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Analysis of a 735 kWp On-Grid Solar Power Plant System on the Rooftop of the Main Office of PT. Pertamina Hulu Rokan

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ABSTRACT

This research analyzes the performance and design of a 100 kW Photovoltaic Solar Power Plant (PLTS) using a Sun-huawei 100 KTL type M1 inverter, which produces 918.75 kVA. The series circuit requires 5-24 solar panels (390 Wp), while the parallel circuit needs 3 panels, with input voltages between 200 V and 1.1 kV. Sankelux solar panels (390 Wp) have a fill factor of 0.85 and 19.88% efficiency. To achieve 735.15 kWp, 1,885 panels (390 Wp) are needed, optimized to 1,884 panels (390 Wp) plus 1 panel (240 Wp), totaling 735 kWp. The circuit includes 20 panels per string for 80 strings and 19 panels per string for 15 strings. Voltage drop analysis shows a maximum standard regulation of 2%. The highest values occur in wings 4 and 5, with voltage drops of 19.16 volts (1.97%) on string 4-7-1_4-7-20 (210.59m) and 19.39 volts (1.99%) on string 5-13-1_5-13-20 (213.11m). Other strings remain within the 2% limit according to NEC standards. It is recommended to use the SNI: PUIL.2020 standard with a voltage drop regulation of 3%. Performance ratio calculations show a value of 84%, meeting the standards set in the regulations (70%-90%) based on IEC 61724 standards. These results indicate excellent performance for the solar power plant in maintaining operational reliability for 25 years. This study emphasizes the importance of proper component selection and careful planning in solar power plant installations.

Keywords: PLTS, Inverter, Solar Panels, PLTS Analysis.

1. Introduction

The utilization of solar power plants (PLTS) is a technological innovation in harnessing solar energy into electricity using the photovoltaic method [1]. In Indonesia, the average solar energy potential is 4.2-4.8 kWh/m² [2][3]. Throughout the year, Indonesia receives relatively constant solar radiation [4]. The government has set a target for solar energy capacity of 0.87 GWp by 2025. In 2020, the realized solar power plants (PLTS) capacity was only 0.15 GWp (17%). Indonesia's solar energy potential reaches 207.8 GWp. [4]. If calculated, the average target that must be achieved from 2021 to 2025 is 0.14 GWp per year.

One of the government agencies developing a program to accelerate Indonesia's clean energy transition is PT. Pertamina Hulu Rokan (PHR) in Rumbai, Pekan Baru, Riau Province. PHR is committed to building a 225 MWp solar power plant (PLTS) in two phases: Cluster-1 with a capacity of 25 MWp and Cluster-2 with a capacity of 200 MWp. Cluster-1 has been completed and partially operational since 2024, while the construction of Cluster-2 is still in the planning stage. The Cluster-1 PLTS is located on a 28.16-hectare site consisting of three locations: Area-1: On-Grid PLTS with a capacity of 21.015 MWp (84.06%) - ground-mounted at PHR's Duri camp oil and gas working area (WK). Area-2: On-Grid PLTS with a capacity of 3.25 MWp (13%) - ground-mounted at PHR's Rumbai WK, Pekan Baru. Area-3: On-Grid PLTS with a capacity of 735 kWp (2.94%) - on the rooftop of the Main Office of PHR's Rumbai WK, Pekan Baru. The construction of this PLTS is managed by PHR's project consultant, PT. Pertamina New and Renewable Energy (NRE).

Specifically for Cluster-1 PLTS, on the rooftop of the Main Office of PHR Rumbai, Pekan Baru. This PLTS has 7 inverters, each with a capacity of 100 kW. There are 1,885 solar panels installed, each with a capacity of 390 Wp. This PLTS uses a Recloser and Disconnecting Switch to connect (interconnect) to the PLN grid (On-Grid system). It is called an On-Grid system because the PLTS is connected to the national electricity grid (PLN), which optimizes the conversion of solar energy into electrical energy [5] [6][7].

This research aims to conduct a technical analysis related to the design, selection of appropriate components, system efficiency improvement, determination of the optimal number of solar panels, analysis of inverter usage, calculation of voltage drop occurring in the DC line from the solar panels to the inverter concerning the voltage drop regulation applied at PHR, which is a maximum of 2% using the National Electrical Code (NEC) standard [8]. Furthermore, it performs a calculation analysis of the PLTS performance ratio to ensure the reliability and operational feasibility of the PLTS.

