ELKHA : Jurnal Teknik Elektro, Vol. 17 No.1., April 2025, pp. 15 - 23
ISSN: 1858-1463 (print), 2580-6807 (online)

Analysis of 3 kW Solar Power Plant Production Optimization by Improving Energy Production Efficiency Using 3d Pvsyst Simulation Method

Teguh Mohammad Fiqri[1*], Redi Ratiandi Yacoub[2], Rudi Kurnianto[3], Rusman[4], and Hasan[5]

[1,4,5] Department of Electrical Engineering, Politeknik Negeri Pontianak, Indonesia
[1,2,3]Department of Master Electrical Engineering, Tanjungpura University, Indonesia
Corresponding Email : [*] teguhmohammad112@gmail.com

Abstract –**This study aims to analyze the effect of optimizing the position of solar panels on improving energy production efficiency in a 3 kW solar power plant (PLTS) system. The 3D PVsyst simulation method was used to model the system and predict performance before and after optimization. Simulation results indicate that repositioning the solar panels can increase energy production by 2% (from 0.99 kWh to 1.01 kWh). A comparison between simulation results and actual data shows reasonably good agreement, although some differences require further investigation. Discrepancies between simulation and actual data may be attributed to several factors, such as weather conditions, component efficiency, and other environmental factors. This study concludes that optimizing the position of solar panels is an effective step to enhance the performance of PLTS systems. However, further research is needed to consider additional factors affecting system performance and to develop more accurate simulation models.**

Keywords: Solar Power Plant (PLTS), optimization, PVsyst, simulation, energy efficiency

I. INTRODUCTION

Solar energy utilization generally takes two forms: converting sunlight into thermal energy and directly converting it into electricity using solar cells. Solar thermal systems collect heat by concentrating sunlight through mirrors or lenses to generate temperatures of up to 300°C / 20 bar, which are used to drive turbines. Meanwhile, solar cells convert electromagnetic waves from sunlight directly into electrical energy. This approach is commonly used in Solar Power Plants (PLTS).

Currently, the utilization of solar energy in Indonesia only accounts for 0.05% of its potential, and the installed capacity of Solar Power Plants (PLTS) is only 100 MW. This capacity needs to increase by 900 MW to meet the targets set in the National Energy Plan (RUEN). The Government's goal of building 6.5 GW of PLTS by 2025 must also be pursued. PLTS is part of the energy solutions for the future, contributing to better air quality.

In the National Energy Plan, as outlined in Presidential Regulation No.79 of 2014, the Indonesian government has set a policy to increase renewable energy in the national energy mix to 23% by 2025 [2]. To support this effort, particularly in solar energy utilization, the government has issued several technical regulations as implementation guidelines. One such regulation is the Minister of Energy and Mineral Resources Regulation No.49 of 2018, amended by Regulations No.13 of 2019 and No.16 of 2019, regarding the use of rooftop solar power systems by customers of PT Perusahaan Listrik Negara (PLN) Persero [3].

This regulation aims to create opportunities for all PLN customers, including households, businesses, government institutions, social organizations, and industries, to participate in utilizing and managing renewable energy for achieving energy security and independence, especially solar energy (EBTKE, 2018). To promote widespread implementation, the government issued Circular Letter No. 363/22/MEM.L/2019 to Cabinet Ministers, Governors, and Regents/Mayors, encouraging the installation of rooftop PLTS systems in buildings, including offices, official residences, warehouses, parking areas, and public facilities [4].

This research focuses on analyzing the energy production of a 3 kW PLTS installed at Polnep. The goal is to improve the efficiency and performance of the existing system. To achieve this objective, the author will use PVsyst software and data from the Sunny Boy SMA inverter already in place at the PLTS.

PVsyst is software used for photovoltaic (PV) system simulation and analysis. Using PVsyst, the author can simulate PLTS performance based on various parameters such as geographical location, panel orientation, and weather conditions. PVsyst also enables the evaluation of different design and operational scenarios to identify the most efficient configuration for the PLTS system. The PVsyst simulation is configured to match the geographic and site-specific conditions of the existing PLTS, providing optimal data for simulations and enabling effective system planning.

Additionally, the author will focus on data collection from the Sunny Boy SMA, an inverter used in the 3 kW PLTS at Polnep. The Sunny Boy SMA can monitor and record energy production data in real time, providing accurate information about system performance. Data from the Sunny Boy SMA will be used for an in-depth analysis of energy production, identifying factors affecting

Manuscript received 2025-01-16 ; revised 2025-03-02; accepted 2025-03-03

efficiency, and finding solutions to improve system performance.

The primary focus of this research is to analyze the energy production of the 3 kW PLTS installed at Polnep. By integrating PVsyst simulations and real-time data from the Sunny Boy SMA, the study aims to provide a comprehensive understanding of system performance and effective optimization strategies. This research is expected to offer practical benefits in PLTS management, such as reducing operational costs, increasing system reliability, and contributing to greater carbon emission reductions.

The results of this study will not only benefit Polnep in managing its PLTS system but also serve as a valuable reference for implementing PLTS in other locations. By improving energy production efficiency in PLTS, we can support the transition to broader and more sustainable renewable energy use.

In conclusion, this research aims to optimize the performance of the 3 kW PLTS at Polnep through energy production analysis and simulation using PVsyst. It also conducts simulations to assess the existing PLTS needs for building energy requirements through 3D modeling in PVsyst software. This approach is expected to make a positive contribution to renewable energy development and environmental preservation. The author also seeks to explore and study the potential of the installed PLTS in the context of West Kalimantan, especially in Pontianak City.

II. METHODOLOGY

A. *Methods of Research*

This study employs a quantitative method to analyze and optimize energy production in a 3 kW Solar Power Plant (PLTS) installed in a building at Politeknik Negeri Pontianak (Polnep). Utilizing PVsyst software with 3D-based simulations combined with SketchUp software for 3D visualization and real-time data from the existing Sunny Boy SMA inverter.

