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Operational Analysis of Rooftop Solar Power Plant at SMK Negeri 3 Kupang

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ABSTRACT: *The implementation of 25 kWp On-Grid Rooftop Solar Power Plant at SMK Negeri 3 Kupang is expected to provide a solution to the problem of dependence on conventional energy and reduce school operational costs. Therefore, it is important to conduct an analysis of the Rooftop Solar Power Plant system at SMK Negeri 3 Kupang, in order to optimize the use of renewable energy and reduce school electricity operational costs. This study aims to determine the performance of the Rooftop Solar Power Plant and the amount of savings that occur. The research method used is a descriptive method and direct measurement of the inverter, MDP, LVMDP to measure the current and voltage to obtain the output power of the Solar Power Plant, PLN and load. The results of the study showed that the operational performance of the Rooftop Solar Power Plant can be known through the efficiency of the Rooftop Solar Power Plant at SMK Negeri 3 Kupang which was obtained with a maximum value that occurred on Saturday of 86.96%. The measurement results showed that there were savings in power and bills at SMK Negeri 3 Kupang. With savings for 7 consecutive days of 84.87%; 91.60%; 35.98%; 58.73%; 57.74%; 25.15%; 84.04%.*

KEYWORDS: *Rooftop PLTS, Ratio Performance, Efficiency, Electricity Savings.*

I. INTRODUCTION

Energy is a very important necessity for living things in their daily lives. Energy is divided into two types: Renewable Energy and Non-Renewable Energy. In the future, renewable energy will play an increasingly significant role in meeting the energy needs of living things. This is because fossil fuels, which are non-renewable energy sources, have been used by conventional power plants for a long time, depleting non-renewable energy sources and causing reserves to dwindle.

Solar energy is energy derived from radiation. This radiant energy can be used directly as a source of electrical power generation through a technology called photovoltaic (PV), commonly known as solar cells. Solar energy used to generate electrical power is called Solar Power Generation or SPP[3]. All aspects of society are inseparable from electrical energy, including the educational environment.

The implementation of a 25 kWp on-grid rooftop solar power plant at SMK Negeri 3 Kupang is expected to provide a solution to the problem of dependence on conventional energy and reduce the significant operational costs associated with electricity usage. In its implementation, the rooftop solar power plant can generate enough electricity to meet most of the school's energy needs for teaching and learning activities. Therefore, it is important to conduct an in-depth analysis of the existing rooftop solar power plant system at SMK Negeri 3 Kupang to evaluate its effectiveness and efficiency in supporting school operations.

II. THEORY

A Solar Power Plant (SPP) is a power generation technology that converts solar photon energy into electrical energy. Conversion occurs in solar modules consisting of cells
photovoltaic cells[4].

A. SOLAR POWER GENERATION SYSTEM

Solar Power Generation Systems are examples of various types of Solar Power Plants (SPPs) that have their own advantages and disadvantages.

Generally, Solar Power Generation Systems are categorized into Centralized Systems (Off-Grid), Connected Systems (On-Grid), and *Hybrid* Systems[9].

B. CALCULATION OF ELECTRICAL POWER AND ROOFTOP PLTS

Manual calculation of the number of components based on the daily load. The calculation is as follows:

1. Electric Power

$$P = V \times I \times \cos\varphi \quad (1)$$

$$= S \times \cos\varphi \quad (2)$$

$$P = V \times I \times \cos\varphi \times \sqrt{3} \quad (3)$$

$$= S \times \cos\varphi \quad (4)$$

2. Photovoltaic Efficiency

The efficiency that occurs in PV (*Photovoltaic)* is the ratio of the output power that can be generated by PV to the input power obtained from the intensity of sunlight. Efficiency formula in PV:

$$\eta = \frac{P\ Output}{P\ Input} \times 100\% \quad (5)$$

$$\eta = \frac{V.I}{I_r.A} \times 100\% \quad (6)$$

Dimana :
Ŋ = PV efficiency (%)
Ir = Solar radiation intensity (Watt/m^2)
P = Electrical power (Watt)
A = PV Area (m^2)
V = PV Voltage (Volt)
I = PV Current (Ampere)

