

DESIGN AND TECHNO-ECONOMIC ANALYSIS OF A HYBRID PHOTOVOLTAIC AND WIND POWER PLANT AT MSTP UNDIP JEPARA

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ABSTRACT

Electricity consumption in the MSTP Jepara building still largely depends on grid electricity, which is predominantly generated from fossil fuels. To reduce this dependency, a hybrid solar–wind power system (PLTH) was designed and analyzed using HOMER software. The proposed system combines a solar photovoltaic (PV) array and a small-scale wind turbine to partially supply the building's electricity demand. Simulation results show that the system operates for approximately 4,367 hours per year with a peak output of 19.8 kW. The solar PV system produces about 35,595 kWh annually, contributing around 9.49% of the total electricity demand, while the wind turbine generates approximately 2,275 kWh per year with a capacity factor of 26% and a penetration level of 0.61%. Overall, the hybrid system can supply approximately 10.097% of the building's annual electricity consumption of 374,902 kWh. An economic evaluation indicates that the system is financially feasible, with a Levelized Cost of Electricity (LCOE) of IDR 1,648 per kWh, a Return on Investment (ROI) of 9%, and an Internal Rate of Return (IRR) of 13.1%. These results suggest that although the contribution of renewable energy remains limited, the proposed PLTH system has practical potential as an initial step toward reducing dependence on fossil fuels in institutional buildings.

Keywords: hybrid power plant; renewable energy; technical analysis; economic analysis; HOMER.

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1. Introduction

Electrical energy has a vital role in technological development. In 2023, Indonesia's per capita electricity consumption rose to 1,337 kWh annually, up 13.98% from 2022 [1]. However, most of the electricity is still generated from non-renewable energy sources, with coal accounting (40.46%), petroleum (30.18%), natural gas (16.28%), and from renewable energy (13.09%) [2]. The use of fossil fuels releases environmentally damaging carbon emissions, and their supplies are depleting [3]. Consequently, the adoption of renewable energy sources is necessary to ensure future energy sustainability. This issue is relevant not only at the national level but is also becoming increasingly critical at the institutional level, where energy consumption continues to increase.

Marine Science Techno Park (MSTP) of Diponegoro University in Jepara is a center for science and technology innovation in the marine sector, which focuses on research, maritime business, and shrimp production. Located in Teluk Awur, Jepara, MSTP UNDIP occupies 52 hectares of land and features laboratories, hatcheries, ponds, a mangrove conservation center, and a student dormitory. MSTP subscribes to P-1/TR (197 kVA) electricity with costs of up to Rp 45–50 million per month [4]. The increase in electricity tariffs and the region's

dependence on fossil fuels demand the optimization of New and Renewable Energy (NRE) as a sustainable energy source.

Indonesia is dedicated to lowering carbon emissions by ratifying the Paris Agreement through Law No. 16 of 2016. The country's GHG emission reduction goal in the 2030 NDC was initially set at 29% unconditionally and 41% conditionally. In 2022, this target was updated in the ENDC to 31.89% unconditionally and 43.20% conditionally. Indonesia also targets achieving net zero emissions by 2060 or sooner [5]. At the institutional level, this commitment further emphasizes the need for renewable energy adoption in facilities such as MSTP Jepara.

The transition toward alternative energy sources, including solar, wind, hydro, and geothermal, is essential to reduce dependence on fossil fuels. Indonesia has solar energy potential with an average radiation of 4.8 kWh/m²/day and a monthly variation of 9%, ensuring year-round availability. Wind energy is feasible in areas with a minimum speed of 4 m/s [6], such as NTT, NTB, South and Southeast Sulawesi, as well as the North and South Coasts of Java. Teluk Awur, Jepara, was chosen as the research site for the potential for alternative energy on the North Coast of Java.

MSTP Jepara is situated in a coastal region with significant potential for renewable energy. According to NASA POWER data, the location receives a common Global Horizontal Irradiance (GHI) of 5.48 kWh/m²/day, demonstrating ample

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solar energy. Additionally, a survey on October 29, 2022, measured maximum wind speed is 4.4 m/s at 2 meters above the surface. This correlates with NASA's data, which shows common wind speed data of 4.4 m/s at 10 meters for the MSTP Jepara area [7]. Furthermore, the absence of on-site renewable energy utilization means that the available solar irradiation (5.48 kWh/m²/day) and moderate wind potential (4.4 m/s) remain underutilized, representing a missed opportunity for cost reduction and energy diversification.

MSTP Jepara also participates in efforts to accelerate the Sustainable Development Goals (SDGs) [8]. This development focuses on the energy sector. Good Energy Management at MSTP Jepara must align with the principles of energy security. Energy security is crucial for sustainable national growth and encompasses three main factors: energy source availability, affordable energy supplies, and the development of new renewable energy resources [9]. The development of New and Renewable Energy at MSTP Jepara should be carried out to optimize energy supply.

Given the high energy demand, cost burden, and underutilized renewable potential, the design of a Hybrid Power Plant (PLTH) becomes a promising solution to improve energy independence at MSTP Jepara. In addition, PLTH can support this area as an educational tourism destination, raise awareness of renewable energy, and serve as a model for other institutions, especially in Indonesia. Maity et al. have designed Hybrid Microgrid for a university campus. The optimal system configuration reduced the cost of electricity from \$0.13/kWh to \$0.026/kWh and yielded a payback period of 17.3 years [10].