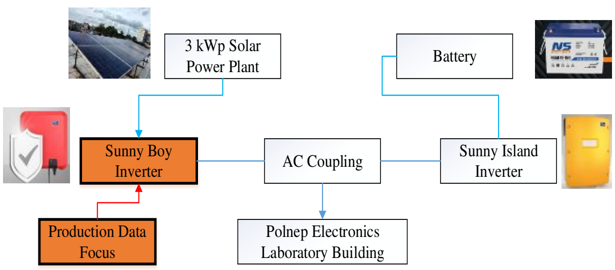

Figure 1. Analysis Focus Scheme

His research aims to examine and analyze improvements in energy production efficiency through the identification and evaluation of factors affecting system performance.

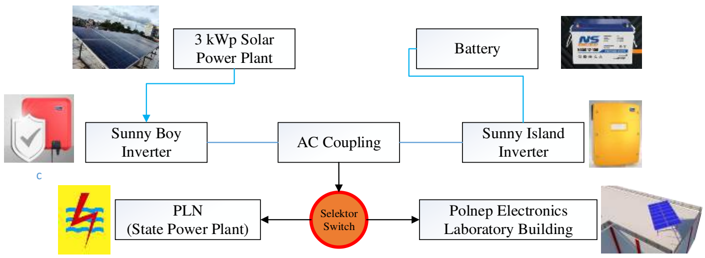

Figure 2. Existing Scheme

This quantitative analysis will produce optimization strategies that can be implemented to achieve improved performance and energy production efficiency in the Solar Power Plant system.

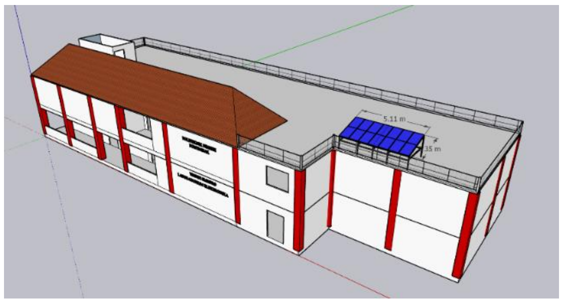

Figure 3. Existing Solar Power Plant System

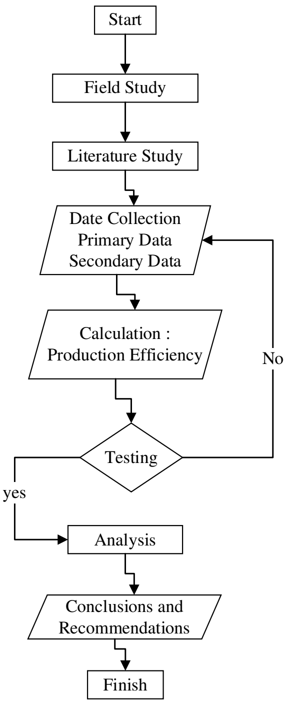

Figure 4. Flow Diagram of Research

B. *Primary Data*

Data was collected directly from the first source. For the primary data in this research, the author will conduct field measurements, such as temperature data and voltage data recorded during the related study.

C. Calculation of Solar Panel Production Plan

1. Calculating Area Array.

In the construction of a solar power plant (PLTS), an area is required to arrange photovoltaic modules into a specific array. The required array area can be calculated using the following formula:

$$\text{Array Area} = \frac{peak\ power}{panel\ efficiency \times radiation\ intensity} \ \ldots\ldots\ldots \quad (1)$$

$$\text{PV Efficiency} = \left(\frac{AC\ Energy\ Consumed}{Energy\ Expected\ to\ be\ produced}\right) \times 100\ \% \ldots\ldots\ldots \quad (2)$$

2. Calculating Power (Watt Peak).

In the construction of a solar power plant (PLTS), an area is required to arrange photovoltaic modules into a specific array. The required array area can be calculated using the following formula:

$$\text{P watt peak} = \text{PV area x PSI x } \eta \text{ pv} \ \ldots\ldots\ldots\ldots \quad (3)$$

PSI = Peak Solar Insolation, which is 1000 W/m^2
η pv = Solar Panel Efficiency

Next, based on the amount of power to be generated, the number of solar panels required can be determined as follows.

$$Total\ PV = \frac{P_{Watt\ Peak}}{P_{Mpp}} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

P watt peak = Power generated (Wp).
PMPP = Maximum output power of the solar panel (W).

D. Secondary Data

Data obtained from existing sources, such as data provided by BMKG related to solar radiation, temperature in the Pontianak City area, and annual wind speed data, are used as references for utilizing PVsyst software.

E. PVsyst.

PVsyst is a simulation software used to design, Figure 5 simulate, and optimize Solar Power Plant (PLTS) systems. This software was developed by the University of Geneva and is widely used by engineers, designers, and researchers in the field of solar energy.

PVsyst is widely used in various applications:

1. Project Planning: Designing and optimizing PV systems for commercial, industrial, and residential projects.
2. Feasibility Studies: Assessing the technical and economic feasibility of PV projects.
3. Academic Research: Utilizing simulations for research and development of PV technologies.
4. Monitoring and Evaluation: Comparing actual system performance with simulation results for monitoring and evaluation.