Regarding previous research on PLTS analysis, it has also been discussed on [9] [10] [5]. The urgency of this research is to analyze the capacitance and efficiency of solar panels, calculate the voltage drop, and analyze the performance ratio capacity of the 735 kWp on-grid PLTS on the rooftop of the Main Office of PT. Pertamina Hulu Rokan. This discussion will provide benefits in validating the performance, reliability, system efficiency, and evaluation of the PLTS system. The main topic of this research is titled "Analysis of a 735 kWp On-Grid Solar Power Plant System on the Rooftop of the Main Office of PT. Pertamina Hulu Rokan".

2. Research method

2.1 Solar Panel Analysis

The analysis conducted aims to determine the number of solar panels to be installed. This is based on the calculation analysis performed in the study by [11][12] , using the following equation to determine the number of solar panels.

$$\text{Number of Solar Panels} = \frac{\text{Kap. PLTS}}{\text{Kap. Pv Module}} \tag{1}$$

Next, conduct an analysis to determine the input power of the solar panels. This refers to the study by [13][14], So that the power capacity of the Solar Panel input can be calculated with, the following

$$\text{Pin} = \text{Irr x Surface Area of PV (Meter)} \tag{2}$$

Determining the Fill Factor (Ff) of Solar Panels by performing calculations based on the research by [15][16] perform the calculation with the following equation.

$$\text{Ff} = \frac{V_{mp} \text{ x } I_{mp}}{V_{oc} \text{ x } I_{sc}} \tag{3}$$

Calculating the Maximum Power (Pmax) of Solar Panels based on the research by [17], perform calculations P_{max} as follows

$$P_{max} = \text{Voc x } I_{sc} \text{ x Ff} \tag{4}$$

Calculating the efficiency value of solar panels based on the calculations used in the research by [1]. The importance of knowing the efficiency value is to determine the level of energy that will be produced by the solar panels [18].

$$\eta = \frac{\text{V x I x Ff}}{\text{Irr x A}} \text{x}100\% \tag{5}$$

2.2 Inverter Analysis

Several analyses were conducted in this study related to the inverter, including determining the inverter capacity. Based on the research by [19], calculations were performed using the following equation.

$$x = \frac{P}{Q} \tag{6}$$

The next analysis determines the series and parallel circuit configuration of Solar Panels to the inverter. Based on the research by [20] [19] to calculate it, refer to the following equation.

Minimal series circuit

$$\text{Minimum PV modules in series of the string's} = \frac{\text{Vmin Inverter}}{\text{Voc PV Modul}} \tag{7}$$

maximum series circuit

$$\text{Maximum PV modules in series of the string's} = \frac{\text{Vmax Inverter}}{\text{Vmp PV Modul}} \tag{8}$$

maximum parallel circuit

$$\text{Maximum PV modules in parallel of the string's} = \frac{\text{Imax In Inverter}}{\text{Imp Modul}} \tag{9}$$

2.3 Drop Voltage Analysis

Determining the voltage drop in the DC lines of a solar power system (PLTS) refers to the IEC (International Electrotechnical Commission) standards, and the NFPA 70 – NEC (National Electrical Code) 2017 standards, as well as IEC 60364-5-52, which state that the voltage drop is allowed a maximum of 2-3% on DC branch circuits. To determine the amount of voltage drop that occurs in the DC lines of each solar panel string to the inverter, calculations can be made using the formula used in the research by [21] as follows.

$$V_r = \frac{[2.I.R_C.L]}{1000} \tag{10}$$

2.4 Performance Ratio Analysis

Based on the research by [22], the calculation of the performance ratio value is carried out through the following steps.

i. Calculating The Output Power of the Solar Power Plant (PLTS). According to the research by [23], the calculation of the output power of the solar power plant (PLTS) needs to be carried out due to component losses amounting to 15%. Therefore, the calculation can be performed using the following equation [24].

$$\text{Pi} = \text{Solar Power Plant x (100\%-15\%)} \tag{11}$$

ii. Calculating the Peak Sun Hours (PSH) value based on the research by [24], the calculation is performed using the following equation.