3. Performance Ratio (PR)

Performance ratio is the ratio between the effective energy produced or used and the energy produced if the solar power system operates continuously. Performance ratio (PR) includes light losses, PV array losses, and solar power system losses. Performance ratio (PR) is a way to calculate the actual efficiency of a solar power system. The equation for solar power system performance ratio is:

$$Performance\ Ratio = \frac{AktualOutput\ PLTS}{EkspektasiOutput\ PLTS} \quad (7)$$

Dimana :
PR = Rasio Performa Sistem (%)
Aktual Output = Daya yang dihasilkan (kW)
Ekspektasi Output = Kapasitas Daya Total PV (kWp)

C. FACTORS AFFECTING SOLAR MODULE PERFORMANCE

The operation of solar modules in absorbing sunlight to generate electricity is also influenced by several factors, including: temperature (temperature correction factor), sunlight intensity, solar module orientation, wind speed, dirt *(soilage)*, *shading*, and solar module tilt angle.

III. METHODOLOGY

The research methods used to obtain an overview of the operational system of the rooftop solar power plant at SMK Negeri 3 Kupang are descriptive methods and direct measurements.

Figure 1 shows a block diagram of the electrical energy installation system at SMK Negeri 3 Kupang using PV module components, DC *Combiner* panels, inverters, MDP and LVMDP, which are designed to provide electrical energy that will be interconnected with the PLN network.

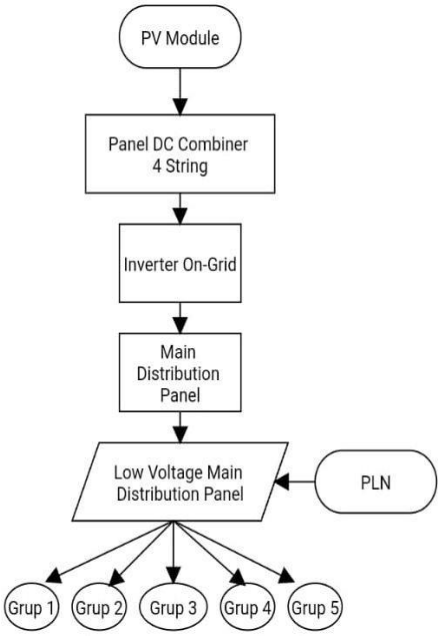


Fig. 1 Roof-mounted PV System Block Diagram

In the process of completing this research, procedures for measuring solar radiation intensity, temperature and humidity, current and voltage, as well as PV and inverter output power were required. These procedures were carried out for a week from 06:00 to 18:00 WITA. The steps of this research can be seen in Figure 2.

