International Journal of Education and Life Sciences (IJELS)
Vol. 4, No. 4 April 2026: 419-438

Design Analysis of a 3300 Wp Rooftop Solar Power Plant with a 15o Roof Angle at the Nusa Tamalanrea Indah Housing Complex in Makassar City

Gatot Suprayogi[1*], Jaka Windarta[2], Asep Yoyo Wardaya[3]
Universitas Diponegoro Semarang
Corresponding Author: Gatot Suprayogi: jakawindarta@lecturer.undip.ac.id

A R T I C L E I N F O

Keywords: Rooftop PLTS, PV modules, ATS, PVSys, Watt Peak, Payback Period

Received : 12 February
Revised : 23 March
Accepted: 20 April

A B S T R A C T

PT. PLN's customer base is growing annually, reaching 3.29 million customers in 2025, bringing the total to 96.2 million by 2025. Residential electricity customers outnumber those from business offices, government buildings, and industrial buildings. The Ministry of Energy and Mineral Resources has allocated a rooftop solar power plant (PLTS) quota of 3.9 GW for 2024-2025. Residential rooftop solar power plant utilization is expected to reach 445 MW by 2025. The year-over-year increase in rooftop solar power plants (PLT) can accelerate the development of clean energy. Safety and installation of rooftop solar power plants must also be maintained according to government regulations to ensure no harm is done to anyone. Rooftop solar power plants offer a tangible opportunity to save electricity from PLN, whether on a small scale (a few watts per unit), or using low-power PV modules, or using high-power PV modules. By utilizing electricity sources from renewable energy from a single source or from multiple sources, we can reduce the use of electricity from PLN which generally comes from fossil sources such as coal, diesel and gas. This reduction in PLN electricity power means reducing the formation of carbon dioxide or CO2 in the air.

DOI: https://doi.org/10.59890/ijels.v4i4.324
ISSN : 3026-2429
https://ntlmultitechpublisher.my.id/index.php/ijels

INTRODUCTION

The demand for fossil energy to support human life continues to increase in line with global population growth. However, fossil energy resources are finite, and their combustion produces CO_2 emissions that contribute to the greenhouse effect, which has become a global concern. In the energy transition era, the development and research of renewable energy sources are essential as promising alternatives to replace fossil energy usage.

Indonesia, located along the equator and endowed with abundant renewable energy potential, offers significant opportunities for research and development in alternative energy sources. As fossil energy production in Indonesia continues to decline while demand increases, the need to meet national energy requirements becomes more urgent. To mitigate the global greenhouse effect, the Indonesian government has introduced several regulations aimed at reducing the use of fossil fuels such as coal and diesel fuel, which contribute significantly to greenhouse gas emissions.

According to a press release (ESDM, 2022), Indonesia has entered an energy transition phase by limiting coal production and gradually shutting down inefficient coal-fired power plants. This marks an important step toward reducing greenhouse gas emissions and requires support from all stakeholders. The current surplus of electricity generated by PT Perusahaan Listrik Negara (PLN) is partly due to extensive contracts with independent power producers (IPPs), which have financial implications for the state, as PLN must fulfill contractual payments despite excess electricity supply in urban areas, while remote regions still experience shortages.

As contracts between PLN and IPPs approach expiration, the current electricity surplus is expected to decline. This condition must be anticipated to ensure a stable electricity supply in the future. Therefore, renewable energy sources must be prepared and developed to meet future energy demands while supporting greenhouse gas emission reduction efforts.

According to the Electricity Supply Business Plan (PLN, 2014), the installed generation capacity in South Sulawesi Province reached 1,437 MW, with an available capacity of approximately 1,238 MW and a peak load of 1,186 MW as of the third quarter of 2014. In regions such as Selayar Regency and islands in Pangkep Regency, electricity supply is entirely dependent on diesel power plants (PLTD), with a generation capacity of around 5.1 MW and a peak load of 4.2 MW. The electrification ratio in South Sulawesi reached 82.33% as of September 2014. In September 2023, PLN conducted scheduled power outages in the South Sulawesi and West Sulawesi regions, including Makassar, lasting up to three hours over several days due to grid maintenance (Terkini.Id, 2023). This highlights ongoing challenges in meeting electricity demand. Furthermore, there is limited data on the adoption of rooftop solar photovoltaic (PV) systems in Makassar as an alternative energy source that can be independently implemented by households. PLN data indicate that household customers in South Sulawesi Province number approximately 2,687,354 (PLN Central, 2025).

LITERATURE REVIEW

The analysis of rooftop solar PV systems using PVsyst software requires field measurement data in residential areas to evaluate potential energy output and support research analysis. Several key parameters are considered to obtain more accurate estimations, including the angle of solar incidence on the rooftop, the installation angle of PV modules, available roof area, geographical coordinates, weather and seasonal conditions, types of PV modules, hybrid inverter types, and control systems such as Automatic Transfer Switch (ATS) and timers to regulate electricity supply to residential loads during daytime.

Not all roof surfaces can be utilized; therefore, proper arrangement of PV modules is necessary by measuring and calculating the available surface area to accommodate installations and allow access for maintenance. The utilization ratio of rooftop areas can be compared with the usable area for PV module placement, including identifying unusable or open spaces.

PVwp=PVarea×PSI×ηPVPV_{wp}=PV_{area} \times PSI \times \eta_{PV}PVwp=PVarea×PSI×ηPV

Where:

- PVwpPV_{wp}PVwp = peak power output
- PVareaPV_{area}PVarea = surface area of PV modules
- PSIPSIPSI = solar irradiance constant
- ηPV\eta_{PV}ηPV = efficiency of PV modules

SOLAR ENERGY

Solar energy is the largest primary energy source in the solar system, continuously radiating energy for millions of years into the future. Its thermal benefits have long been utilized by humans, and in the modern industrial era, solar energy has been extensively studied for generating direct current (DC) electricity through advanced technologies.

Solar energy originates from nuclear fusion reactions within the sun, producing photon radiation that spreads throughout the solar system, with a small portion reaching Earth. According to *Solar Energy Engineering: Processes and Systems* (Kalogirou, 2019), solar radiation reaching Earth is within the visible wavelength range of 0.38×10^{-6} to 0.7×10^{-6} meters.