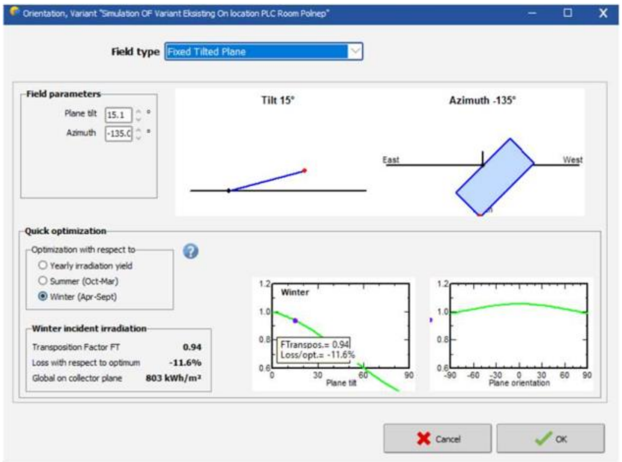

Figure 5. Azimuth & Tilt Configuration PVsyst

PVsyst is a highly useful tool for designing and analyzing PV systems. With features such as climate and component databases, performance simulations, and economic analysis, PVsyst enables users to optimize the design and performance of PV systems. In the context of research at Politeknik Negeri Pontianak, PVsyst can be used to simulate the performance of a solar power system (PLTS) with an SMA inverter and analyze the factors affecting system efficiency in a tropical environment.

III. RESULTS AND DISCUSSION

A. Evaluation and Dimensions of the Existing Location

The elevation installed on the existing 3 kW solar power plant (PLTS) corresponds to the actual building structure and is applied using technical drawing language, Figure 6, specifically dimensional drawings of the building to be analyzed. These dimensional measurements provide elevation data for the placement of the existing PLTS on the building. This dimensional data is critical for providing elevation information from the ground level (Elevation 0.0) of the Electronics Laboratory building at Polnep. The building's dimensions and the 0.0 elevation position are shown in the diagram below.

Figure 6. Dimension of elevation Building

The dimensional measurements in the drawing are based on observations and manual measurements conducted in the field. This is done to ensure that the simulation results align with the actual physical structure.

B. Database

The production database for the related research includes both secondary and primary data, where the author establishes correlations between the related data to identify the basis of the analysis to be conducted and tested. The production database is structured to achieve more optimal research results, as outlined below.

1. Sunny Boy Production Data Collection.

The illustration of the Sunny Boy inverter is shown in the image below, along with an explanation of how to retrieve production data from the Sunny Boy SMA inverter, Figure 7.

No	Date	PV Yield (kWh)	Purchased Electricity (kWh)
782	21-Feb-24	1.038	0.127
783	22-Feb-24	1.121	0.127
784	23-Feb-24	1.355	0.127
785	24-Feb-24	1.256	0.126
786	25-Feb-24	1.038	0.127
787	26-Feb-24	1.011	0.127
788	27-Feb-24	1.355	0.127
789	28-Feb-24	1.011	0.127
790	29-Feb-24	1.256	0.127

Figure 7. Time Series Data Energy

2. Secondary Data.

The secondary data collected as a reference for optimizing the PLTS, which will be input into the PVsyst 7.4 software, includes previous research data such as journals that serve as a foundation for the study. The secondary data collected is as follows.

Table 1. Secondary Data on Weather Anomalies

Month	Wind Velocity		Temperature	HDI	GHI		HDI
	Knot	m/s	C	kWh/m²	Wh/m²	kWh/m²	Wh/m²
January	1.5	0,771667	29	77.2	106.75	0.10675	57.645
February	1.4	0,720222	34	77.2	117.375	0.117375	63.3825
March	1.8	0,926	34	77.2	121.70833	0.12170833	65.7225
April	1.4	0,720222	34	77.2	132.04167	0.13204167	71.3025
May	1.1	0,565889	34	77.2	145.125	0.145125	78.3675
June	1.2	0,617333	34	77.2	149.04167	0.14904167	80.4825
July	1.8	0,926	30	77.2	146.66667	0.14666667	79.2
August	1.9	0,977444	28	77.2	120.625	0.120625	65.1375
September	1.6	0,823111	30	77.2	105.20833	0.10520833	56.8125
October	1.3	0,668778	34	77.2	101.70833	0.10170833	54.9225
November	1.2	0,617333	28	77.2	104.91667	0.10491667	56.655
December	1.7	0,874556	34	77.2	103.45833	0.10345833	55.8675
Total	1.5	0,771667	27	77.2	105.20833	0.10520833	56.8125
Average	19.4	0	410	1003.6	1559.8333	1.55983333	842.31

The complete solar radiation data provided directly by BMKG consists of daily data for the year 2019, as follows.

Based on the data presented and the comparison made, the data obtained from the research journal Sagian, 2013 and the data from BMKG Pontianak show the comparison of solar radiation intensity (in units of Wh/m²) in Pontianak City for each month between 2013 and 2019.

Table 2 and tabel 3, the 2013 data comes from the research journal, while the 2019 data is sourced from BMKG Pontianak. This data has been discussed with BMKG Pontianak for the validation of solar radiation data in Pontianak City.