$$\text{Pout} = \text{Pi x PSH minimum} \tag{12}$$

$$\text{Pout} = \text{Pi x PSH maximum} \tag{13}$$

$$\text{Pout} = \text{Pi x PSH Average} \tag{14}$$

iii. Calculating the Energy Yield (Ey) to determine the energy produced by the solar power plant (PLTS) on an annual basis. The calculation analysis is based on the following equation [25].

$$\text{Ey} = \text{E Output PLTS x 365 days} \tag{15}$$

iv. Calculating the Performance Ratio (PR) first involves calculating the ideal energy (E ideal) produced by the solar power plant (PLTS) system [11]. It can be calculated as follows.

$$\text{Eideal} = \text{Htilt x Daya Per-PV x Number of Solar Panels} \tag{16}$$

v. To determine the ideal energy produced by the solar power plant (PLTS), based on research by [11] can be calculated using the following equation.

$$\text{Htilt} = \text{PSH} \times 365 \tag{17}$$

vi. Calculating the Performance Ratio (PR) based on the research by Leloux et al. (2012)[23], the PR calculation is performed using the following equation.

$$\text{PR} = \frac{\text{Ey}}{\text{Eideal}} \times 100\% \tag{18}$$

The result of the performance ratio (PR) calculation is a determinant of the capacity of the solar power plant (PLTS) itself. A PLTS is considered feasible to operate if it has a PR value of 70%-90% [26].

2.5 Electrical Design

The specifics of this research involve analyzing the electability and factors for selecting inverter capacity, calculating considerations for the circuit used as the input energy from the solar panels to the inverter. Then, it includes calculating the solar panels, such as studying the capacity and determining the number of solar panels, and analyzing calculations to determine the efficiency level of the solar panels to be used. Furthermore, it involves analyzing the voltage drop that occurs when electricity flows from the solar panels to the inverter in each wing, as the maximum voltage drop limit regulation is set at 2%, so the expected voltage drop should comply with the standards set at PHR. Additionally, it includes calculating the performance ratio to determine the energy capacity that will be produced by the PLTS and to determine the feasibility of the PLTS as a requirement for obtaining the PLTS operational eligibility certificate (SLO). The detailed design of the PHR PLTS system is shown in Figure 1 below:

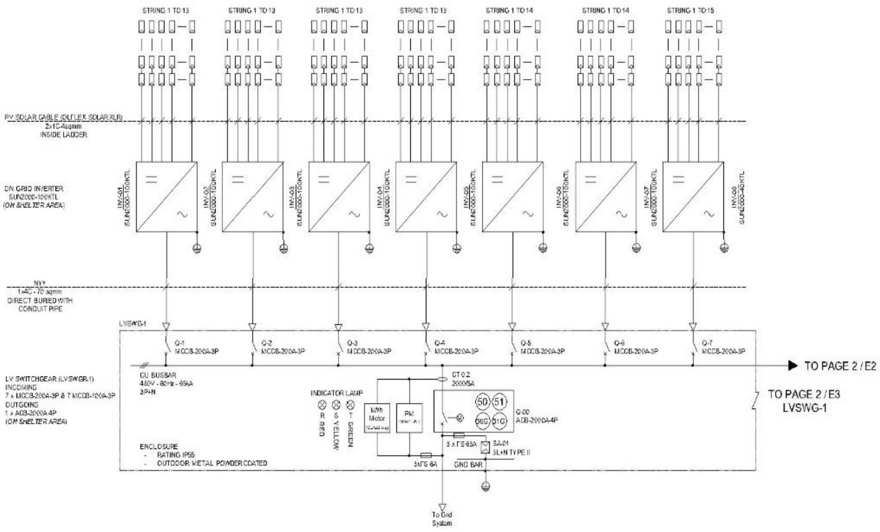

Figure 1. Detail Engineering Design (DED) PLTS 735 kWp

3. Results and discussion

3.1 Inverter

Table 1. Inverter Specification Data [27]

Item	Description
Inverter Sun2000-100 KTL-M1 Specifications :	
Efficiency	98,6%
Maximum input power	112.200 W
Maximum input voltage	1.100 V
Operating voltage range	200-1.000 V
Minimum star-up voltage	200 V
Maximum current per-MPPT	26 A

