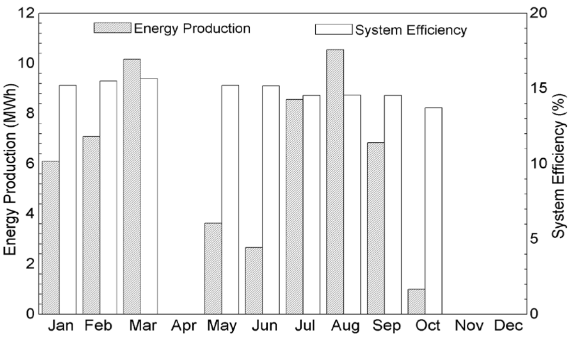

Fig. 16: Graph of system efficiency and energy production of 93.6 kWp rooftop PV system at Building 625 Puspiptek Serpong

5. Conclusion

This study evaluated the KPIs of a 93.6 kWp rooftop PV system in South Tangerang. The data processing technique for solar radiation data gap filling was also completed. The result of the study showed that the reference yield and final yield vary from 3.24 to 4.32 kWh/kWp-day and 2.94 to 3.70 kWh/kWp-day, respectively. The daily PR average value of the PV system ranged from 82 % to 91.6 %. This value is relatively higher than the standard value. The lowest average daily CF of the PV system was 12.12 % in January, and the highest average was 15.67 % in July. Lastly, the system efficiency of the 93.6 kWp rooftop PV system varied from 13.7 % to 15.7 %. The PR values are much greater than predicted when compared to previous investigations. However, every other parameter is average. As a result, it verifies that the PV system is operating well.

Furthermore, several issues were discovered during this study, including data gaps during data collecting and significant losses on specific days. Consequently, many preventive measures must be taken. It is vital to regularly inspect the monitoring system to prevent data gaps during data collection. Integrating the PV system with a module and ambient temperature sensor is also incredibly valuable for analyzing high losses. Moreover, it is preferable to analyze the performance of a PV system at shorter periods, such as daily or weekly, so that current problems and failures can be identified instantly. It will assist the operator in taking corrective action to make the system more efficient and cost-effective.

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Nomenclature

PV	Photovoltaic
KPI	Key performance indicator
PR	Performance ratio (%)
Y_r	Reference yield (kWh/kWp/day) or (h/day)
Y_f	Final yield (kWh/kWp/day) or (h/day)
CF	Capacity factor (%)
CF_d	Monthly capacity factor (%)
CF_m	Daily capacity factor (%)
L_c	Array capture losses
L_s	System losses
L_{total}	Total losses
η_{syst}	System efficiency (%)
E_{AC}	Energy AC delivered to the grid (kWh)
$E_{AC,m}$	Monthly energy AC delivered to the grid (kWh)
$E_{AC,d}$	Daily energy AC delivered to the grid (kWh)
E_{DC}	Energy DC produced by PV system (kWh)
$P_{PV,rated}$	Daya nominal PV system (W)
H_t	Global solar radiation (kWh/m^2)
H_R	The PV system's reference irradiance (kWh/m^2)
S	The total surface area of PV modules

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