Table 2. Solar Radiations Data in 2019

Date	January	February	March	April	May	June	July	August	September	October	November	December
1	26.4	131.0	250.0	99.2	142.7	100.9	135.3	148.5	113.0	179.3	4.7	9.3
2	26.4	63.1	124.7	192.8	163.9	154.8	114.2	64.1	134.7	8.1	8.4	29.3
3	27.6	19.7	357.3	130.9	135.5	128.3	94.1	81.5	145.4	13.6	9.5	9.8
4	27.7	63.4	122.5	348.1	100.4	129.6	146.9	45.3	12.0	11.0	8.1	7.5
5	28.9	76.3	64.5	64.7	331.8	146.9	88.1	83.7	39.8	12.1	17.1	24.9
6	28.4	53.5	101.0	174.9	205.7	79.3	86.3	114.3	13.7	15.2	4.9	5.0
7	27.0	126.7	14.5	90.2	59.0	251.4	164.6	205.9	92.8	0.0	1.3	5.0
8	28.5	105.4	133.1	176.1	147.7	115.5	187.4	150.8	120.5	7.2	10.2	11.4
9	27.2	51.8	110.7	2.0	100.2	71.6	138.3	7.4	52.5	34.0	8.0	12.1
10	27.6	96.9	159.7	-	26.9	119.4	103.4	104.4	74.2	2.7	28.2	13.1
11	26.1	113.3	135.9	116.4	108.7	12.8	115.6	146.8	224.5	15.9	17.4	0.8
12	26.5	36.8	292.4	90.9	87.1	99.4	128.6	112.2	9.6	17.8	8.8	14.0
13	26.8	136.4	19.7	98.9	7.6	137.2	38.4	44.5	114.7	14.1	1.2	14.6
14	26.3	133.8	116.0	130.1	143.6	295.7	115.7	152.6	156.6	2.6	7.3	6.6
15	27.3	167.0	37.2	125.3	190.0	127.0	158.5	1.5	132.2	11.2	12.8	17.3
16	27.7	108.4	125.4	70.6	71.3	38.1	77.3	2.0	158.5	11.3	231.1	8.8
17	27.3	173.7	104.5	217.6	103.5	54.5	17.8	124.4	116.0	11.0	14.0	20.6
18	27.6	123.3	9.2	314.4	7.2	152.2	236.6	183.9	66.5	16.1	0.4	18.3
19	26.6	73.4	133.1	124.1	1.9	1.0	0.0	89.7	55.9	8.8	9.6	11.8
20	27.0	107.5	128.4	84.7	229.6	215.1	26.3	15.9	98.6	18.3	18.2	13.0
21	28.9	151.8	133.5	136.0	98.8	122.6	116.4	15.9	204.3	18.3	0.1	18.8
22	28.1	165.0	70.0	7.7	91.3	75.8	81.4	186.7	86.1	10.1	15.2	17.0
23	27.8	287.4	255.4	146.3	131.4	132.0	130.6	124.9	98.1	10.2	1.5	5.9
24	26.0	191.8	109.9	41.7	140.7	97.5	91.8	0.4	78.0	18.6	7.9	11.4
25	27.6	57.1	92.3	61.6	64.0	134.1	120.7	1.4	88.4	7.0	7.1	11.5
26	27.1	141.8	187.4	110.1	89.9	157.9	-	180.1	6.1	8.5	15.6	8.4
27	26.2	134.4	187.5	185.9	13.4	26.3	58.6	119.7	1.1	10.3	9.1	13.2
28	27.1	147.4	185.1	112.6	167.9	106.2	160.9	183.9	118.2	53.8	17.0	2.2
29	27.9		26.5	106.3	206.9	98.9	119.4	89.8	139.0	12.9	13.6	-
30	27.3		140.5	193.4	148.7	113.3	80.3	15.0	2.1	12.7	29.1	-
31	29.5		202.7		20.9		125.4	9.8		10.8		-

Table 3. Comparison of Solar Radiation Data for 2013 & 2019

Month	2013	2019
	Wh/m²	Wh/m²
January	106.75	27.3
February	117.375	115.6
March	121.7083	133.2
April	132.0417	129.4
May	145.125	114.1
June	149.0417	116.5
July	146.6667	108.6
August	120.625	90.6
September	105.2083	91.8
October	101.7083	18.8
November	104.9167	17.9
December	103.4583	12.2
Average	105.2083	81.33333
Total	1454.625	976

C. Calculation of the Solar Power System.

1. Energy Calculation Based on PV Specifications

Data PV
STC = 1000w/m
Temp = 25 ºC
V.mpp = 25.11 Volt
I.mpp = 8.54 A
Air masses AM 1.1

Figure 8. Brief Specification of Installed Solar Panel

Figure 8 is calculation for existing 3 kW solar power system is as follows. It is known that the existing solar panels have a capacity of 210 Wp, with 14 pieces. Therefore, the calculation is as follows.

$210 \times 14 = 2940\ wp$
$P = V \times I$
$25.11\ V \times 8.54\ A$
$214.439\ watt$

Effective Energy Absorption = 4 Hours
$P = 2940\ wp \times 4$
$11.760\ wh\ In\ 1\ day$

The losses used as reference factors affecting the energy generated by the PV system are as follows, where the impact of these losses will be used as a reference for energy calculations.

1. Regeneration Factor = 20 % = 0.8
2. Loss Factor = 20% = 0.8
3. Backup Energy = 15 % = 0.85

   Thus, When calculated: 20% × 20 × 15% = 0.544

2. Battery data at location.

Battery Type NSAG $100\ Ah\ 12V = 8\ Pcs$
Total $= \ 100\ x\ 8 = 800\ Ah$
Based on the energy specifications obtained:

$$P = V\ x\ I$$
$$V = 12 \text{ Volt}$$
$$A = 800 \text{ Ah}$$
$$Thus, P = VxI \ = 12\ x\ 800 = 9600\ wh$$

Total Energy Generated After Loss Factors Are Applied

$P \ = 11760\ wh$
Loss = 0,544

Thus $= P\ x\ (Loss)$
Energy Effected by loss= $11760\ x\ 0{,}544 =$

3. Array Area PV

- Linier Power = 2.94 kwp (Installed PV)
- Effective Irradiation = 4 Hours (Assumed from ESDM guidelines)
- Panel Efficiency = 20 % (Assumed from ESDM guidelines)

Nominal DC Energy :

Linear Power x Effective Irradiation x Number of Days x Panel Efficiency

Nominal DC Energy =
$2.94\ kWp\ 4\ \ Hours/day \times 30\ day\ \times 20\%$ = 69.36 kWh

After performing the calculations based on the basic formula used, the nominal energy that should be produced is 69.36 kWh. However, in one month, the monitoring system produced 34.536 kWh (Monitoring results from the Sunny Boy Inverter). Based on the observations, the sample data has been processed in the form of a graph as follows.