Compared with existing studies, this research extends prior work in both technical scope and evaluation methods. Febrian Hadiatna applied the Hybrid Optimization of Multiple Energy Resources software to assess household-scale hybrid systems and reported feasibility using Net Present Value and Internal Rate of Return. While this approach is suitable for small installations, it does not explicitly address detailed system sizing, protection design, or operational performance at larger scales [11]. Studies by Kiswanto, Setia, and Utami provide valuable insights into prototype development and small residential applications. However, their scope generally focuses on basic system implementation without presenting an integrated framework that combines detailed photovoltaic array and string configuration, direct current and alternating current cable sizing, combiner and protection arrangement, battery cycling behavior and loss evaluation, and scenario-based system performance analysis [12-14]. These observations indicate that existing studies are predominantly limited in scale and level of engineering detail, particularly when transitioning from prototype or residential systems to more complex applications. In addition, integrating solar and wind energy in a hybrid configuration introduces technical challenges such as resource intermittency, optimal capacity sizing, and system reliability, which must be carefully analyzed to ensure both technical feasibility and economic viability.

This study presents a comprehensive institutional-scale hybrid photovoltaic and wind power system design by integrating renewable resource assessment based on satellite data and on-site measurements, detailed component-level electrical design, and an evaluation of system performance and operational behavior. Economic feasibility is assessed alongside other criteria using Net Present Cost, Levelized

Cost of Energy, Return on Investment, Internal Rate of Return, Present Worth, Annual Worth, Payback Period, and Discounted Payback Period. The author believes that this integrated approach will result in a more complete system in the future. This study also places strong emphasis on core engineering design aspects.

2. Methodology

2.1. Design and simulation

The research consists of several stages, beginning with problem identification and a review of relevant literature. Next, the research will also collect data on solar irradiation and wind speed to estimate the potential of renewable resources at the study location. Based on these data, the main system components will be selected, and the initial capacity of the hybrid solar-wind power plant is determined. HOMER software is used to assess the technical design based on its optimization criteria. Also, this software was used by Muskan et al. to design a PV-diesel generator hybrid system to meet the electricity demand of Akhnoor town in the Jammu district of Jammu and Kashmir, India [15]. In addition, Riayatsyah et al. designed a campus hybrid renewable energy system combining PV and wind turbines, which contributed up to 82% of the total electricity demand while reducing energy costs, highlighting its applicability in institutional environments [16].

In this study, the system must supply at least 10% of the annual electrical load as a minimum target while also demonstrating acceptable economic performance. After these requirements are satisfied, a detailed economic feasibility analysis is performed. The overall research methodology is illustrated in figure 1.

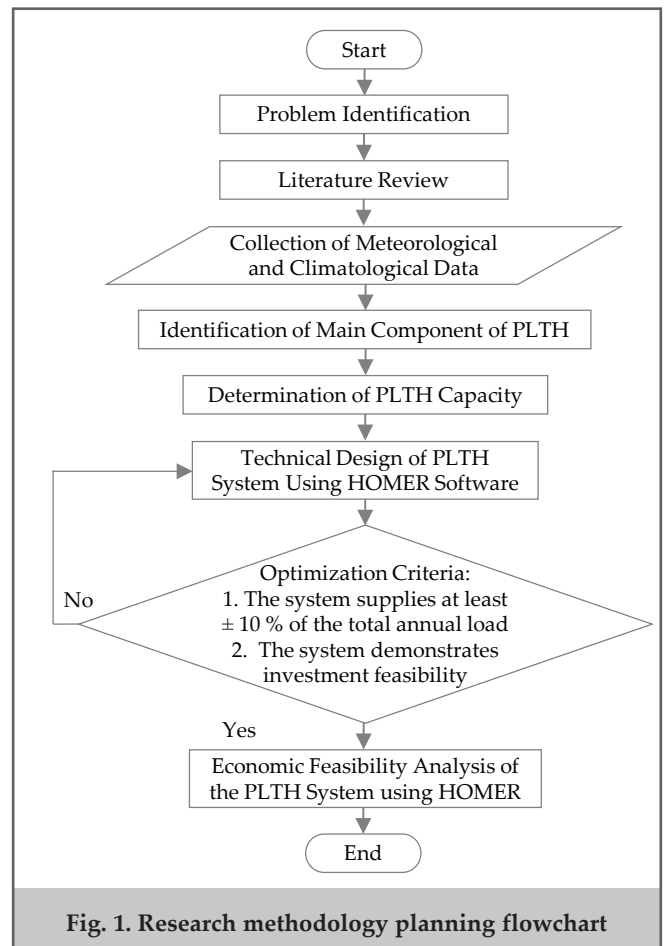


Fig. 1. Research methodology planning flowchart



Fig. 2. Research location

The research starts with problem identification and literature review, followed by renewable resource assessment, component selection, system sizing, and HOMER-based simulation. The process will be reviewed iteratively until the technical target of supplying at least 10% of the annual load and the economic feasibility criteria are satisfied.

2.2. Research location

This study was conducted at MSTP Jepara in the Teluk Awur area, Tahunan District, Jepara Regency, Central Java. This location is selected because the hybrid solar-wind power plant is planned to be implemented in that area. The geographical coordinates of the study location are 6°37'12" S and 110°38'24" E, as shown in figure 2.

Figure 2 describes the geographical location of MSTP Jepara in Teluk Awur, Central Java. The site was selected due to its proximity to coastal wind resources and its relatively high solar irradiation potential, which is suitable for the hybrid solar-wind power system implementation.

2.3. Meteorological data

2.3.1. Intensity of solar radiation

Solar irradiation is a key parameter in the planning and design of solar PV systems [17]. In this study, solar irradiation data for the research site were obtained from the NASA POWER database. The monthly solar irradiation values for the MSTP Jepara location are summarized in table 1.

Table 1 indicates that the average solar irradiation at MSTP Jepara is 5.48 kWh/m²/day. This value demonstrates favorable solar energy potential and supports the feasibility of photovoltaic system deployment at the study location.