Pin=E×AP_{in}=E \times APin=E×A

Where:

- PinP_{in}Pin = received power (W)
- EEE = solar irradiance (W/m^2)
- AAA = surface area of PV modules (m^2)

The position of the sun continuously changes throughout the day, forming an elliptical path relative to the equator, and solar radiation is unavailable at night (Duffett-Smith & Zwart, 2012). The amount of solar energy received on Earth's surface is influenced by weather conditions (clear or cloudy), time, location, shading from surrounding objects, and the angle of solar incidence.

Weather conditions in Makassar, such as rainfall and cloud cover, also affect PV module performance. With temperatures ranging from 22°C to 35.5°C, humidity around 76.85%, and wind speeds of 4.08 knots, these environmental factors influence module cooling and overall system efficiency in rooftop solar PV applications (BPS Makassar, 2024).

MONO-CRYSTALLINE PV MODULES.

Mono-crystalline PV modules, or monochrome PV modules, are the first type of PV module developed, featuring a more regular crystal structure. One example of a PV module has the following specifications.

Figure 3. Specifications of a PV module (Nurhalizaa, 2024).

Generally, it has higher efficiency than the polychrome type but has a more competitive market price.

POLY-CRYSTALLINE PV MODULE.

Poly-crystalline PV modules, or polychrome PV modules, are a type of PV module with a random crystal pattern. They generally have lower efficiency than the monochrome type but are more affordable.

CONTROL MODULE.

In the Off-Grid Solar Power Plant Operation and Maintenance Guide (ESDM, 2017), a control module, according to SNI 8395:2017, is a hardware device that functions as a device to regulate the charging and discharging of electric current in the battery. A solar power plant system generally requires several controllers tailored to the planned system.

Several types of SCC control equipment commonly available on the market that can be used in PV module applications are as follows:

Battery charging control.

DC/AC inverter.

INVERTER

An inverter is an electrical device that converts direct current (DC) into alternating current (AC). It consists of various electronic circuits integrated into a single unit to transform DC power into AC power.

According to the *Guidelines for Operation and Maintenance of Off-Grid Solar Power Systems* (ESDM, 2017), based on SNI 8395:2017, an inverter is defined as an electrical device that functions to convert direct current (DC) into alternating current (AC). By using an inverter, common household AC electrical loads can be operated similarly to when they are powered by electricity supplied by PT. Perusahaan Listrik Negara (PLN).

ELECTRICAL LOAD CONTROL

Control equipment used for safety in an electrical system must be tailored to the requirements of the electrical circuit. This involves determining which components need to be controlled and how the system should be regulated based on the data to be analyzed.

This control system ensures that a rooftop solar power system (PLTS Rooftop) operates only when solar energy is available during daytime hours and switches to electricity from PLN during the morning, evening, and nighttime.

Several control devices can be used to manage electrical load usage according to system requirements, including:

AUTOMATIC TRANSFER SWITCH (ATS)

An Automatic Transfer Switch (ATS) is a device used to automatically connect and disconnect electrical current between power sources within a circuit. Various types of switches are available on the market.

An electromagnetic switch operates according to the available power sources, where electrical current is regulated to flow to the load from two different power supply circuits. In this study, the rooftop solar power system (PLTS Rooftop) is designated as the primary source. If there is insufficient power generated from the PLTS, the supply is automatically transferred to PLN as a backup source.

METHODOLOGY

This study utilizes the PV Syst software to analyze the potential of a rooftop solar power system (PLTS Rooftop) in a household. Several scenarios of PV module tilt angles are examined to obtain sufficient data for analysis. The limitations of this study include:

1. Obtaining information on the amount of solar energy that can be received in a specific area in South Sulawesi Province, particularly in Makassar. The amount of solar energy captured by PV modules depends on the characteristics and efficiency of the modules used. This also includes identifying specifications of PV modules commonly available in the Indonesian market.
2. Obtaining measurement data on rooftop area and estimating the number of PV modules that can be installed based on roof conditions and optimal tilt angles to maximize solar radiation absorption. The collected data serve as primary input for PV Syst software to assess the potential development of renewable energy systems in residential areas in Makassar.
3. Optimizing the utilization of electrical energy from the rooftop solar system based on daytime household electricity consumption. Daytime load serves as the reference for monthly and annual energy demand. Nighttime load is not analyzed, as the power source will be switched to the PLN grid. Additionally, several control circuit designs are proposed in accordance with SNI standards to achieve optimal daytime energy utilization in residential settings.

RESEARCH RESULTS

The electrical power requirements of each household are determined by daily activities, along with a certain amount of backup capacity. This backup power is generally used to handle initial power surges, typically around 125% of the rated capacity of electrical appliances. In other words, electrical loads do not always operate at 100% of the available power capacity.

A household typically consumes the most electricity when all family members are active at home, particularly from morning to afternoon, in the evening, and during weekends.

Table 3. Daily household electrical load over 24 hours.

No	Beban Listrik	Jumlah	Daya	Daya Alat	Jam																								h	Wh
			(W)	(W)	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	1	2	3	4	5		
1	Lampu penerangan	10	20	200	■													■	■	■	■	■	■	■	■	■	■	■	12	2400
2	TV	1	120	120		■					■	■	■					■	■	■									4	480
3	Rice Cooker	1	350	350		■				■						■													3	1050
4	Kulkas	1	300	300	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	24	7200
5	Mesin cuci	1	310	310				■	■	■																			3	930
6	AC	1	350	350							■	■	■	■						■	■	■							7	2450
7	Pompa air	1	125	125				■	■	■						■	■	■											6	750
																													Total Daya Beban	15284

Table 4. Household electrical load in 12 hours.