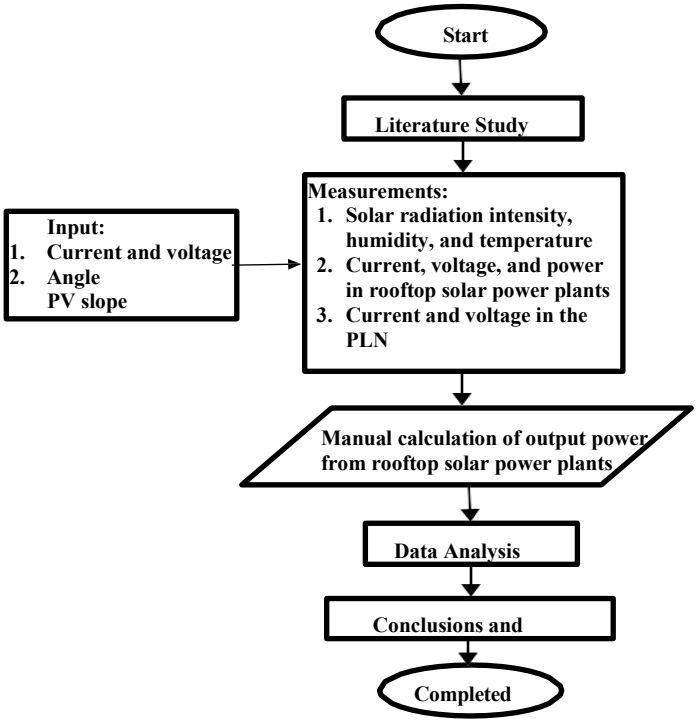


Fig. 2 Research Flow Char

IV. RESULTS AND DISCUSSION

The 25 kWp *On-Grid* Rooftop Solar Power Plant at SMK Negeri 3 Kupang consists of installed equipment components, including 76 solar modules with a total of 4 *strings*, 1 DC *Combiner* Panel, 1 Solis inverter, 1 *Main Distribution Panel* (MDP), and 1 *Low Voltage Main Distribution Panel* (LVMDP).

A. RESEARCH DATA RESULTS

1) Solar Radiation Intensity Data (kWh/m_2)

The solar radiation intensity data used is taken from statistical data (Global Solar Atlas). This solar radiation intensity data represents the average for September 2024. Solar radiation intensity plays a crucial role in determining the electricity production of a system. solar panels because the higher the environment around the solar panels, the more electricity generated by the solar panels.

Tbl. 1. Solar Radiation Intensity Data

Hour (WITA)	Radiation (kWh/m²)
06.00	0,017
07.00	2,611
08.00	7,889
09.00	12,293
10.00	15,44
11.00	17,174
12.00	17,819
13.00	17,403
14.00	15,72
15.00	12,715
16.00	8,734
17.00	3,985
18.00	0,288

Solar radiation intensity data taken from the Global Solar Atlas shows that peak solar radiation intensity occurs between 11:00 and 13:00 WITA, with solar radiation intensity ranging from 17.174 to 17.819 kWh/m^2.

2) Measurement Data for Temperature (°C) and Humidity (%)

The temperature and humidity measurement data used is data taken from the Meteorology, Climatology, and Geophysics Agency (BMKG).

Tbl. 2. Average Temperature and Humidity Data

Day/Date	Temperature (°C)	Humidity (%)
Sunday, 15/09/2024	22	78
Monday, 16/09/2024	25	72
Tuesday, 17/09/2024	26	74
Wednesday, 18/09/2024	23	76
Thursday, 19/09/2024	24	81
Friday, 20/09/2024	24	83
Saturday, 21/09/2024	23	90

Measurements were taken by measuring the temperature (°C) and humidity (%) in the area around the rooftop solar power plant from 6:00 a.m. to 6:00 PM WITA over a period of 7 days (Sunday, September 15, 2024 to Saturday, September 21, 2024).

From this data, it was found that the average maximum temperature occurred on Tuesday at 26°C, while the average maximum humidity occurred on Saturday at 90%.

3) Calculation of Output Power and Efficiency Produced by PV

In accordance with the data collection method used in the field, the calculated PV input power is the result of $P = V \times I$ for each string. This power will enter the *On-Grid* inverter, which will become the inverter output as 3-phase AC current. The calculated PV efficiency is the result of

$$Efisiensi\ PV\ (\%) = \frac{Output\ Inverter\ (kW)}{Kapasitas\ PV\ (kWp)} \times 100$$

Tbl. 3 Power Inverter Data and Maximum Efficiency

Day/Date	Time(WITA)	AC Inverter Output (W)	Efficiency
Sunday, 15/09/2024	12.00	16.330	65,32%
Monday, 16/09/2024	12.00	16.370	65,48%
Tuesday, 17/09/2024	13.00	16.610	66,44%
Wednesday, 18/09/2024	10.00	12.900	51,60%
Thursday, 19/09/2024	12.00	17.630	70,52%
Friday, 20/09/2024	07.00	7.030	28,12%

Saturday, 21/09/2024	12.00	21.740	86,96%

Data collected through observation and calculation on the inverter to obtain power and efficiency every hour from 06:00 to 18:00 WITA. The data above shows that the maximum power output occurred on Saturday at 12:00 WITA with a power of 21,740 W. Total PV output power greater than the AC output due to power losses in the PV, power losses in the conductors, and power losses in the inverter. PV efficiency is calculated data which ultimately shows that maximum PV efficiency occurs on Saturday at 12:00 WITA with an efficiency of 86.96%. Maximum efficiency and power output occur on Saturdays when there are no teaching and learning activities at school. This can be attributed to several factors, including solar radiation intensity, temperature, humidity, *shading,* and wind speed.