Wind speed and direction

Wind speed and direction are important parameters in the planning of a wind power plant, particularly for determining an appropriate turbine type and capacity. The wrong selection of turbine specification can significantly impact the overall system power output [18]. NASA POWER agroclimatology database is the resource of wind speed and direction data for this research. Then, the wind characteristics data is in table 2 below.

From the table above, the average wind speed and direction shows 4.40 m/s yearly and indicates moderate wind resources, which are suitable for small-scale wind turbine applications.

2.3.2. Annual electricity use

Table 3 presents the annual data of electricity consumption in the MSTP Jepara building.

According to table 3, the annual demand reaches approximately 373 MWh, which serves as the basis for determining the required capacity of the hybrid renewable energy system.

2.4. Determination of key components

2.4.1. Main components of solar power plants

Determining the capacity of a solar power plant (PLTS) is an important step in system planning, as it ensures that the installed system can meet the expected electricity demand. This process requires consideration of the building's electrical load, the availability of solar resources at the study location, and other relevant technical factors [19]. SunPower SPR-400-WHT-Dpv, with a rated capacity of 400 Wp, was selected for

Table 1
Solar irradiation at
MSTP Jepara

Month	Solar Irradiation (kWh/m ² /day)
January	4.22
February	4.53
March	5.43
April	5.52
May	5.5
June	5.27
July	5.73
August	6.41
September	6.8
October	6.4
November	5.33
December	4.61
Average	5.48

Table 2
Wind speed and direction
at MSTP Jepara

Month	Wind Direction	Wind Speed (m/s)
January	288.56° (↖)	4.98
February	296.62° (↖)	5.17
March	293.56° (↖)	3.27
April	60.06° (↗)	3.45
May	75.75° (↗)	3.91
June	103.96° (↘)	4.84
July	112.75° (↘)	4.95
August	114° (↘)	5.2
September	109.19° (↘)	4.37
October	231.12° (↙)	3.9
November	309.38° (↖)	3.03
December	296.88° (↖)	5.68
Average		4.40

Table 3
Annual electricity use of
the MSTP Jepara building

Month	kWh/Month	kW/Month
January	30,910	41,546
February	32,625	46,875
March	27,678	37,202
April	30,627	42,538
May	24,724	33,231
June	36,332	50,461
July	37,923	50,972
August	15,727	21,138
September	19,944	27,700
October	32,868	44,177
November	42,761	59,390
December	40,981	55,082
Total	373,100	51,0312

this study. The detailed technical specification of the selected module is provided in table 4 below.

Table 4 summarizes the electrical characteristics of the selected PV module. These parameters are used for determining the string configuration and evaluating system performance.

The Trina Solar SPR-400-WHT-D solar module is shown in figure 3 as follows.

Figure 3 shows the solar module selected for the proposed PV system. The module was chosen due to its high efficiency, suitable operating voltage range, and compatibility with the selected inverter configuration.

The inverter type used is Huawei SUN2000-25KTL-M5 with a capacity of 25,000 W for solar PV. The inverter specifications are shown in table 5 below.

Table 5 presents the specifications of the selected inverter, which is responsible for converting DC power generated by the PV array into AC power suitable for building loads.

The number of solar modules per string is determined based on calculations that reflect the actual environmental conditions at the design site $V_{oc,max}$ $I_{sc,max}$ [20] using equations 1, 2, and 3 as follows.

$$T_{module,max} = T_{air,max} + \frac{NOCT - 20}{80} \times 100 \quad (1)$$

$$T_{module,max} = 38.4 + \frac{45 - 20}{80} \times 100$$

$$T_{module,max} = 38.4 + \frac{45 - 20}{80} \times 100$$

$$T_{module,max} = 69.65 \text{ }^{\circ}\text{C}$$

$$V_{oc,max} = V_{oc} + (T_{coef,Voc} \times V_{oc} \times (T_{module,min} - 25^{\circ}\text{C})) \quad (2)$$

$$V_{oc,max} = 85.3 + (-0.00229 \times 85.3 \times (20.1 - 25))$$

$$V_{oc,max} = 86.26 \text{ V}$$

$$I_{sc,max} = I_{sc} + (T_{coef,Isc} \times I_{sc} \times (T_{module,max} - 25^{\circ}\text{C})) \quad (3)$$

$$I_{sc,max} = 5.74 + (0.00031 \times 5.74 \times (69.65 - 25))$$

$$I_{sc,max} = 5.82 \text{ A}$$

The above calculation is carried out using the parameters in table 4 and equations 1, 2, and 3. It was found that the value $V_{oc,max}$ is 86.26 V and $I_{sc,max}$ is 5.82 A. To calculate the number of modules per string, equation 4 is used as follows.

$$\text{Modul per string} = \frac{V_{MPPT,max}}{V_{oc,max}} \quad (4)$$

$$\text{Modul per string} = \frac{820}{86.26}$$

$$\text{Modul per string} = 9.50$$

$$\text{Modul per string} \approx 9$$

Based on the calculation results, the maximum number of modules in each string was determined to be 9. To determine the optimal number of solar panels in the design, with a target of meeting 10% of the annual load of the MSTP Jepara building, a trial-and-error method was applied to obtain the appropriate number of panels. Using this method, the optimal number of solar panels required to cover 10% of the annual load of the MSTP Jepara building was found to be 56 units of 400 Wp solar panels. According to