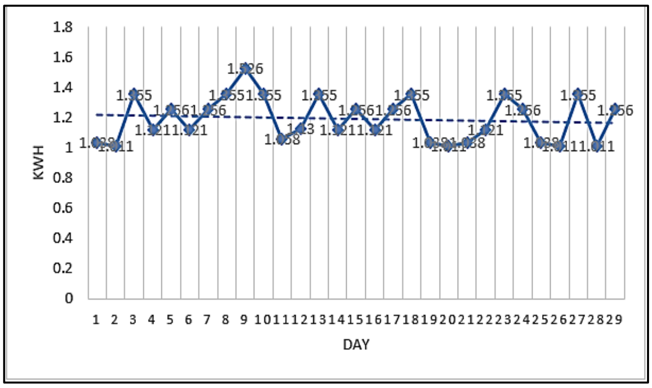

Figure 9. Energy Data for The Last 1 Month

- $System\ Efficiency = \left(\frac{AC\ Energy\ Produced}{Expected\ Energy}\right) \times\ 100\%$

- $System\ Efficiency = \left(\frac{34{,}536\ kwh}{69{,}36\ kwh}\right) \times 100\ \% = \ 49{,}77\%$

$$Array\ area = \frac{Peak\ Power}{(PV\ Efficiency\ x\ Intensity)}$$

Data : Peak Power = 2940 Wp
PV Efficiency = 49.77 %
Intensity= $121.218\ {}^{W}/_{m^2}$ (Secondary Data)

Thus:

$$Array\ Area\ :\ \frac{2940\ wp}{49 \times 77\ \% \ \times\ 121.218\ w/m^2}$$
$$= \ 48.77\ m^2$$

D. Simulation With PVsyst.

To achieve optimal results in analyzing the 3 kW solar power system installed in the Polnep Laboratory building, software with the best qualifications is utilized to obtain results that closely match actual conditions. In this analysis, the author uses the PVsyst software. The display and identity details of the related software are shown below.

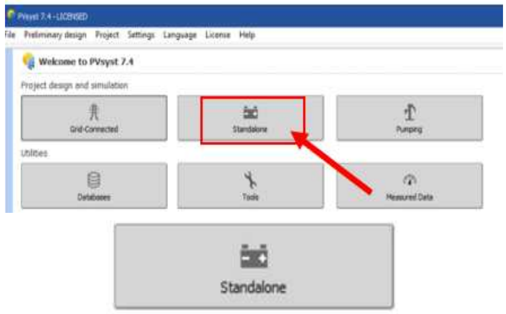

Figure 10. Initial PVsyst Selecting the Standalone Menu

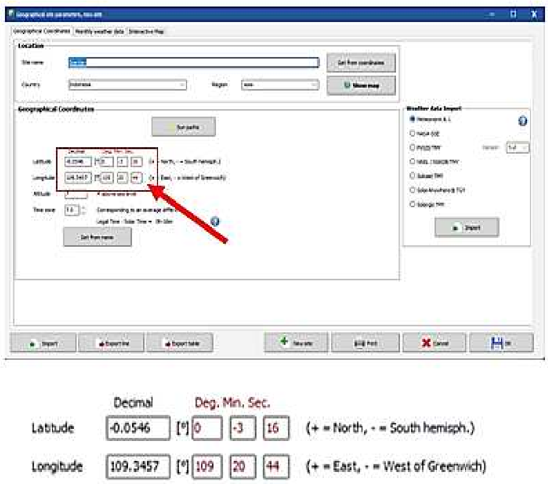

Figure 11. The Menu Entering the Coordinate of Existing Location

After accessing the menu (Geographical Site Parameter, New Site) as shown in Figure 12, enter the desired location's coordinates in the (Latitude & Longitude) fields. Coordinate data can be directly checked on Google Earth or Google Maps, which will direct you to the exact location, as displayed in Figure 12.

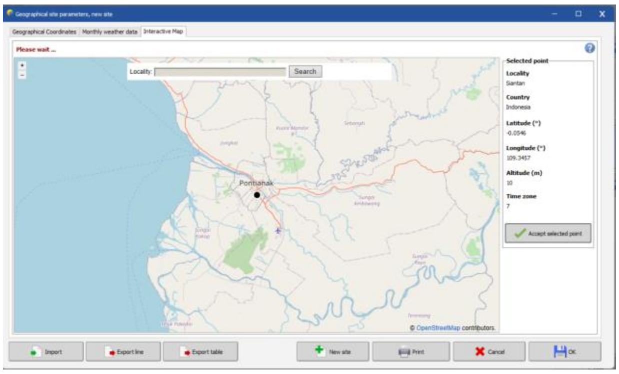

Figure 12. Interactive Map of the Existing PV Location

In Figure 11, after entering the coordinates of the location to be analyzed, input the relevant data that affects the actual location, such as Global Horizontal Irradiation (GHI/Solar Radiation)**,** Horizontal Diffuse Irradiation (HDI)**,** Temperature, and Wind Velocity, as shown in Figure 13**.**

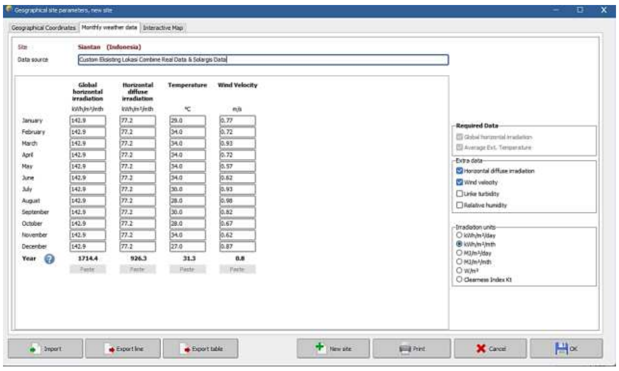

Figure 13. Display of Monthly Input Data for the Existing System

The next step is to analyze the potential for shading on the solar panel modules. Using the "Construction/ Perspective" feature in PVsyst, the researcher can create a three-dimensional model of the solar panel installation location. This model is then used to identify areas that are prone to shading, whether from nearby buildings, trees, or other objects.