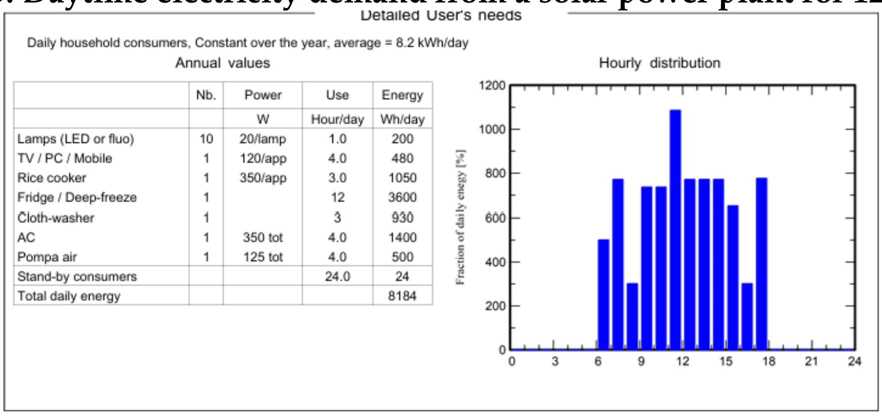
No	Beban Listrik	Jumlah	Daya	Daya Alat	Jam																								h	Wh
			(W)	(W)	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	1	2	3	4	5		
1	Lampu penerangan	10	20	200	■																								1	200
2	TV	1	120	120		■					■	■	■																4	480
3	Rice Cooker	1	350	350		■				■						■													3	1050
4	Kulkas	1	300	300	■	■	■	■	■	■	■	■	■	■	■	■													12	3600
5	Mesin cuci	1	310	310				■	■	■																			3	930
6	AC	1	350	350							■	■	■	■															4	1400
7	Pompa air	1	125	125				■	■	■						■													4	500
																													Total Daya Beban	8184

Therefore, the average 24-hour power demand analysis is 15,284 kWh. Meanwhile, the average 12-hour power demand from morning to evening is 8,184 kWh. This power demand is input into the PV System simulation program.

Daytime Power Requirements

A household's electricity needs from 9:00 AM to 3:00 PM can be predicted from normal daily demand.

Table 5. Daytime electricity demand from a solar power plant for 12 hours.



	Nb.	Power	Use	Energy
		W	Hour/day	Wh/day
Lamps (LED or fluo)	10	20/lamp	1.0	200
TV / PC / Mobile	1	120/app	4.0	480
Rice cooker	1	350/app	3.0	1050
Fridge / Deep-freeze	1		12	3600
Cloth-washer	1		3	930
AC	1	350 tot	4.0	1400
Pompa air	1	125 tot	4.0	500
Stand-by consumers			24.0	24
Total daily energy				8184

Nighttime Power Requirements.

The power demand from 6:00 PM until 6:00 AM in the morning is transferred by the timer control system to the PLN grid, eliminating the need for PLN power during the night.

Rooftop Pv Module Installation Techniques.

With the help of PV Syst software, it is possible to analyze the maximum power the PV modules can receive. Generally, PV modules are installed facing the sun or according to the roof construction model or roof angle for convenience and to minimize material use.

At the research site, located south of the equator, the PV modules are angled south so that the PV module surface faces north, in accordance with the roof angle of the research house.

To maximize solar capture, which will be determined from 6:00 AM to 6:00 PM, using the PV Syst software database simulation, the PV module selection and orientation can be adjusted to actual conditions.

Maximum solar energy can only be obtained and optimized during the day, from 10:00 AM to 3:00 PM. This is the optimal time to store excess electrical energy in batteries.

System summary

Grid-Connected System		Tables on a building			
Orientation #1		Near Shadings		User's needs	
Fixed plane		Linear shadings : Fast (table)		Daily household consumers	
Tilt/Azimuth	15 / -24 °			Constant over the year	
				Average	8.2 kWh/Day
System information					
PV Array		Inverters		Battery pack	
Nb. of modules	6 units	Nb. of units	1 unit	Storage strategy: Self-consumption	
Pnom total	3300 Wp	Pnom total	5.00 kWac	Nb. of units	3 units
		Pnom ratio	0.660	Voltage	26 V
				Capacity	539 Ah

Figure 10. Equipment data contained in the PV Syst. program database.

Assuming 12 hours of electricity usage at an installed capacity of 3,300 Wp, the average electricity consumption is 8.2 kWh/day.

However, using the average daily electricity consumption data for 12 hours during the day, assuming approximately 80% solar power usage without forcing the PV modules to operate at maximum capacity continuously, the required power availability is 8.2 kWh x 125% = 10.25 kWh.

Maximizing solar energy intake for 6 hours, the expected electricity can be stored in three 26 V, 180 Ah batteries, for a total battery capacity of 540 Ah.

If the selected PV modules are 550 Wp, the resulting electricity output is
550 Wp x 6 = 3,300 Wp.

Using an SCC controller with an input voltage limit of 180 Voc, the PV module output voltage is 49.95 Voc. With these limits, the PV module circuit can be connected in series and parallel to meet the Voc requirements for this SCC device.

If a series of 4 and a string of 2 parallel modules are used, the result is: 49.95 x 4 = 99.9 Voc and a current of 14.04 x 2 = 28.08 Isc.

If a series of 2 and a string of 4 are used, the result is: 49.95 x 2 = 199.76 Voc and a current of 14.04 A x 4 strings = 56.16 Isc.

Both are still safe for the SCC controller, which has a maximum limit of 80 A and uses cables with a diameter of 25–35 mm².

A 550 Wp PV module has dimensions of 2.28 m x 1.14 m = 2.5992 or 2.6 m².

The selection of DC cables for PV modules is adjusted to the maximum Isc current of the PV module string, multiplied by 125% for a safety factor according to standards.

Roof surface area is crucial to ensure the maximum number of PV modules can be installed, taking into account the area for regular maintenance. The roof slope angle and direction are also important to minimize the cost of the installed PV module support frame without additional materials required to create a safe additional frame angle to achieve the desired PV module azimuth angle.

The roof area of the research house is 10 m long x 9 m wide = 90 m2, minus the water reservoir area of 3.5 m x 3 m = 10.5 m2 and two roof voids measuring 1 m x 0.8 m = 0.8 m2. Therefore, if 80% of the roof area is used, it can accommodate 77 m2 x 80% = 62.3 m2 of PV modules. Thus, the total area that can be accommodated with PV modules is 62.3 m2 : 2.6 m2 = 24 PV modules.