Table 4
Specification of SPR-400-WHT-D solar module

Electrical	
Rated maximum power (P_{max})	400 Wp
Open circuit voltage (V_{oc})	85.3 V
Short circuit current (I_{sc})	5.87 A
Maximum power voltage (V_{mp})	72.9 V
Maximum power current (I_{mp})	5.49 A
Power density (W/mm^2)	185.18
Nominal operating cell temperature ($^{\circ}\text{C}$)	45.8
Temperature coefficient of P_{max} ($\%/^{\circ}\text{C}$)	-0.353/ $^{\circ}\text{C}$
Temperature coefficient of V_{oc} ($\%/^{\circ}\text{C}$)	-0.229/ $^{\circ}\text{C}$
Temperature coefficient of I_{sc} ($\%/^{\circ}\text{C}$)	0.031/ $^{\circ}\text{C}$

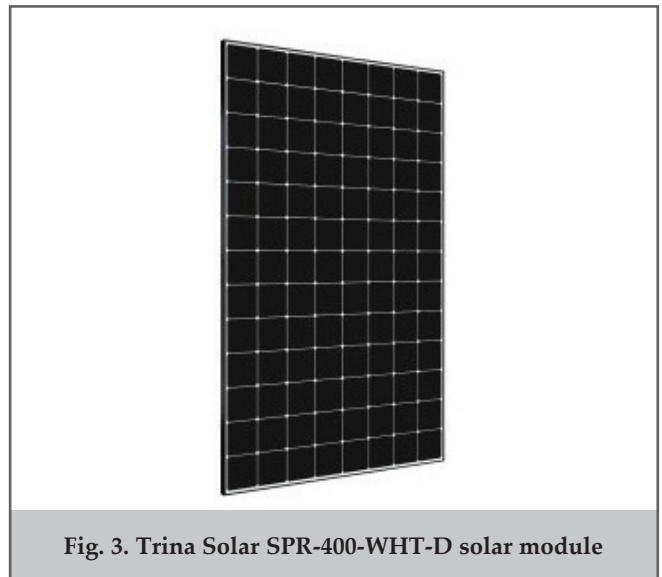


Fig. 3. Trina Solar SPR-400-WHT-D solar module

Table 5
Specifications of SUN2000-25KTL-M5 inverter

Input	
Max DC input power	37,500 W
Max DC input voltage	1100 V
Max input current per MPPT	20 A
Max short-circuit current per MPPT	40 A
Min startup voltage	200 V
MPPT voltage range	200 – 1000 V
Full-load MPPT voltage range	530 – 800 V
Rated input voltage	600 V
Max number of input	4
Output	
Rated output power	25,000 W
Rated output voltage	380 V, 3W/N+PE
Rated output current	38 A
Maximum output current	42 A
Frequency	50/60 Hz
Power factor	0.8
Maximum output current	38 A
Maximum efficiency	98.4%

Table 6
Specification of AeolosV-1kW wind turbine

Parameters	Value
Started wind speed	1.5 m/s
Cut-in wind speed	2.5 m/s
Rated Wind speed	10 m/s
Nominal voltage DC	380 V
Nominal power	1000 W
Maximum power	1500 W
Gross weight	78 kg
Blade height	1 m
Survival wind speed	50 m/s
Number of blades	3
Blade material	Alluminium alloy
Generator	Three-phase permanent magnet
Control system	Rem Hydraulics
Mount Height	2~12 m (9 m)
Generator protection level	IP54

**Fig. 4. AeolosV-1kW wind turbine****Table 7**
Specification of SMA Windy Boy 1200 inverter

Parameter	Value
Max DC input power	1320 W
Max DC input voltage	400 V
DC Nominal Voltage	120 V
Max DC Input current	12.6 A
Operating Range	100 - 400 V
Power ON / OFF Voltage	200V / 300V
AC Nominal Power	1200 W
Max Output Current	6.1 A
Nominal AC Voltage	220V, 230V, 240V
AC Operating Range	180 – 260 V
Frequency	50/60 Hz
Phase	1-phase
Power factor	1
Maximum current	38 A
Maximum efficiency	92.1%

the calculation in Equation 4.4, with a maximum of 9 modules in one string, the panels were arranged in a configuration of 8 series and 8 parallel strings, resulting in a total of 56 solar panels.

2.4.2. Main components of PLTB

The selection of wind turbines is influenced by the wind direction characteristics at the site. Horizontal Axis Wind Turbines (HAWT) are more suitable for locations with relatively constant wind directions, while Vertical Axis Wind Turbines (VAWT) are better suited for variable wind conditions, although they generally have lower efficiency. For this reason, the AeolosV-1kW (1000 W) wind turbine was selected, and its specifications are presented in table 6.

Table 6 summarizes the technical specifications of the selected wind turbine. The turbine was selected based on the wind characteristics of the study site and the required system capacity.

The AeolosV-1kW vertical axis wind turbine is shown in the following figure 4.

In this research, a grid-tie inverter, the SMA Windy Boy 1200 from SMA manufacturer with a capacity of 1200 W, was selected for the wind power system (PLTB). The specifications of the SMA Windy Boy 1200 inverter are presented in table 7.

The capacity of the wind turbine is minimized due to high investment costs and relatively low efficiency under Indonesia's wind conditions. In this research, one Aeolos V 1 kW wind turbine, equipped with an AC generator and an integrated braking system, was utilized. The turbine output is connected to an SMA Windy Boy 1200 W inverter.

2.5. Determination of supporting components

2.5.1. Supporting components of solar power plants

A. DC cables and connectors

The output current per string equals the maximum power current, since a series connection does not affect current. The cable's cross-sectional area is calculated using Equation 5, as shown below.

$$A = \frac{I_{mp}}{J} \quad (5)$$

where J is the allowable current for copper wires (approximately 4 – 6), then: A/mm²

$$A = \frac{5.49 \text{ A}}{5 \text{ A/mm}^2}$$

$$A = 1.098 \text{ mm}^2$$

Based on calculations, the minimum cross-sectional area of the cable required is 1,098 mm². Therefore, a 4 mm² LEONI cable was selected. The required cable lengths include:

1. Cable between panels: 12 meters per string, with 7 strings, 84 meters in total.
2. Cable from string to combiner box: 40 meters per string, 280 meters total.
3. Cable from the combiner box to the inverter: 10 meters.