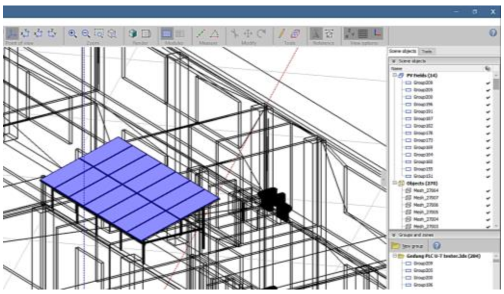

Figure 14. Synchronization of the Existing 3 kW Solar Power System Based on 3D

In Figure 14**,** to obtain a more detailed and accurate 3D model, the geometry of the project location, including surrounding buildings and topography, is first modeled using SketchUp software. This 3D model is then exported into a format compatible with PVsyst and imported into the 'Construction/Perspective' menu for further shading analysis.

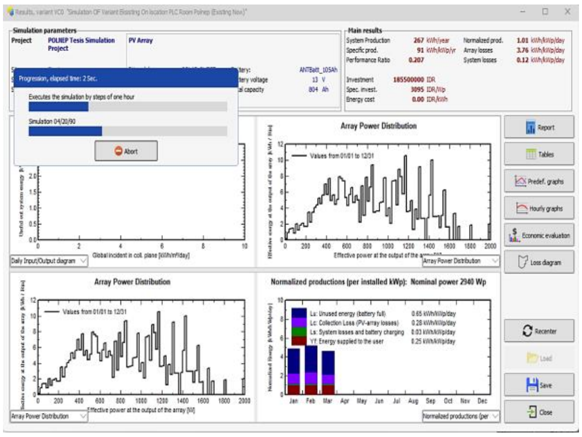

Figure 15. PVsyst Software Simulation Run Process

In Figure 15, the process of running the simulation data after all the data has been input into PVsyst, as shown in Figure 10**.**

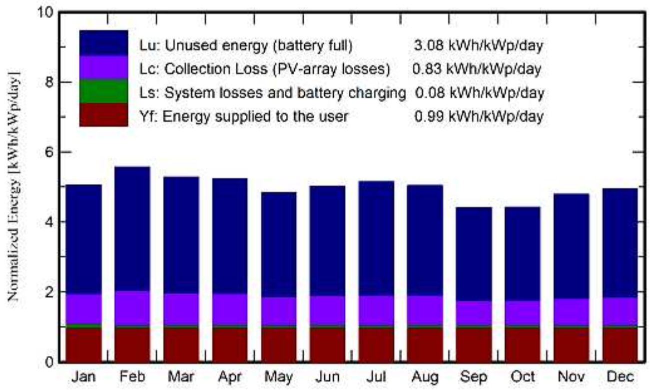

Figure 16. Normalized Productions

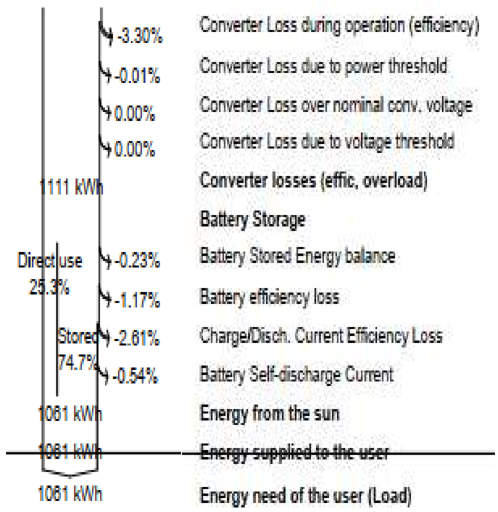

Figure 17. Loss Diagram Graph Before Optimization By Pvsyst

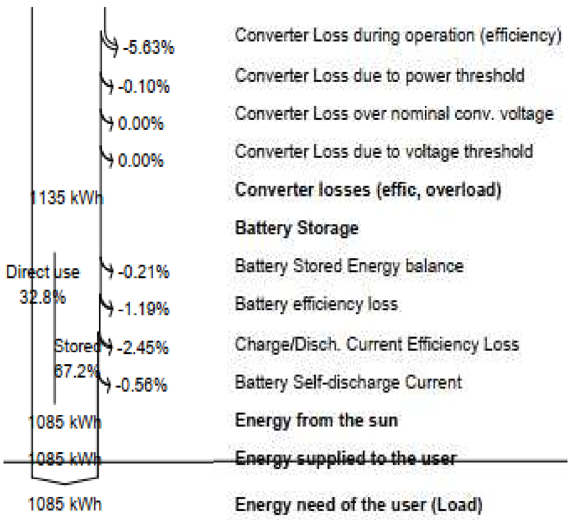

Figure 18. Loss Diagram Graph After Optimization By PVsyst

Based on Figure 17 and Figure 18, which are the loss diagrams, the PVsyst simulation results show that the optimization process successfully improved the efficiency of the solar power system by reducing the percentage of unused energy and increasing the amount of energy that was effectively used.

In conducting the simulation analysis based on the 3D simulation, an evaluation was also carried out on the 3D system. Several experimental analyses of the solar panel tilt radius showed no significant changes. The changes observed in the analysis were due to the repositioning of the solar panels to align with the direction of sunrise and sunset, as shown in Figure 19.