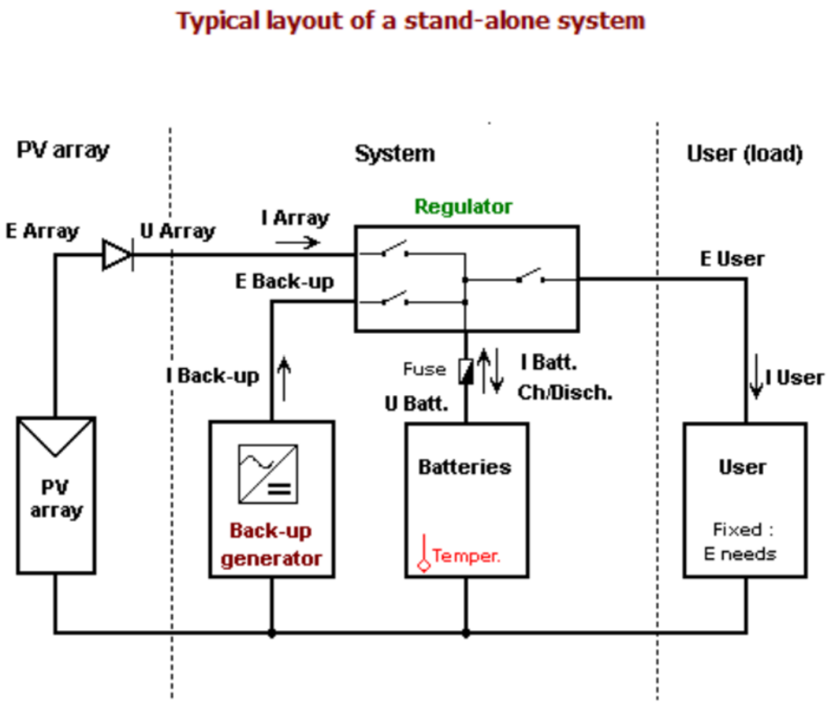


Figure 11. General circuit of PLTS from PVSyst.

Selection of Control Modules and Inverters

The selection of control modules and inverters listed in the PV Syst software database is adjusted to materials available in the domestic market to support this research analysis.

With the help of PV Syst software, various combinations can be simulated, including reference configurations, the number of loads to be served, the appropriate inverter capacity, and the targeted electrical power output. These factors determine the required number of PV modules, and their combination significantly influences the overall investment cost.

The specifications of the Solar Charge Controller (SCC) for battery charging and the inverter must consider maximum limit values for safe operation, such as open-circuit voltage (Voc) and short-circuit current (Isc). In this analysis, no electrical energy storage system (battery) is used.

Scc Control Module

The selection of SCC controllers listed in the PV Syst catalog is adjusted to materials available in the Indonesian domestic market to facilitate cost analysis for investment calculations.

SCC controllers are generally integrated with battery charging systems and inverters in a single unit. However, they can also be selected as separate units, consisting of a battery charger and a standalone inverter.

Plts Control Protection

Additional equipment is required to ensure that the solar power system operates safely and does not overload the circuit. Most protection features are typically integrated into the SCC. The equipment listed in the PV Syst catalog is adjusted to materials available in the domestic market.

However, additional protection is necessary for cable installations, ATS configuration, timers, and overload protection to comply with electrical installation standards such as PUIL, IEC, or SII.

Battery Selection Analysis

Battery selection from the PV Syst catalog is adjusted to materials available in the local Indonesian market. Wet batteries can be used, but they are physically larger and heavier than dry batteries and have shorter charge cycles.

In this analysis, only small-capacity batteries are used, sufficient to operate the SCC or inverter rather than for large-scale energy storage. This approach aims to reduce investment costs and optimize the use of rooftop solar systems in an off-grid configuration.

Wet Battery

The selection is based on materials available in the domestic market. Wet batteries require more maintenance and adequate ventilation due to gas emissions generated when the battery overheats during operation. The most commonly available type is the VLA battery.

Dry Battery

Dry batteries are also selected based on availability in the domestic market. They have smaller dimensions compared to wet batteries, longer usage cycles, and do not produce liquid or gas emissions. However, they may swell if heat is not properly dissipated due to poor ventilation. The most common type available is $LiFePO_4$.

Plts Analysis Using Pv Syst Software

PV Syst software is selected as one of the primary tools for system design in this study, alongside other available software such as PV*SOL, which also offers online simulation features.

The rooftop area used for PV module installation must also allow access for maintenance. The total roof area in this study is 10 m × 9 m = 90 m^2. However, it is recommended that not all roof space be utilized, considering roof shape constraints and the need to provide access for technicians during maintenance or repair of PV modules.

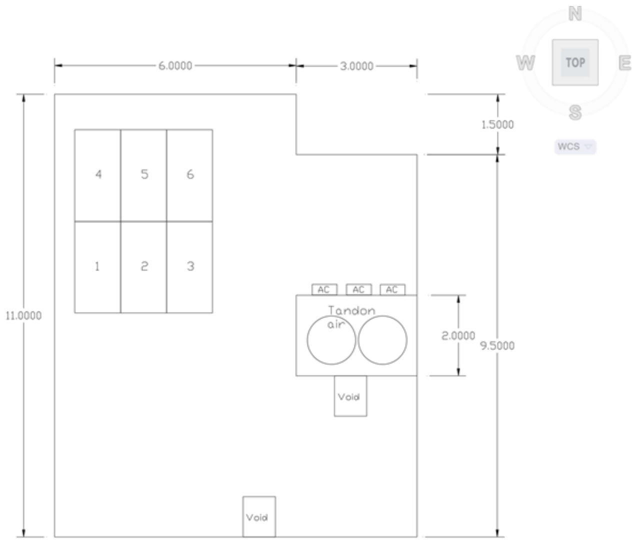


Figure 12. Ideal Position of PV Modules on the Rooftop

Total Active Power Used Simultaneously

The total active load power can be calculated by summing the power consumption of all electrical equipment used simultaneously during peak daytime usage, which occurs at 11:00 AM:

Total Active Power = 350 + 300 + 310 + 125 = **1,085 W**

ENERGY CONSUMED IN kWh

Electrical energy consumption can be calculated using the following formula:

E = P \times t

where:

- **P** = power in kW
- **t** = usage time in hours

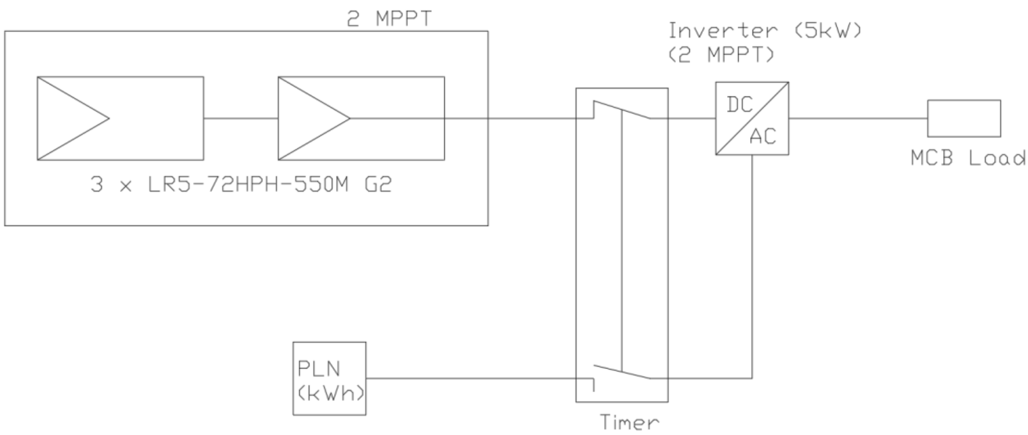


Figure 14. Single-Line Diagram with Rooftop PLTS Timer

Assume nighttime duration = 12 hours (6:00 PM – 6:00 AM):

E=0.77 kW×12 hours≈9.24 kWhE = 0.77\ \text{kW} \times 12\ \text{hours} \approx 9.24\ \text{kWh}E=0.77 kW×12 hours≈9.24 kWh

Therefore, a household with the usage pattern above consumes approximately **9.2 kWh** during nighttime hours.

To ensure that the Miniature Circuit Breaker (MCB) operates safely, a safety margin of 20–30% should be added:

Power with Margin=770 W×1.3≈1000 W\text{Power with Margin} = 770\ \text{W} \times 1.3 \approx 1000\ \text{W}Power with Margin=770 W×1.3≈1000 W

Using a power factor of 0.8 (standard for residential households in Indonesia):

Apparent Power (VA)=10000.8≈1250 VA\text{Apparent Power (VA)} = \frac{1000}{0.8} \approx 1250\ \text{VA}Apparent Power (VA)=0.81000 ≈1250 VA

Therefore, for this household, a minimum electrical capacity of **1,300 VA** is recommended to ensure safe operation in accordance with PLN standards.

Table 6. Equipment Prices

Depreciable assets

Asset	Depreciation method	Depreciation period (years)	Salvage value (IDR)	Depreciable (IDR)
PV modules				
LR5-72HPH-550M	Straight-line	20	0.00	7.200.000.00
Supports for modules	Straight-line	20	0.00	800.000.00
Inverters				
SH5.0RS	Straight-line	20	0.00	5.500.000.00
Batteries	Straight-line	20	0.00	15.000.000.00
Accessories, fasteners	Straight-line	20	0.00	250.000.00
		Total	0.00	28.750.000.00

Table 7. Rooftop PLTS maintenance costs.

Operating costs

Item	**Total IDR/year**
Maintenance	
Cleaning	200.000.00
Total (OPEX)	200.000.00
Including inflation (1.00%)	220.190.04

System summary

Total installation cost	18.375.000.00 IDR
Operating costs (incl. inflation 1.00%/year)	220.190.04 IDR/year
Useful energy from solar	5691 kWh/year
Energy sold to the grid	953 kWh/year
Cost of produced energy (LCOE)	33.1421 IDR/kWh

Economic Calculation Analysis.

This estimate can be adjusted if equipment or usage times are different. For energy efficiency, it is recommended to use LED lights, set the air conditioner to the optimal temperature, and turn off unused equipment.

- Nighttime energy (6:00 PM–6:00 AM): approximately 9.2 kWh
- Nighttime peak power with safety margin: ±1,000 W
- Suitable electricity capacity: 1,300 VA (PLN)

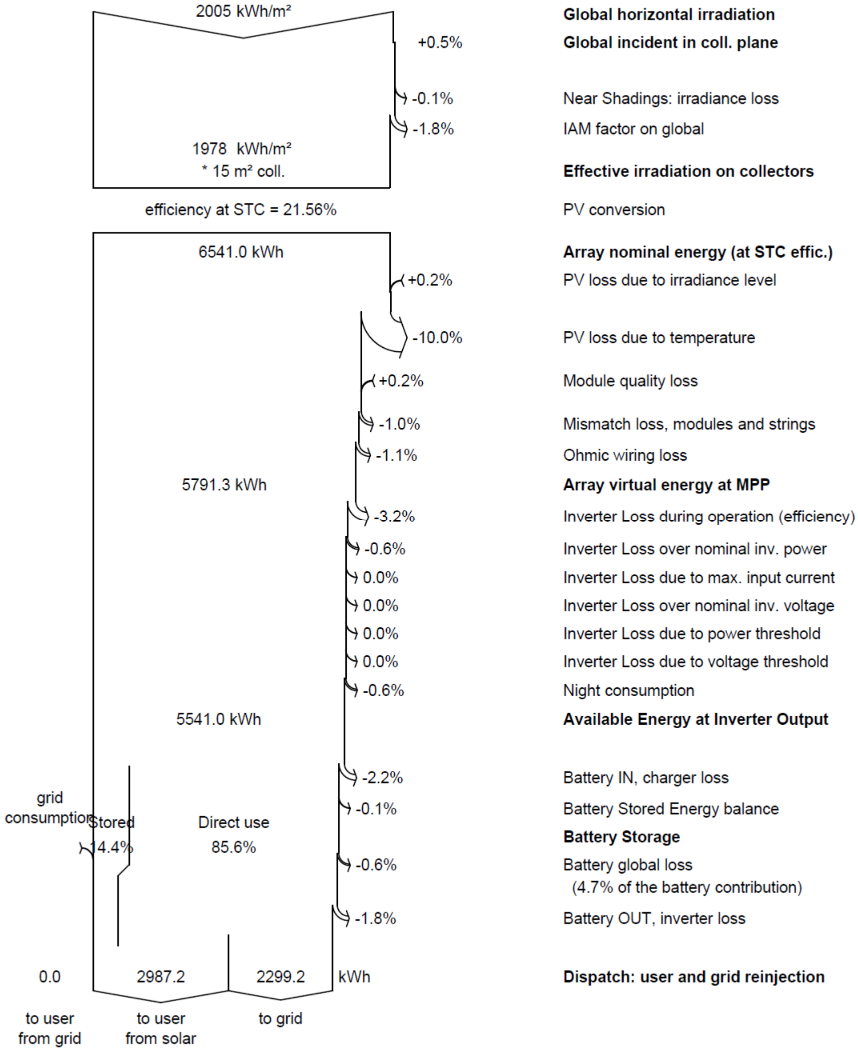


Figure 15. Electricity loss diagram for a rooftop solar power plant.