Thus, the total DC cable needed is 374 meters. The LEONI 4 mm² cable display is shown in figure 5.

Figure 5 describes the DC cable used for interconnecting the solar modules, combiner box, and inverter. The selected cable size fulfilled the current-carrying requirement while minimizing voltage drop losses.

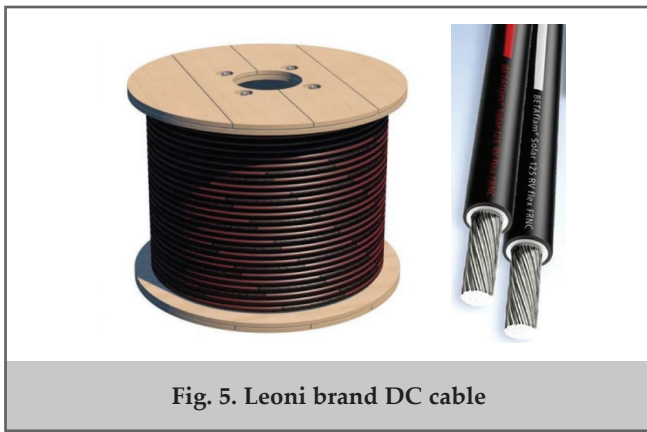


Fig. 5. Leoni brand DC cable



Fig. 6. MC4 Connector

Connectors are required to interconnect the solar panels. In this system, MC4 connectors are used. A total of 56 pairs (male and female) are required for panel-to-panel connections, along with 7 additional pairs for connecting each string to the combiner box. Thus, the total number of MC4 connectors needed is 63 pairs, or 126 individual connectors. The type of connector used is illustrated in figure 6.

Figure 6 presents the MC4 connector used in the PV system. These connectors provide reliable electrical connections and ensure safe operation under outdoor environmental conditions.

B. Combiner box

The designed system uses an 8 series configuration to increase the total voltage, which is calculated using equation 6 as follows.

$$\begin{aligned} V_{\text{Total}} &= V_{\text{mp}} \times \text{number of series} \\ V_{\text{Total}} &= 72.9 \text{ V} \times 8 \\ V_{\text{Total}} &= 583.2 \text{ V} \end{aligned} \quad (6)$$

With a current of 5.49 A for each string, the SANDI PVB-12 combiner box is selected, which can accommodate up to 12 strings. This combiner box is equipped with a 1000 V – 40 kA / 2P DC Surge Protection Device (SPD), a 1000 V / 4P PV DC circuit breaker from Schneider, and a 1000 V DC fuse with high voltage withstand capability. The detailed specifications of the SANDI PVB-12 combiner box are shown in table 8.

Table 8 Specifications combiner box Sandi PVB-12	
Input	
Maximum PV Array Input String	12
Maximum PV Array Voltage	1000 VDC
Input Rated Current (each string)	10A / 15A
Over Current Fuse (input)	Yes
Module Protection (Anti-Reverse)	Yes
Input Type Connector	PG9 Cable Grand
Output	
Output String	1 (Customized)
Rated Output Current	120A / 180A
Output DC Circuit Breaker	Yes
Surge Protection Device	Yes
Output Type Connector	PG21 Cable Grand

Table 8 shows the specifications of the selected combiner box. The equipment integrates multiple PV strings and provides protection against overcurrent and surge conditions.

The display of the PVB-12 Password Type Combiner Box is shown in figure 7 as follows.

Figure 7 shows the combiner box used to collect the output from multiple PV strings before delivering the power to the inverter. The device also provides protection through integrated fuses, breakers, and surge protection components.

C. AC cable

The output of the inverter is in AC current format, and the AC cable is sized based on the total power output of the system using the equation 7.

$$\begin{aligned} P_{\text{Total}} &= P_{\text{max panel}} \times \text{number of panel in series} \times \\ &\quad \times \text{number of strings} \\ P_{\text{Total}} &= 400 \text{ W} \times 8 \times 7 \\ P_{\text{Total}} &= 22,400 \text{ W} = 22.4 \text{ kW} \end{aligned} \quad (7)$$

If the total power of the system has been calculated, the output current of the inverter can be calculated using equation 8.

$$I = \frac{P}{V \times \sqrt{3} \times \text{Power Factor}} \quad (8)$$

Assuming the power factor = 1, the output current is calculated as follows:

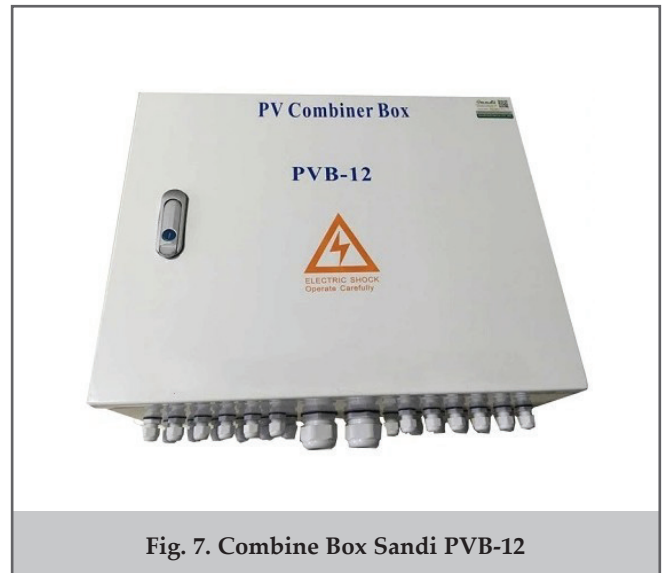


Fig. 7. Combine Box Sandi PVB-12



Fig. 8. First cable brand AC cable

$$I = \frac{22.400 \text{ W}}{380 \text{ V} \times \sqrt{3} \times 1}$$

$$I \approx 33.9 \text{ A}$$

Based on the calculation results, the selected AC cable is a NYHHY 6 mm² cable manufactured by First Cable, which is capable of carrying a current of up to 33.9 A at 380 VAC. The distance between the inverter and the MDP connection point is 10 meters. Therefore, the total required cable length is 10 meters. The 6 mm² First Cable is shown in figure 8.