Item	Description
Frequency	50 Hz
Number of inputs	20
Power factor	0,8
Rated active power output	100 kW
Rated output voltage	220 V/380 V, 230 V/400 and 277 V/480
IP rating	IP66
Solar panel Merk Sankelux-300 Wp Specifications :	
Open Circuit Voltage (Voc)	48,74 V
Maximum Power Voltage (Vmp)	41,55 V
Maximum Power Current (Imp)	9,44 A

From the above specification data, several calculation analyses can be performed, including the following.

a. Determining the Apparent Power Capacity (Inverter Output) To perform the calculation analysis of the apparent power energy generated by the PV system at PHR with a capacity of 735 kWp and an inverter power factor based on the inverter specification data of 0.8, the following calculation analysis can be performed :

$$S = \frac{735\ \text{kWp}}{0{,}8}$$

$$S = 918{,}75\ \text{kVA}$$

So, the apparent power energy that will be generated by the PV system is 918.75 kVA. This is the total capacity that must be handled by the electrical equipment connected to the PV system, including the inverter and other protective equipment.

b. Minimum Series Circuit for Inverter Input :

$$\text{Minimum solar panel series of strings} = \frac{\text{Vmin Inverter}}{\text{Voc PV Modul}}$$

$$\text{Minimum solar panel series of strings} = \frac{200\ \text{Volt}}{48{,}74\ \text{Volt}} = 4{,}10\ \text{Units}$$

The minimum requirement for solar panels to the input or DC inverter connection connector, if a series configuration per string is performed, is at least 4.10 panels or rounded up to 5 panels per string.

c. Determining the Maximum Series Circuit for Inverter Input :

$$\text{Maximum solar panel series of strings} = \frac{\text{Vmax Inverter}}{\text{Vmp PV Modul}}$$

$$\text{Maximum solar panel series of strings} = \frac{1000\ \text{Volt}}{41{,}55\ \text{Volt}} = 24\ \text{panels}$$

Based on the results of several calculation analyses above, the number of solar panels required in a series configuration is 5 panels per string. The maximum number of solar panels in a series configuration leading to the inverter input per string is 24 panels.

d. Determining the Maximum Parallel Circuit for Inverter Input :

$$\text{Maximum solar panel parallel of strings} = \frac{\text{Imax In Inverter}}{\text{Imp Modul}}$$

$$\text{Maximum solar panel parallel of strings} = \frac{26\ \text{A}}{9{,}44\ \text{A}} = 2{,}75\ \text{panles}$$

Based on the results of several calculation analyses, the requirement for solar panels is determined by the configuration used. If using a series configuration, 5 panels are needed in one inverter input string, with a maximum of 24 panels. For a parallel configuration, the maximum requirement for solar panels as input to the inverter is 3 panels.

3.2 Solar Panel Calculation Analysis

Table 2. Spesification of Solar Panel [27]

Panel Surya Sankelux-390 Wp	
Nominal Max Power (Pmax)	390 Wp
Opt. Operating Voltage (Vmp)	41,55 V
Opt. Operating Current (Imp)	9,44A
Open Circuit Voltage (Voc)	48,74 V
Short Circuit Current (Isc)	9,87 A
Irradiasition	1000 W/m^2
Type of Cell	Mono-Crystalline
Dimentions	1980 x 1002 x 40 mm
Heavy	24 kg
Durability Standards	IP66

Based on the above specification data, several calculation analysis steps can be performed, including.

a. Solar Panel Fill Factor Analysis (Ff)

The calculation analysis of the solar panel fill factor is necessary as it determines the output power level of the solar panel. The calculation can be performed as follows.

$$\mathrm{Ff} = \frac{\mathrm{V_{mp}\ x\ I_{mp}}}{\mathrm{V_{oc}\ x\ I_{sc}}}$$
$$\mathrm{Ff} = \frac{41{,}55\ \mathrm{x}\ 9{,}44}{48{,}74\ \mathrm{x}\ 9{,}87}$$
$$\mathrm{Ff} = 0{,}82 \text{ or } 82\%$$

The result of the fill factor or the solar panel fill factor. The larger the fill factor (Ff) of the solar panel, the better the performance and efficiency of the solar panel. However, this calculation result is already considered good, as it is said to be good if the value ranges between 0.7 untul 0.85 [28].