Investment Costs.

The 2026 electricity selling price for R1 household customers by PT PLN is IDR 1,444.70. This price serves as the benchmark for calculating the average income generated to recover the investment cost of a rooftop solar power plant.

By analyzing the electricity demand as a daily requirement, monthly electricity usage and comparable prices are considered as the monthly and annual income for the rooftop solar power plant.

To generate 5541 kWh of inverter output power for direct household use, several components are required for the rooftop solar power plant. These components require costs, which we include in the analysis as the initial investment cost. Each component has an estimated lifespan and efficiency, which are taken into consideration, as well as periodic maintenance or replacement costs.

Recovery Costs.

Year	Own funds	Run costs	Self cons. Saving	Cumul. Profit
0	30,665,000	0	0	(30,665,000)
1	0	250,000	4,313,517	(26,601,483)
2	0	250,000	4,313,517	(22,537,966)
3	0	250,000	4,313,517	(18,474,449)
4	0	250,000	4,313,517	(14,410,932)
5	0	250,000	4,313,517	(10,347,415)
6	0	250,000	4,313,517	(6,283,898)
7	0	250,000	4,313,517	(2,220,381)
8	0	250,000	4,313,517	1,843,136
9	0	250,000	4,313,517	5,906,653
10	0	250,000	4,313,517	9,970,170
11	0	250,000	4,313,517	14,033,687
12	0	250,000	4,313,517	18,097,204
13	0	250,000	4,313,517	22,160,721
14	0	250,000	4,313,517	26,224,238
15	0	250,000	4,313,517	30,287,755
16	0	250,000	4,313,517	34,351,272
17	0	250,000	4,313,517	38,414,789
18	0	250,000	4,313,517	42,478,306
19	0	250,000	4,313,517	46,541,823
20	0	250,000	4,313,517	50,605,340

Table 8. Payback Period

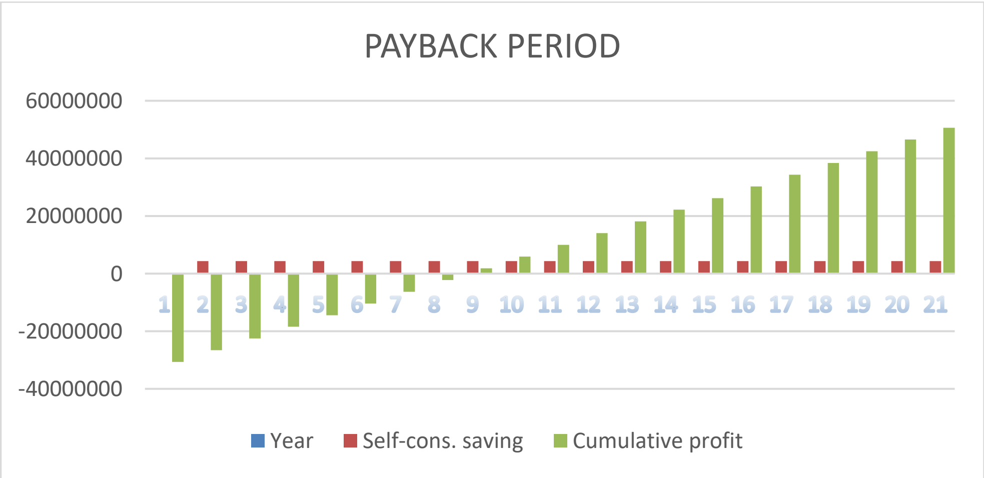


Figure 16. Payback Period Curve

Capital budgeting refers to the use of capital or personal funds to initiate a company project. Therefore, capital budgeting is the process of evaluating and selecting long-term investments that align with a company's objective of wealth maximization. Cash inflow and cash outflow represent projected future revenues and expenditures. A company is considered financially healthy when cash inflow exceeds cash outflow.

The objectives of capital budgeting are to:

1. Estimate long-term profits and losses resulting from invested capital.
2. Carefully determine the company's funding requirements, since excess funding may create additional fixed costs, while insufficient funding can disrupt production processes.
3. Support decisions related to fixed asset purchases (equipment or machinery) and other long-term expenditures (capital expenditures).

Capital expenditure refers to the outlay of company funds expected to generate long-term benefits (rate of return) over more than one year, such as the purchase of land, machinery, and other fixed assets. These expenditures are often referred to as *outlays*.

The motives for undertaking capital expenditure investments include:

1. Expansion investment
2. Replacement investment
3. New product activities or business diversification (renewable investment)

The capital budgeting process involves:

1. Preparing an investment proposal (investment project)
2. Estimating cash flows, including outflows, from the proposal
3. Evaluating the projected cash flows
4. Selecting investment proposals based on project acceptance criteria such as Payback Period (PP), Net Present Value (NPV), and Internal Rate of Return (IRR)

Material Purchase, Installation, and Maintenance Costs:

1. Six PV modules at Rp. 1,200,000 each
2. One SCC and Hybrid Inverter at Rp. 5,500,000
3. Three batteries at Rp. 5,500,000 each
4. One control box at Rp. 1,165,000
5. Eight aluminum frames at Rp. 100,000 each
6. Annual PV module cleaning cost at Rp. 250,000
7. Installation and transportation cost at Rp. 1,000,000

Thus, the initial investment required is **Rp. 30,665,000**, referred to as **CF_0 (Initial Cash Flow)**.

The investment evaluation process for residential application produced the following results:

1. **Payback Period (PP):** 7 years and 2 months

2. **Net Present Value (NPV):** Rp. 27,957,104
3. **Internal Rate of Return (IRR):** 8%
4. **Net Profit:** Rp. 19,940,340

The Payback Period considers the time required for a company to recover its initial investment (CF_0). According to Franco Petrecca (2014), this method ignores the concept of the *Time Value of Money*, meaning that cash flows are not discounted using a specific discount rate.