Figure 8 illustrates the AC cable selected for connecting the inverter output to the main distribution panel. The cable specification was chosen based on the calculated output current and installation distance.

D. MCB

The MCB is selected with a nominal current of 125% to 150% of the main load current to avoid unnecessary disconnection, as calculated using equation 9.

$$I_{\text{nominal}} = I_{\text{load}} \times 1.5 \quad (9)$$

$$I_{\text{nominal}} = 33.9 \times 1.5$$

$$I_{\text{nominal}} = 50.9 \text{ A}$$

Based on the calculation results above, the selected MCB is a 3-phase MCB 50A from the manufacturer Acti9 with the Acti9 IC60 model.

2.5.2. PLTB supporting components

A. DC cables and connectors

$$I = \frac{P}{V} \quad (10)$$

$$I = \frac{1000}{220}$$

$$I = 4.55 \text{ A} \approx 4.6 \text{ A}$$

B. AC cable

The inverter has a rated power of 1200 W with an output voltage of 220 VAC. Therefore, the output current is calculated using Equation 10.

$$I = \frac{1200}{220}$$

$$I = 5.45 \text{ A} \approx 5.5 \text{ A}$$

To accommodate a current of up to 5.5 A, a 2×4 mm² NYH cable manufactured by Pulung with a total length of 20 meters is used. The Pulung brand AC cable is shown in figure 9.

Figure 9 shows the AC cable used for the wind turbine



Fig. 9. Pulung brand AC cable

system. The cable size is adequate to accommodate the inverter output current while maintaining acceptable voltage drop limits.

C. MCB and SPD

The MCB is selected with a nominal current rating of 125–150 % of the main load current to prevent disconnection during minor current spikes, as determined using Eq. (9).

$$I_{\text{nominal}} = 6 \times 1.5$$

$$I_{\text{nominal}} = 9 \text{ A}$$

3. Results and analysis

3.1. Electricity production results

The solar PV system has an installed capacity of 22.4 kW and produces an average output of about 4.06 kW, equivalent to roughly 97.5 kWh per day. This corresponds to a capacity factor of 18.1%. The total annual energy generation reaches 35,595 kWh, with a levelized cost of electricity (LCOE) of 690 IDR/kWh which is equivalent to approximately USD 0.041/kWh. The system operates for approximately 4,367 hours each year and is able to reach a peak power output of around 19.8 kW. Elmnifi and Duyun demonstrated experimentally and numerically that appropriate thermal management can improve the electrical performance of photovoltaic panels [21]. The simulation results show that solar energy accounts for about 9.54% of the total electricity generation. This share suggests that, under the current system configuration, the photovoltaic (PV) units have not been utilized to their maximum capability. There is still room to increase the contribution from solar energy, which could help further lower reliance on fossil fuel-based electricity while strengthening the long-term sustainability of the overall system. The electricity production profiles of the solar PV system and the wind turbine are presented in figures 10 and 11, respectively.

Ismayilov et al. applied long-term meteorological data and Weibull distribution analysis to estimate wind-power density and support the identification of suitable wind-energy locations [22]. A subsequent data-driven assessment showed that the combination of long-term ERA5 data, Weibull parameters, and wind-power-density calculations provides a reproducible framework for evaluating wind-energy resources [23]. Based on the simulation results, the 1 kW wind turbine delivers an average output of about 0.26 kW, equivalent to approximately 6.24 kWh of electricity per day. This corresponds to a capacity factor of around 26%, indicating that the turbine is able to operate fairly consistently

under the local wind conditions. On an annual basis, the wind turbine generates roughly 2,275 kWh and records an operating duration of about 7,918 hours. From an economic perspective, the Levelized Cost of Electricity (LCOE) for the wind system is estimated at IDR 5,471 per kWh, or approximately USD 0.33/kWh. Despite this performance, the penetration level of wind energy in the overall power system remains low at only 0.61%. When compared with the solar PV system, the contribution of the wind turbine is relatively small. Nevertheless, its presence still provides practical ben-

efits by diversifying the energy mix and slightly reducing dependence on fossil fuel-based electricity. In this hybrid configuration, wind energy mainly plays a supporting role rather than serving as the primary source, although its contribution could become more significant in the future with improvements in turbine technology and efficiency. The detailed electricity production results obtained from the HOMER simulation are presented in table 9.