b. Solar Panel Efficiency Value Analysis

The calculation can be performed as follows :

$$\eta = \frac{\mathrm{V\ x\ I\ x\ Ff}}{\mathrm{Irr\ x\ A}} \mathrm{x} 100\%$$
$$\eta = \frac{48{,}74\ \mathrm{x}\ 9{,}87\ \mathrm{x}\ 0{,}82}{1000\ \mathrm{x}\ 1{,}984} \mathrm{x} 100$$
$$\eta = 0{,}198\ 826\ 772\ 18\ \mathrm{x}100$$
$$\eta = 19{,}88\ \%$$

The results of the solar panel efficiency calculation indicate that the efficiency value obtained is 19.88%. Therefore, the efficiency value of the Sankelux solar panel is considered good because the rating for Mono-Crystalline type solar panels is above 14-22%[29], Thus, the calculated efficiency value of the solar panel is classified as good for application in the installation of a 735 kWp solar power plant on the PHR rooftop.

c. Analysis of Solar Panel Input Power

Calculation It is necessary to perform calculations to determine the incoming power or Pin of the solar panel. This can be done in several steps, starting with measuring the solar panel’s ability to absorb solar energy. If the solar panel specifications are known :

Irradiation = $1.000\ \mathrm{W/m^2}$
Dimentions = 1.980 mm x 1.002 mm

Therefore, it can be calculated as follows :

P_{in} = Irr x Efficiency of solar panel x A (Meter)
P_{in} = 1.000 W/m^2 x 19,88 % x (1.980 mm x 1.002 mm)
P_{in} = 1.000 W/m^2 x 19,88 (1,98m x 1,002m)
P_{in} = 1.000 W/m^2 x 19,88 x 1,984 m^2
P_{in} = 394,42 Watt

Based on the above calculations, it is known that the energy reception capacity (Wh/m²) for one solar panel is 394.42 Watts. Meanwhile, previous research resulted in an input power of 426.79 Watts with a solar panel specification of 535 Watts, an area of 2279 mm x 1134 mm, and an efficiency of 20.7%.

d. Analysis of Solar Panel Output Power Calculation

Calculating the output power of the solar panel is important to determine the capacity of power that will be generated by the installed solar panel. The output power of the solar panel (Pmax), also known as peak power (Watt Peak) in Wp units, is equal to the maximum output power (Pout) of the solar panel. Based on the calculations and data in Table 2 above, it can be determined as follows :

VOC = 48,74 V
ISC = 9,87 A
Ff = 0,82

Therefore, it can be calculated using the following formula

P_{max} = Voc x I_{sc} x Ff
P_{max} = 48,74 x 9,87 x 0,82
P_{max} = 394,47 Wp

The calculated output power of the solar panel to be used is 394.47 Wp, rounded to 390 Wp (as stated in the specifications of the Sankelux solar panel to be installed)

e. Analysis of Solar Panel Quantity Calculation

It is necessary to perform an analysis of the calculation of the number of solar panels as the main energy producer for the solar power plant. This is done to refer to other supporting components that will be used. Referring to Table 2 above, the calculation analysis can be determined as follows :

K_{PLTS} = 735 kWp
Solar panel Power = 390 Wp

$= \frac{735 \text{ kWp}}{390 \text{ Wp}}$

$= \frac{735.000 \text{ Wp}}{390 \text{ Wp}}$

= 1884,61 Unit “rounded to 1,885 solar panels”.

The calculation results above indicate that the total requirement for solar panels is 1,885 units. The calculation results show the suitability of the number of solar panels to be installed in the 735 kWp solar power plant on the Pertamina Hulu Rokan rooftop.

f. Number of Solar Panels in Each String

To determine how many strings are needed as the input voltage supply to the inverter from a total of 1,885 solar panels. This, of course, refers to the inverter input voltage limits based on the inverter specifications in Table 1, which is an input voltage range from 200-1000 VDC and a maximum of 1,100 volts. Meanwhile, for the solar panels, referring to the specifications in Table 2, the output voltage (VOC) of one solar panel is 48.74 volts.