4) Measurement Results of PLTS and PLN Power Supply Against Load Requirements

Based on measurement data obtained at the rooftop solar power plant at SMK Negeri 3 Kupang on *the Low Voltage Main Distribution Panel* (LVMDP), the total power supply from the solar power plant, PLN, and the total power demand on the load were obtained. If the power supplied by the solar power plant and PLN exceeds the power required by the load, the power will be exported to the grid. If the power supplied by the PLTS and PLN is insufficient to meet the power demand of the load, it will be imported from PLN. In accordance with the data collection method used in the field, the export-import power obtained is the result of $Exim = (PLTS + PLN) - Beban$.

Tbl. 4 Average Power Supply Data for the Load

Day/Date	PLTS (kW)	PLN (kW)	Load (kW)
Sunday, 15/09/2024	7,60	4,81	3,56
Monday, 16/09/2024	8,70	5,27	2,48
Tuesday, 17/09/2024	2,53	3,75	2,44
Wednesday, 18/09/2024	3,71	2,72	2,62
Thursday, 19/09/2024	3,82	3,52	3,18
Friday, 20/09/2024	1,13	3,20	3,72
Saturday, 21/09/2024	7,76	5,37	2,09

The data collected is measurement data from the Low Voltage Main Distribution Panel (LVMDP) to obtain the average total power from the solar power plant, PLN, and the load for each hour from 06:00 to 18:00 WITA. The maximum average power supplied by the PLTS occurred on Monday at 8.70 kW, while the maximum average power supplied by PLN occurred on Saturday at 5.37 kW. The peak demand on the load occurred on Friday with a total power requirement of 3.72 kW. If the power supplied by the PLTS and PLN is greater than the load demand, the remaining power will be exported to the grid. Meanwhile, if the power supplied by the PLTS and PLN is less than the load demand, the load will take power from the PLN. In this case, there is power export and import between the PLTS and PLN.

B. Analysis And Discussion Of Research Data

1) Analysis of Solar Radiation Intensity

The peak intensity of solar radiation occurs between 11:00 a.m. and 1:00 p.m. WITA, with the highest value at 12:00 p.m. WITA at 17,819 kWh/m². During this period, solar panels produce maximum power output. Conversely, in the morning (6:00-7:00 WITA) and afternoon (5:00-6:00 WITA), radiation is very low, with a value of 0.017 kWh/m² at 6:00 WITA, so the power output of solar panels is very minimal at these times.

2) Temperature and Humidity Analysis Air

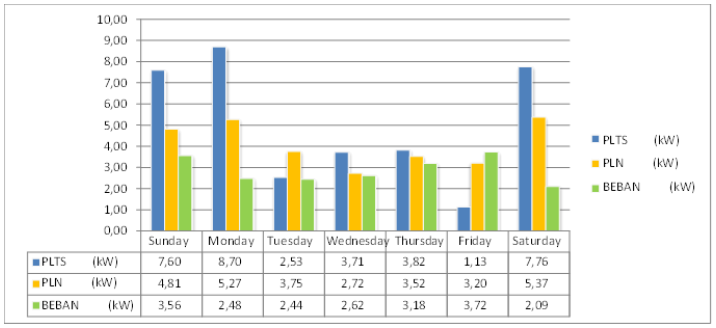
temperature and humidity affect the performance of solar panels. An increase in temperature and Humidity can reduce the efficiency of solar panels, as panels are more efficient at lower temperatures. On Tuesday, the average maximum temperature was recorded at 26°C, which can reduce efficiency even though solar radiation is high. Humidity is also fluctuating, peaking on Saturday at 90%, which has the potential to reduce the efficiency of photovoltaic energy conversion. Even though solar radiation is high, the increase in temperature between 11:00 a.m. and 2:00 p.m. WITA can cause a decrease in the efficiency of solar panels.