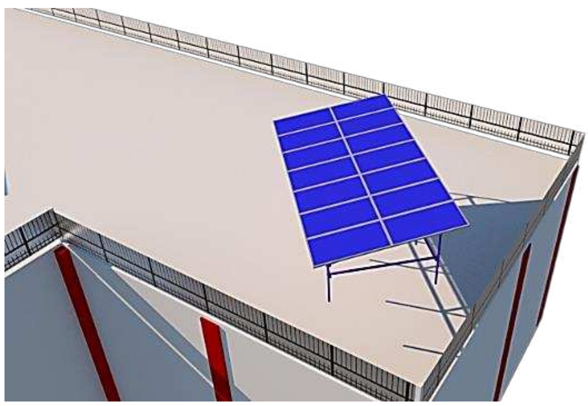

Figure 19. Simulation design after optimization

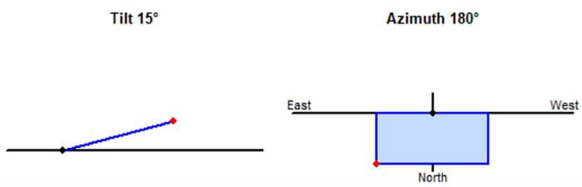

Figure 20. Values for Tilt and Azimuth After Optimization

Figure 21. Values for Tilt and Azimuth Before Optimization

In Figure 20 & Figure 21, the change in the solar panel orientation before and after optimization is shown, where:

1. Tilt: The tilt angle of the panel relative to the horizontal plane. The same tilt value (15°) in both conditions indicates that the tilt angle of the panel was not changed during optimization.
2. Azimuth: The orientation angle of the panel relative to the south (an azimuth of 0° means the panel faces south). A significant change occurred in the azimuth value:
   a. Before Optimization: Azimuth -135°, meaning the panel is tilted towards the southwest.
   b. After Optimization: Azimuth 180°, meaning the panel faces directly south.

The change in panel orientation from southwest to south has significant implications for the performance of the solar power system, as it affects the reception of solar radiation:

1. Before Optimization: With a southwest orientation, the panel will receive solar radiation indirectly, especially during the day. This reduces the amount of radiation that can be converted into electrical energy.
2. After Optimization: A southward orientation allows the panel to receive solar radiation directly and optimally throughout the day, especially at midday when the sun's intensity is highest. This increases the amount of radiation captured and boosts energy production.

Table 4. Effective Energy from The Array

Categories	After Optomization	Before Optomization
PV loss due to irradiance level	-5.79%	-0.56%
PV loss due to temperature	-16.39%	-12.22%
Module quality loss	1.25%	0.75%
Mismatch loss, modules and strings	-0.60%	-0.60%
Ohmic wiring loss	-2.69%	-2.17%
Unused energy (battery full)	-68.56%	-74.18%
Efecetive Energy From Array	1204 kWh	1149 kWh

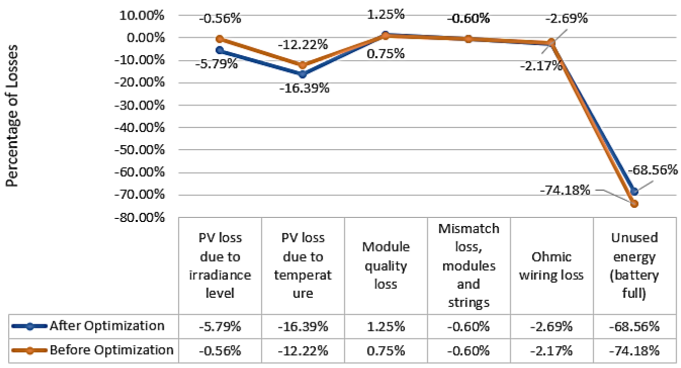

Figure 22. Loss Diagram of effective energy from the array

Based on the table and graph above, the results of the PVsyst simulation, particularly to determine the effective energy of the array, are as follows:

1. Increased Effective Energy: After optimization, the effective energy of the array increased from 1,149 kWh to 1,204 kWh. This indicates that the optimization has successfully improved energy production.
2. Reduction in Losses: Most types of energy losses experienced a reduction after optimization. This means the optimization efforts successfully minimized various factors causing energy loss.
3. Greatest Impact: The most significant energy loss occurs due to radiation levels and temperature. The reduction in losses in these components greatly contributes to the increase in effective energy.

Table 5. Total Energy Supplied to The Users

Categories	After Optimization	Before Optimization
Direct use	32.80%	25.30%
Stored	67.20%	74.70%
Battery Stored Energy balance	-0.21%	-0.23%
Battery efficiency loss	-1.19%	-1.17%
Charge/Disch. Current Efficiency Loss	-2.45%	-2.61%
Battery Self-discharge Current	-0.56%	-0.54%
Energy to users	1085	1061

Table 5, which is explained based on the loss diagram produced from the 3D PVsyst simulation of the existing position change to achieve the best azimuth value, can be outlined as follows:

1. Increase in Final Energy: After optimization, the final energy available for users increased from 1,061 to 1,085. This indicates that the optimization successfully improved the amount of usable energy.
2. Changes in Energy Usage:
   a. Direct Use: The percentage of energy used directly increased, indicating that more energy is being used in real-time.
   b. Stored: The percentage of energy stored in the batteries decreased, showing that the batteries are more efficient in supplying energy as needed.
   c. Losses: Most types of energy losses decreased, indicating that the system's overall efficiency improved.

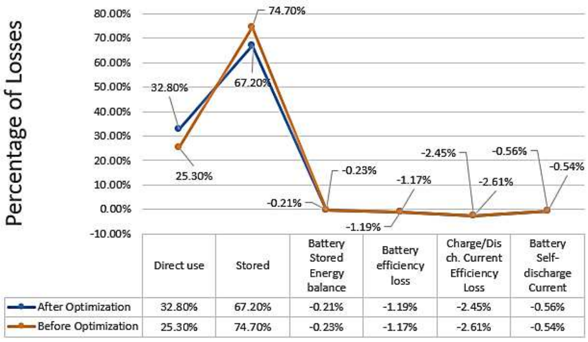

Figure 23. Loss Diagram of Energy Supplied to Users

Figure 23, the loss diagram graph provides a clear overview of the changes in the percentage of energy losses across various system components before and after optimization. Based on the loss diagram graph, which focuses on the factors causing energy loss before and after optimization, the following can be outlined: General Reduction in Losses: Overall, the percentage of energy losses in most components decreased after optimization. This indicates that the optimization efforts successfully reduced various types of energy loss.