From this data, an analysis can be performed to calculate the number of solar panels needed in one string as follows:

Known:

Max capacity voltage inverter = 1.100 Volt

Min capacity voltage inverter = 200 Volt

VOC of panels = 48,74 Volt

Quantity solar panel of strings $= \frac{\text{Max capacity voltage inverter}}{\text{VOC Panel Surya}}$

$= \frac{1.000\ \text{Volt}}{48{,}74\ \text{Volt}}$

= 20,51 panels

Based on the above calculations, the ideal number of solar panels per string is 20.51, rounded to 20 solar panels. This is due to the input voltage limit of the inverter per string being 1,100 volts.

g. Comparative Results of Calculation Analysis

Based on the above calculation analysis, a comparison can be made regarding the optimal result of the number of solar panels obtained, which is 1,884.61 units for 735 kWp of energy. However, when compared to using 1,885 solar panels consisting of 1,884 units each with a capacity of 390 Wp, the energy produced is 734,760 Wp, and 1 solar panel with a capacity of 240 Wp. Therefore, this will optimize the use of the number of solar panels with a capacity of 735 kWp.

3.3 Analysis of DC String Line Voltage Drop Calculation

Table 5. Highest Voltage Drop Data for Each Wings

Group	L (m)	String Code	Drop Voltage (Vr)	Persntas (%)
Wings 1	165,25	1-1-1_1-1-20	15,04	1,54
Wings 2	142,85	2-3-1_2-3-20	13,00	1,33
Wings 3	174,98	3-4-1_3-4-20	15,92	1,63
Wings 4	210,59	4-7-1_4-7-20	19,16	1,97
Wings 5	213,11	5-13-1_5-13-20	19,39	1,99
Wings 6	198,74	2-5-1_2-5-20	18,09	1,86
Wings 7	110,00	7-9-(9-19)_7-10-(1-9)	10,01	1,03

Based on Table 5, the comparison of the highest voltage drop ratings above shows that the highest voltage drop occurs in wings 4 and 5. For string code 4-7-1_4-7-20, the voltage drop reaches 19.16 volts with a percentage of 1.97% in wing 4, with a conductor length of 210.59 meters from the solar panel string point to the inverter. Meanwhile, for string code 5-13-1_5-13-20, the voltage drop reaches 19.39 volts with a percentage of 1.99% in wing 5, with a conductor length of 213.11 meters from the solar panel string point to the inverter. For more detailed information, the results can be displayed in the following graph:

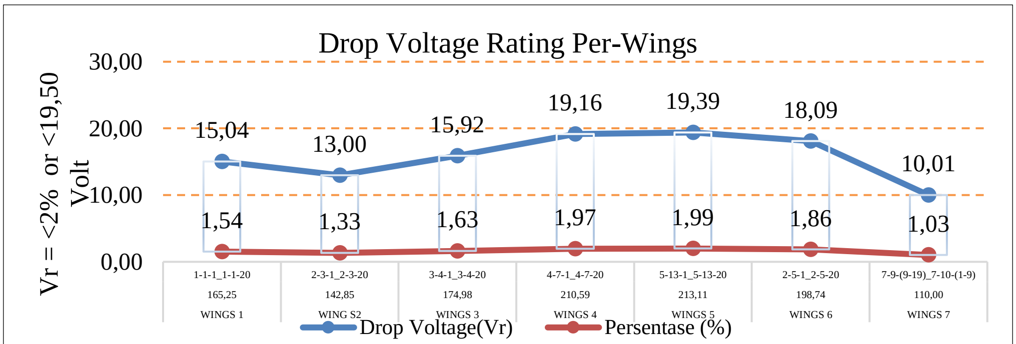

Figure 2. Graph of Highest Voltage Drop for Each Wing

Based on the results displayed in the graph above, it can be concluded that the voltage drop occurring in the strings with codes 4-7-1_4-7-20 and 5-13-1_5-13-20 is extremely high, approaching the regulatory voltage drop limit of 2%. It is recommended that these specific strings undergo an evaluation of the cable size used to ensure better compliance with the regulation concerning the significant voltage drop that is nearing the limit. Additionally, a reevaluation of the design is also suggested, as it could influence the case study further to achieve the desired capacitance prioritized as the expected voltage drop.

a. Comparative Results of Calculation Analysis

Based on the results of the comparative calculation analysis, the highest voltage drop value is approaching 2% of the regulatory standard set for the PHR solar power plant, which is guided by the European standard: National Electrical Code (NEC) [8]. Meanwhile, compared to the SNI: PUIL 2020 standard, it can be established that the voltage drop on single-phase conductor lines is a maximum of 3%. This will optimize the voltage drop value if taken from the highest value of 1.9%.