Simulation results indicate that energy utilized from the rooftop solar system reached **5,691 kWh (88.7%)**, while **11.3%** was stored in batteries. Of the 88.7% generated power, approximately **953 kWh** remained unused because the rooftop PV system was configured with an Automatic Transfer Switch (ATS) to prevent connection to the PT PLN (Persero) grid, a configuration commonly referred to as an **On-Grid Self-Consumption System**.

Annuity Cash Flow refers to a series of equal cash flows occurring at regular intervals over a specified period. In capital budgeting, annuity cash flow is often used to evaluate investments that generate consistent annual returns, such as savings from electricity cost reductions produced by rooftop solar systems.

Formula: $PP = \frac{CF_0}{CF_t}$……………………………………………………………(4.2)

Where:
PP = Payback Period
CF0 = Cash flow in year zero or the beginning or initial investment
CFt = Cash flow in year n
If the cash flow is not an annuity, the following equation is used:

The acceptance criterion with PP is if the project's PP < the maximum acceptable PP within a time unit, for example, one year.

Formula: 〖PP〗_project <maximum acceptable PP
……………………………….(4.3)

Net Present Value is the overall cash flow pattern of an investment in relation to time (n) and based on a certain discount rate (r). This method compares the incoming cash flow (return) with the cash flow already spent by the company (initial investment).

The criterion for project acceptance is if cash inflow > cash outflow.

Formula: NPV = 〖PV〗_n- 〖CF〗_0
…………………………………………………………………………(4.4)

Where:
〖PV〗_n = total cash value in n years
〖CF〗_0 = cash investment in the initial year

Internal Rate of Return is a method for comparing the rate of return (IRR) that will be received with the cash flow that the company has already spent or the initial investment or 〖CF〗_0. (Petrecca, 2014).

Table 9. Costs in calculating Rooftop PLTS.

Cost of the system

Installation costs

Item	Quantity units	Cost IDR	Total IDR
PV modules			
LR5-72HPH-550M G2	8	1.200.000.00	9.600.000.00
Supports for modules	8	10.000.00	80.000.00
Batteries			4.500.000.00
Other components			
Accessories, fasteners	1	150.000.00	150.000.00
Wiring	1	500.000.00	500.000.00
Combiner box	1	45.000.00	45.000.00
Monitoring system, display screen	1	1.000.000.00	1.000.000.00
Measurement system, pyranometer	1	1.500.000.00	1.500.000.00
Installation			
Transport	1	1.000.000.00	1.000.000.00
		Total	18.375.000.00
		Depreciable asset	14.330.000.00

Operating costs

Item	Total IDR/year
Maintenance	
Cleaning	200.000.00
Total (OPEX)	200.000.00
Including inflation (1.00%)	220.190.04

System summary

Total installation cost	18.375.000.00 IDR
Operating costs (incl. inflation 1.00%/year)	220.190.04 IDR/year
Useful energy from solar	5691 kWh/year
Energy sold to the grid	953 kWh/year
Cost of produced energy (LCOE)	33.1421 IDR/kWh

Simple payback is the time required for an investment to recover its costs. The payback period equation is as follows:

Formula: $SP = \frac{C}{C_{ener} - (C_{operasi\ dan\ perawatan} + C_{eksisting})}$ ....(4.5)

Where:
SP = Simple payback
C = Cost incurred
Cener = Total annual usage costs
Co&p = Total operating and maintenance costs
Cekisting = Total annual electricity usage costs

Table 10. Estimated equipment life.

Depreciable assets

Asset	Depreciation method	Depreciation period (years)	Salvage value (IDR)	Depreciable (IDR)
PV modules				
LR5-72HPH-550M	Straight-line	20	0.00	7.200.000.00
Supports for modules	Straight-line	20	0.00	800.000.00
Inverters				
SH5.0RS	Straight-line	20	0.00	5.500.000.00
Batteries	Straight-line	20	0.00	15.000.000.00
Accessories, fasteners	Straight-line	20	0.00	250.000.00
		Total	0.00	28.750.000.00

Net Present Value is the sum of all costs incurred and the present value of all costs incurred in an investment period, with the following equation:

Formula: $NPV = \sum_{n=0}^{n} \frac{Cn}{(1+r)^n}$ ....(4.6)

Where:
NPV =
Cn = Cost in the nth year
n = duration of the project
r = discount rate

$0 = \sum_{n=0}^{N} \frac{Cn}{(1+IRR)^n}$ ....(4.7)

Table 11. PLN R1 tariff rates.

Financing	
Own funds	30.665.000.00 IDR
Electricity sale	
Feed-in tariff	1.444.00000 IDR/kWh
Duration of tariff warranty	20 years

The Internal Rate of Return (IRR) is the value of all costs after they have been converted to their present value (PV). The IRR will make the NPV of all costs equal to zero, according to equation (4.7).

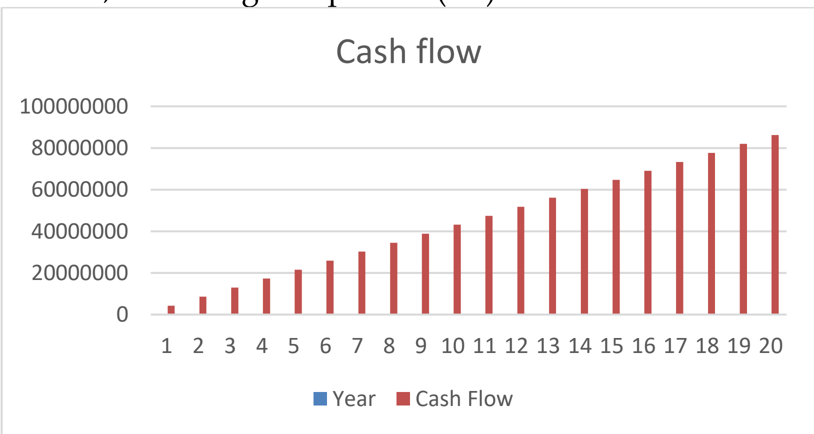


Figure 17. Rooftop PLTS Income.