Table 9 summarizes the annual electricity generation from both the solar and wind power systems. The solar

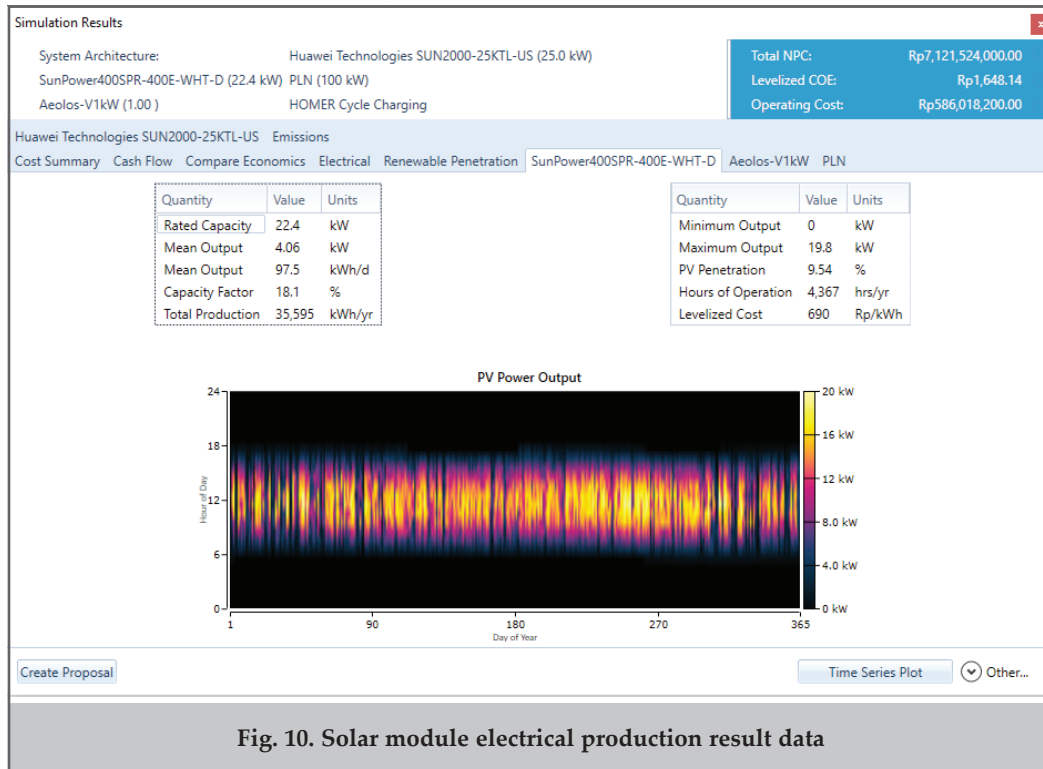


Fig. 10. Solar module electrical production result data

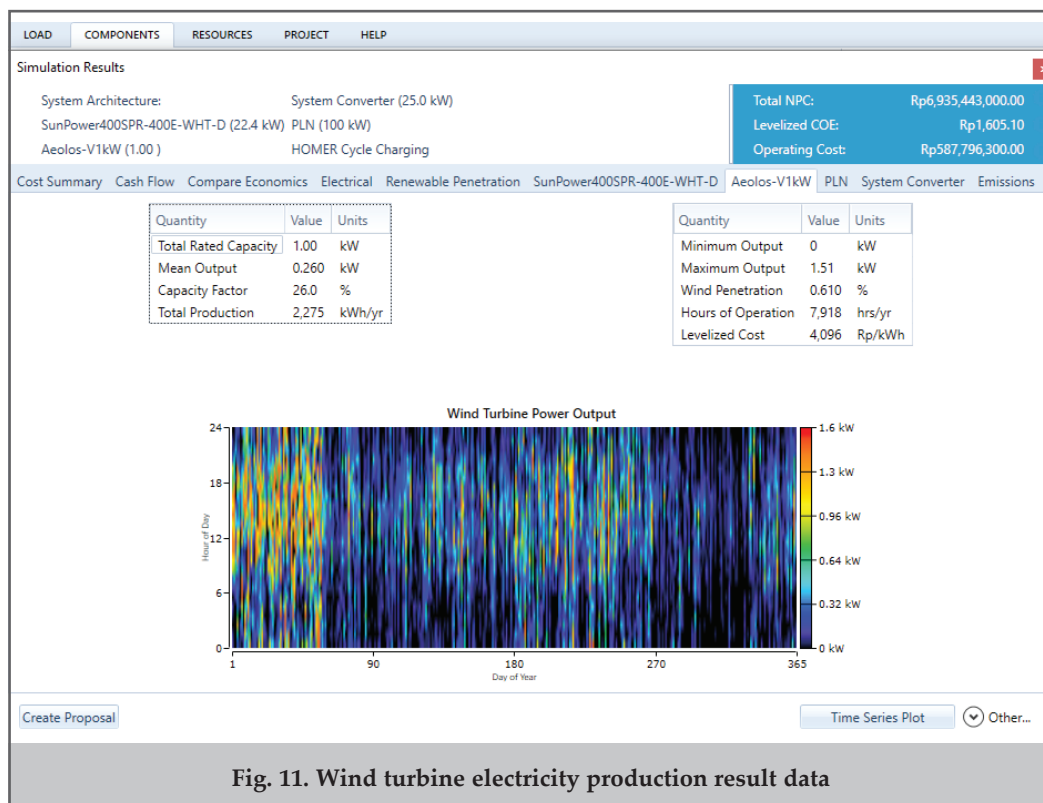
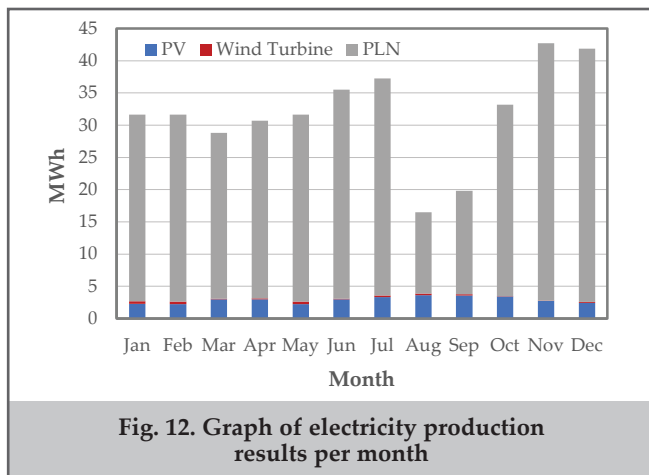