3.4 Analysis of Performance Ratio Calculation

Referring to the Global Horizontal Irradiation data taken from the Global Atlas Irradiations report in January, February, and March 2024, it was found that the average was 5.36 over the three days of measurement in Table 6 below :

Table 6. Solar Radiation at PHR Solar Power Plant in 2024 (00.584083°, 101.442417°)

Month	Daily Average (kWh/m²)	Monthly Total (kWh/m²)
January	5,14	154,18
February	4,66	139,86
March	6,29	188,67
Average	5,36	160,9

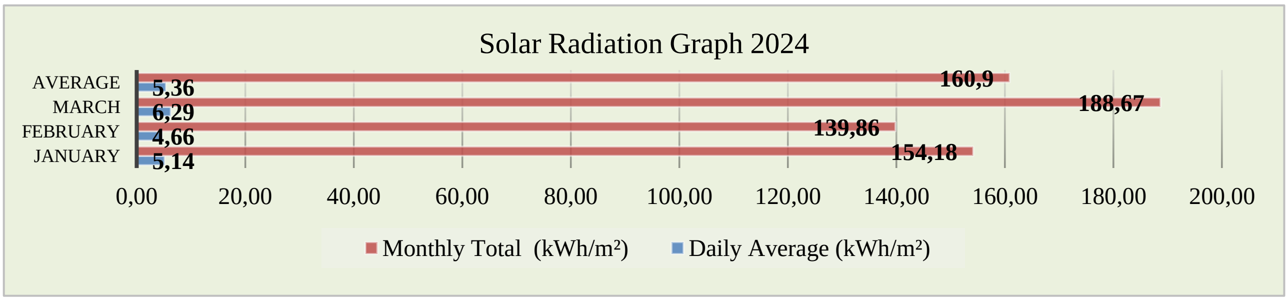

Figure 3. Average Solar Radiation Graph of PHR Solar Power Plant (PLTS) for the Year 2024

Based on the radiation data presented in Table 6 and Figure 3 above, it can be concluded that the average radiation at the Rumbai PHR Solar Power Plant (PLTS) at the coordinates 00.584083°, 101.442417° is 5.36 kWh/m² over three consecutive months, obtained from the global atlas report data accessible via the link: https://globalsolaratlas.info/. Next, to perform the calculation analysis of the Performance Ratio of the PHR Solar Power Plant, several calculation steps can be carried out as follows :

a. Calculating the output power (Pi) of the Solar Power Plant (PLTS)

Referring to the assumption that component losses (new equipment due to dust, dirt, etc.) have losses of 15%. The calculation can be carried out as follows :

Pi = Overall of Energys PLTS x (100%-15%)
Pi = 735 kWp x 85%
Pi = 735.000 Wp x 0,85
Pi = 624.750 Wp, or 624,75 kWp

From the above calculations, it is proven that the reduction or energy loss from a total of 1,885 solar panels with a total energy of 735 kWp becomes 624.75 kWp. The next step is to perform a calculation analysis of the minimum radiation (referring to Figure 3), where the peak sun hour (PSH) is 4.66 kWh/m², obtained from the global atlas data for February 2024. The calculation can then be carried out using the following equation :

Pout = Pi x PSH
Pout = 624,75 kwh/m2 x 4,66
Pout = 2.911,34 kWh

Based on these calculations, the lowest radiation result is 2,911.34 kWh. Next, referring to Figure 3, it is known that the highest PSH is 6.29 kWh/m², so the highest radiation produced by the Solar Power Plant (PLTS) can be calculated as follows :

Pout = Pi x PSH
Pout = 624,75 kwh/m2 x 6,29
Pout = 3.929,68 kWh

Based on the above calculations, the highest radiation result is 3,929.68 kWh. Next, referring to Figure 3 above, it is known that the average PSH is 5.36 kWh/m², so the average radiation produced by the Solar Power Plant (PLTS) can be determined by performing the following calculation :

Pout = Pi x PSH rata-rata
Pout = 624,75 kwh/m^2 x 5,36
Pout = 3.348,66 kWh

From the above calculations, the average output power of the Solar Power Plant (PLTS) is 3,348.66 kWh. Next, the energy yield calculation will be performed using the radiation energy produced from the above average energy, which can be done using the following equation :