CONCLUSION

The demand for electrical energy continues to increase alongside population growth and business expansion, as reflected in the rising number of customers of PT PLN (Persero). Indonesia's geographical location along the equator provides significant potential for utilizing photovoltaic modules to convert solar energy into electricity without disrupting the PLN grid, creating both opportunities and challenges. With the assistance of PVsyst software, simulations can be conducted for various roof shapes and building orientations, such as residential houses with diverse designs. Rooftop solar power systems require further analysis and research to evaluate their potential in reducing fossil fuel dependence for electricity generation. Based on the simulation and design analysis, several conclusions can be drawn regarding rooftop solar investment:

1. Rooftop solar installations can be applied to various roof structures, from small-scale systems to larger capacities depending on available roof area and electricity demand. Reduced electricity costs paid to PLN can gradually be achieved through the utilization of rooftop solar systems in equatorial regions without requiring modifications to roof angle or orientation.
2. The rooftop solar design in this study achieved a capacity of 3,300 Wp without altering the roof structure, generating 5,541 kWh of electricity. With an initial investment cost of Rp. 36,650,000, the project is considered financially competitive, with a payback period of approximately 7 years and 2 months.
3. The self-consumption rooftop solar system analyzed in this study is considered financially beneficial for meeting household electricity demand of 2,987.2 kWh and feasible as an investment. However, approximately 2,299.2 kWh of unused electricity remains, indicating the possibility of adding more household electrical loads.
4. Rooftop solar systems can last up to 20 years or longer. Although PV modules remain functional over long periods, they still require maintenance and periodic replacement due to gradual efficiency degradation over time.

RECOMMENDATIONS

Several recommendations from this study may serve as discussion points for future development:

1. Greater public campaigns and socialization are needed to encourage rooftop solar adoption, starting from small-scale systems or household electric vehicle charging, to support greenhouse gas reduction and mitigate global warming.
2. Collaboration among academics, government, and society is necessary to promote alternative energy sources that can replace fossil fuels producing carbon dioxide emissions, particularly those easily applicable to daily household needs.
3. Large-scale technological adoption should be supported by central government subsidy policies to facilitate access to rooftop solar materials for communities in urban, rural, and especially isolated regions far from city infrastructure.
4. Government support is needed to encourage independent and sustainable energy transition, including revising regulations to allow the repurchase of electricity generated by rooftop solar systems.
5. The government should establish regulations for managing waste from PV modules and batteries to protect the environment, including the development of recycling systems for solar power system waste.

REFERENCES

Anurag Shrivastava, Solar energy capACity assessment and performance evaluation of a standalone PV System using PV SYST, (2023), Solar energy capacity assessment and performance evaluation of a standalone PV System using PV SYST

AS Mathur, Techno-economic feasibility and sensitivity analysis of a stand-alone solar photovoltaic power plant with battery energy storage using *PV Syst*, (2025), Techno-economic feasibility and sensitivity analysis of a stand-alone solar photovoltaic power plant with battery energy storage using PV Syst

BPS Kota Makassar. (2024). Statistik Daerah Kota Makassar 2024, Vol. 10, 2024. https://makassarkota.bps.go.id/

Bruno Andre, Automatic Transfer System Generic Book, (2016), DOI:10.13140/RG.2.2.12707.66089

ESDM. Panduan Pengoperasian Dan Pemeliharaan PLTS *Off-Grid*. 2017.

G. Petrecca, Energy Conversion and Management: Principles and Applications, DOI 10.1007/978-3-319-06560-1_19, # Springer International Publishing Switzerland 2014.

https://makassar.terkini.id/berikut-jadwal-pemadaman-listrik-di-maros-pangkep-siang-ini-sampai-malam-cek-wilayahmu/. download tanggal 28 Maret 2024.

https://www.builder.id/panduan-memilih-panel-surya/. download tanggal 28 Maret 2024.

Jaka Windarta, Analisis Teknis dan Ekonomis Pembangkit Listrik Tenaga Surya *Off-Grid* Menggunakan *Software PV Syst* untuk Usaha Mikro Kecil dan Menengah (UMKM) Coffeeshop Remote Area, (2021), https://doi.org/10.14710/teknik.v42i3.40242

Kementrian Energi Dan Sumber Daya Mineral Republik Indonesia, Siaran Pers, Nomor: 391.Pers/04/SJI/2022, Tanggal: 8 Oktober 2022.

Moorthi, V. Power Electronics Devices, Circuits and Industrial Applications. Oxford University Press. 2010.

Mohammad Baqir, Analysis and design of solar *PV Syst*em using *PV Syst software*, (2022), Analysis and design of solar PV System using PV Syst software

Nfaoui, M. at all.2021. Modeling, Simulation and Comparison of the Photovoltaic Productivity by Using the MATLAB/PV System.

Nike Sartika, Perancangan Dan Simulasi Sistem Pembangkit Listrik Tenaga Surya (Plts) Atap Pada Masjid Jami' Al-Muhajirin Bekasi, (2023), https://doi.org/10.14710/transmisi.25.1.1-9

PT. PLN. Rencana Usaha Penyediaan Tenaga Listrik PT. PLN 2015 – 2024, 2014.

Standar Nasional Indonesia 6197, Konservasi energi pada sistem pencahayaan. 2020.

PLN Pusat. (2025). Statistics PLN tahun 2024. https://web.pln.co.id/

Sujarwanto Dwiatmoko, Soaking up the Sun: Solar Energy Optimization during Pandemic, Study Case at Micro, Small and Medium Enterprises (MSME) Rattan Crafts Center in Trangsan Village, Sukoharjo, Central Java, (2022), https://doi.org/10.21771/jrtppi.2022.v13.no1.p12-19

Syarief Albar, Integrating *PV* plant 689 kWp into Coal-Fired Power Plant (CFPP) 615 MW at Paiton: To reduce auxiliary load and coal consumption, (20222), https://doi.org/10.24036/teknomekanik.v5i2.17072

Valentin, G. (1998-2004). User Manual For *PV**SOL Ver.2.4.

Xuan Cuong Ngoa, The Imp*AC*t of Electrical Energy Consumption on the Payb*AC*k Period of a *Rooftop* Grid-Connected Photovoltaic System: A case Study from Vietnam, (2022)