3) Analysis of PV Output Power and PV Efficiency of the PLTS System at SMK Negeri 3 Kupang

Installed capacity of 25 kWp with 76 solar panels divided into 4 strings. The data collected records the power output from the solar panels and inverters in the

form of AC. Fluctuations in the power output of the solar power plant throughout the day are influenced by varying sunlight intensity, with the highest output around 12:00 WITA and the lowest output in the morning and evening. The performance of the solar power plant was measured by efficiency, with the highest efficiency on Saturday (7,030 W) at 86.96% and the lowest on Friday (21,740 W) at 28.12%. The power supplied by the solar power plant is more dominant than that supplied by PLN. Factors affecting efficiency include the angle of sunlight and inverter operations that sometimes shut down, causing power output to be unmeasurable at certain times.

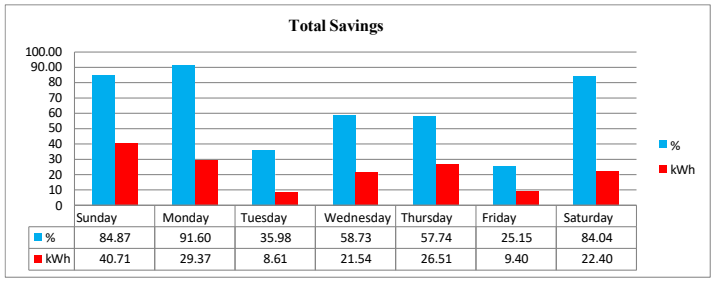
4) Analysis of Average Power Supply Against Load Demand at SMK Negeri 3 Kupang



	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
PLTS (kW)	7,60	8,70	2,53	3,71	3,82	1,13	7,76
PLN (kW)	4,81	5,27	3,75	2,72	3,52	3,20	5,37
BEBAN (kW)	3,56	2,48	2,44	2,62	3,18	3,72	2,09

Fig 3. Average Power Supply Graph Against Load Requirements

When power from the solar power plant and PLN exceeds load requirements, the unused surplus power is exported to the grid for use by other consumers. Conversely, if the power supply is insufficient, the load will draw additional power from PLN. During the operation of the rooftop solar power plant from morning to evening, the power supply from the solar power plant is more dominant than that from PLN. Power exports and imports between the solar power plant and PLN occur according to the calculation Exim = (Solar Power Plant + PLN) - Load. Results



	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
%	84.87	91.60	35.98	58.73	57.74	25.15	84.04
kWh	40.71	29.37	8.61	21.54	26.51	9.40	22.40

Fig 4. Total Savings Graph

The calculation of power savings at SMK Negeri 3 Kupang shows that from morning to afternoon, power savings occur when the solar power plant is operating. If the power from the solar power plant is sufficient or exceeds demand, the load will be supplied entirely by the solar power plant; if not, PLN will supply the shortfall. The greatest savings occurred on Sunday, at 84.87% with 40.71 kWh saved, equivalent to IDR 37,652.29. Monday also showed high savings of 91.60%, 29.37 kWh, IDR 27,170.64. Conversely, Friday had the lowest savings of 25.15%, 9.40 kWh, Rp 8,698.34. Overall, savings were higher on weekends (Saturday-Sunday) compared to weekdays (Tuesday-Friday), indicating a more efficient energy usage pattern on weekends. These savings only apply when the solar power plant operates during the day, while at night all power is supplied by PLN.

Measurements show exports and imports on various days, for example Sunday (Exports = 115.875 kW, Imports = 0.913 kW), Monday (Exports = 149.274 kW), Tuesday (Exports = 50.67 kW, Imports = 0.772 kW), with daily variations in exports and imports.

5) Analysis of Total Power Savings at SMK Negeri 3 Kupang

is because the power supply from the solar power plant is greater than the power supply from PLN, to meet the load requirements. With savings for 7 consecutive days:

Sunday 84.87%, Monday 91.60%, Tuesday 35.98%, Wednesday Thursday 58.73%, Friday 57.74%, Saturday 84.04%.

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