Ey = Pout x 365 days
Ey = 3.348,66 kWh x 365 days
Ey = 1.222.261 kWh/year

From the above calculations, it is shown that the Ey calculation results from the total component losses of the solar panels against the PSH, resulting in an energy yield of 1,222,260.9 kWh/year. For more details, the amount of energy produced by the Solar Power Plant (PLTS) can be seen in Table 7 below :

Tabel **7.** Output Energi PLTS

Energy of the Solar Power Plant (PLTS) from the Lowest PSH (kWh)	Energy of the Solar Power Plant (PLTS) from the Highest PSH (kWh)	Energy of the Solar Power Plant (PLTS) from the Average PSH (kWh)	Energy Yield / Ey (kWh/Year)
2.911,34	3.929,68	3.348,66	1.222.260,9

b. Calculating the Performance Ratio (PR)

From the theory explained in Chapter 2, the performance ratio (PR) is considered feasible if it is in the range of 70% to 90%. To determine the capacity of the PR, it can be calculated based on the average PSH value of 5.36. The following is the calculation of the ideal energy of the Solar Power Plant (PLTS) :

Calculating Htilt as a parameter for determining the tilt direction of the Solar Power Plant (PLTS) in the Performance Ratio (PR).

Htilt = PSH x 365 days
Htilt = 5,36 kWh/m^2 x 365
= 1.956,4 h/year

From the above htilt results, an Htilt value of 1,956.4 kWh/year is obtained. Then, the calculation of ideal energy is as follows:

Eideal = Htilt x Power Per-PV x Number of PV
Eideal = 1.956,4 h/th x 735 kWp
Eideal = 1.437.954 kWh/year

Based on these calculations, an Eideal value of 1,437,954 kWh/year was obtained. Then, the calculation of PR is carried out according to the following equation :

$$PR = \frac{\text{Eyield}}{\text{Eideal}} \text{x} 100\%$$
$$PR = \frac{1.222.261 \text{ kWh/tahun}}{1.437.954 \text{ kWh/tahun}} \text{ x } 100$$
$$PR = 84\ \%$$

Based on the performance ratio calculations, a PR of 84% was obtained. This indicates that the overall solar power system (PLTS) meets the established standards, which are between 70% and 90% for the performance ratio of a PLTS. The purpose of calculating the performance ratio is to ensure the efficiency level of the PLTS operates under normal sunlight conditions. The higher the PR value, the better it is for the PLTS system to maintain reliability and performance.

c. Comparative Results of Calculation Analysis

Based on the results of the performance ratio calculation analysis for a 735 kWp solar power system, a comparison can be made between the manual calculation results and those obtained using the Helioscope simulation application. The manual calculation analysis yielded a performance ratio of 84.00%, while the performance ratio obtained using the Helioscope analysis was 79.00%. This indicates an increase in the performance ratio by 5%.

4. Conclusions

Based on the results of several calculation analyses conducted for the PHR solar power system design, The 100 kW PHR PLTS inverter (Sun-huawei 100 KTL type M1) produces an apparent power of 918.75 kVA. The series configuration requires 5-24 solar panels (390 Wp), while the parallel configuration only needs 3 panels, with a maximum input voltage of 1.1 kV and a minimum of 200 V. The Sankelux solar panels (390 Wp) have a fill factor of 0.85 and an efficiency of 19.88%. To achieve 735.15 kWp, 1,885 panel units are needed, with optimization requiring 1,884 units (390 Wp) plus 1 unit (240 Wp), resulting in 735 kWp. The configuration consists of 20 panels per string for 80 strings and 19 panels per string for 15 strings, making a total of 1,885 solar panel units. Based on the analysis results, the standard voltage drop regulation for the PHR solar power plant allows a maximum of 2%. However, the highest values occur in wings 4 and 5. In the string with code 4-7-1_4-7-20, the voltage drop reaches 19.16 volts (1.97%) with a conductor length of 210.59 meters to the inverter. Meanwhile, in string 5-13-1_5-13-20, the voltage drop reaches 19.39 volts (1.99%) with a conductor length of 213.11 meters. Other strings are safe as they do not approach the 2% standard voltage drop regulation of the European National Electrical Code (NEC). It is recommended to use the SNI: PUIL.2020 standard with a voltage drop regulation of 3%. The performance ratio calculation analysis yields 84%, which meets the performance ratio capacity standard according to IEC 61724, ranging from 70% to 90%. This is considered very good for the performance of a solar power plant in maintaining reliability over an operational period of around 25 years.

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