1. Significant Reduction in Losses Due to Radiation and Temperature: The largest reduction in energy losses occurred in the components "PV loss due to irradiance level" and "PV loss due to temperature." This shows that the optimization successfully improved the solar panel's efficiency in converting sunlight into electricity, even though radiation and temperature conditions vary.
2. Small Increase in Module Quality Loss: Although a reduction occurred in most components, there was a slight increase in the "Module quality loss" component. This may be due to other factors unrelated to optimization, such as the age of the modules or minor damage to the panels.
3. Significant Reduction in Unused Energy: The significant decrease in "Unused energy (battery full)" indicates that the energy generated is more effectively utilized, both for direct consumption and storage in the batteries.

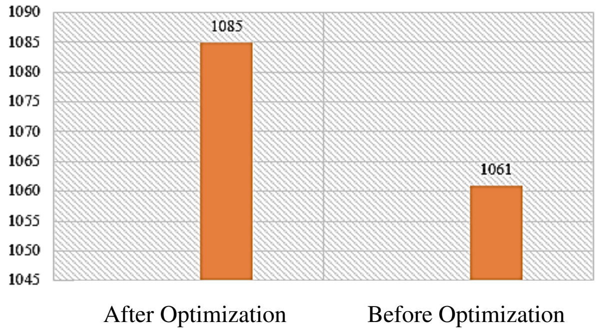

Figure 24. Graph Eergy to Users

E. For Energy Production System (system Production)

Energy production before optimization: 1,061 kWh
Energy production after optimization: 1,085 kWh

Calculation Method:

1) Calculate Production Increase*:*
Production increase = Production after optimization - Production before optimization
- Production increase = 1085 kWh - 1061 kWh
- Production increase = 24 kWh

2) Calculate the percentage increase ***:***
- Percentage Increase

$$=\left(\frac{Production\ increase}{Production\ before\ Optimization}\right) x\ 100\%$$

- Percentage Increase $= \left(\frac{24\ kWh}{1{,}061\ kWh}\right) x100\%$
- Percentage Increase = 2.26%

Based on the calculation results, after optimization, the energy production of the solar power system (PLTS) increased by approximately 2.26%. This indicates that the optimization efforts successfully improved the energy production efficiency of the PLTS.

IV. Conclusion

Optimization Increases Production: Adjustments to the solar panel positioning as part of the optimization successfully increased energy production by 2% (from 0.99 kWh to 1.01 kWh). This indicates that the optimization process effectively improved system performance. Changing the azimuth angle to 180° with a tilt angle of 15° increased energy production to 1.01 kWh with an efficiency of 18.95%.

References

[1] Suwarti, "Optimasi Pembangkit Listrik Tenaga Surya Tipe Solar Home System dengan Kapasitas 800 Wp," J. ISAINTEK, vol. 5, no. 2, pp. 101–119, 2022.

[2] A. Energi, L. Di, R. S. J. Prof, and H. B. Saanin, "Evaluasi Intensitas Konsumsi Energi Listrik Melalui Audit," vol. 5, no. 2252, pp. 103–107, 2016.

[3] J. A. Nasir, "Optimasi Perancangan Sel Surya Untuk Pembangkit Listrik 3500 w," vol. 2, no. 2, pp. 115–119.

[4] H. Gusmedi, D. Despa, J. Teknik, and E. Universitas, "optimasi penggunaan energi pada sistem pencahayaan konservasi energi," 2012.

[5] S. Samsurizal, R. Afrianda, and A. Makkulau, "Simulasi optimalisasi kapasitas pembangkit listrik tenaga surya pada atap gedung Optimization of solar power plant capacity on the roof of the building," vol. 27, no. 1, pp. 31–37.

[6] M. Rif, S. Hp, M. Shidiq, R. Yuwono, H. Suyono, and A. P. Cell, "Optimasi Pemanfaatan Energi Listrik Tenaga Matahari di Jurusan Teknik Elektro Universitas," vol. 6, no. 1, pp. 44–48, 2012.

[7] M. Sulastri and T. Aritonang, "Perancangan Model Optimasi Penggunaan Energi Pada Gedung SD Plus Gembala Baik Pontianak," vol. 10, no. 1, pp. 23–29, 2018.

[8] Mucharomah, N. M., Fatah, M. C., & akbar, z. A. (2023). Analisis Desain PLTS Atap Tipe Gable Roof menggunakan Metode Weight Score. ELKOMIKA: Jurnal Teknik Energi Elektrik, Teknik Telekomunikasi, & Teknik Elektronika, 11(2), 408.

[9] Yan, K., Shen, H., Wang, L., Zhou, H., Xu, M., & Mo, Y. (2020). Short-term solar irradiance forecasting based on a hybrid deep learning methodology. Information (Switzerland), 11(1).

[10] Hidayat, S., et al. (2019). The Impact of Tropical Climate on Solar Panel Efficiency. Journal of Renewable Energy Research, 7(2), 123-130.

[11] Ramli, M., et al. (2016). Effects of Ambient Temperature on the Performance of Photovoltaic Systems in Tropical Regions. Renewable Energy Journal, 21(4), 245-251.

[12] Ahmed, M., et al. (2018). Real-Time Monitoring and Optimization of PV Systems Using IoT. International Journal of Smart Grid and Clean Energy, 6(3), 324-332.

[13] Yadav, A., & Banerjee, R. (2017). Advanced Inverter Technologies for Solar PV Applications. Energy Technology and Policy, 11(1), 95-105.

[14] Kumar, S., et al. (2020). Solar PV Systems in Educational Institutions: A Case Study. Journal of Sustainable Energy, 8(1), 87-94.

[15] Zhang, T., et al. (2015). Integration of Renewable Energy Technologies in University Curriculums. Journal of Clean Energy Education, 5(2), 57-65.

[16] Kalogirou, S. (2009). Optimization of Solar PV Systems. Journal of Solar Energy, 83(9), 1154-1168.

[17] Shukla, A., et al. (2016). Maintenance Strategies for Enhanced Efficiency of Solar PV Systems. Renewable and Sustainable Energy Reviews, 54, 1012-1020.