Fig. 11. Wind turbine electricity production result data



Component	Unit Price (IDR)	Quantity	Unit	Total (IDR)
Solar Panel SPR-400-WHT-D	2,400,000	54	Unit	129,600,000
Wind Turbine AeolosV-1kW	70,624,865	1	Unit	70,624,865
Inverter SUN2000-25KTL-M5	22,645,220	1	Unit	22,645,220
Solar Panel Mounting Structure	27,000,000	1	Set	27,000,000
DC Combiner box	5,712,000	1	Unit	5,712,000
Inverter SMA Windy Boy 1200	14,000,000	1	Unit	14,000,000
DC Cable 1 × 4mm ²	18,500	374	Meter	6,919,000
AC Cable 5 × 6 mm ²	145,000	10	Meter	1,450,000
MC4 Connector	6,000	63	Pair	378,000
MCB 3 Phase 50A	350,000	1	Unit	350,000
AC Cable 2 × 4 mm ²	23,250	20	Meter	465,000
DC Cable 1 × 4 mm ²	18,500	40	Meter	740,000
SPD DC 250V	288,000	3	Unit	288,000
MCB 1 Phase 10A	50,000	2	Unit	100,000
Operational and Maintenance	15,000.000	1	Year	15,000,000
Installation and Permit Processing	55,000.000	1	Unit	55,000,000
Total				334,647,220

Parameter	Value
Net present cost (IDR)	457,709,327.5
LoE (IDR /kWh)	1,648
Present worth (IDR)	221,429,700
Annual worth (IDR /tahun)	19,121,280
Return on investment (%)	9%
Internal rate of return (%)	13.1%
Simple payback (tahun)	6.97 years
Discounted payback (tahun)	9.24 years

Production	kWh/year	%
Solar Modules	35.595	9.49
Wind Turbines	2.275	0.607
Grid Purchase	337.033	89.9
Total	374.902	100

PV system produces approximately 35,595 kWh per year, accounting for about 9.49% of the building's total annual electricity demand. In contrast, the wind power system contributes around 2,275 kWh per year, or roughly 0.607% of the total load. When combined, the hybrid solar-wind system generates a total of 37,870 kWh annually, which corresponds to 10.097% of the overall electricity consumption of the MSTP Jepara building. These findings indicate that nearly one-tenth of the building's energy demand can be supplied by renewable sources, contributing to a reduction in fossil fuel dependency while supporting long-term energy sustainability. The monthly production results are illustrated in figure 12.

Figure 12 shows the monthly electricity production profile of the hybrid system. Solar PV generation dominates throughout the year, while wind energy contributes a relatively smaller portion. Seasonal variations in solar irradiation and wind speed influence the monthly production levels.

3.2. Economic analysys of PLTH design

The economic assessment of a hybrid renewable energy system should consider the allocation of available resources, investment costs, operating costs, and long-term economic returns. Valiyev and Aliyeva demonstrated that optimization under resource and cost constraints can improve overall energy-system efficiency and economic performance [24]

3.2.1. Initial investment costs

The initial investment cost for the photovoltaic and wind turbine PLTH design at MSTP Jepara is presented in table 10. The cost data in the table are expressed in Indonesian rupiah (IDR). For reference, the exchange rate used in this research is IDR 1,000 equivalent to USD 0.0602, or USD 1 equivalent to IDR 16,660.

Table 10 summarizes the initial investment required for implementing the hybrid solar-wind power system. The total investment cost is IDR 334,647,220, with solar modules and wind turbines representing the largest capital expenditures.

3.2.2. Economic analysis of PLTH

The HOMER application results of the economic analysis of the design of hybrid power plants, based on simulations are shown in table 11.

Table 11 presents the economic analysis data of the renewable energy power generation system. The system achieves a Net Present Cost (NPC) of IDR 457,709,327.5 (approximately USD 27,460) and a Levelized Cost of Electricity (LCOE) of IDR 1,648/kWh (approximately USD 0.099/kWh). This LCOE is lower than the conventional electricity purchase price of IDR 1,699.58/kWh, or approximately USD 0.102/kWh. Therefore, these results indicate that the project is economically viable. Nevertheless, investment feasibility

should not be evaluated solely from the expected financial return because uncertainty and investment risks may affect the actual economic performance of a project. Economic and mathematical modeling can support a more comprehensive assessment of capital investment and project risk under uncertain conditions [25]. The Present Worth (PW) of IDR 221,429,700 (approximately USD 13,290) and the Annual Worth (AW) of IDR 19,121,280 (approximately USD 1,150) further confirm the system's positive economic performance. The financial evaluation indicates that the proposed system

delivers a Return on Investment (ROI) of 9% with an Internal Rate of Return (IRR) of 13.1%, suggesting that the investment remains financially reasonable under the assumed conditions. The Simple Payback Period is estimated at 6.97 years, while the Discounted Payback Period extends to approximately 9.24 years. Although this reflects a relatively long capital recovery period, the results indicate that the system is still capable of recovering its initial costs within the project lifetime and begins to generate net economic benefits after approximately nine years of operation.

Conclusions

The results demonstrate that the proposed hybrid solar–wind power system can partially meet the electricity demand of the MSTP Jepara building. Based on HOMER simulations, the solar PV system generates 35,595 kWh/year (9.49% of total demand), while the wind turbine contributes 2,275 kWh/year (0.607%). Together, the hybrid system produces approximately 37,870 kWh/year, supplying about 10.1% of the building's annual electricity consumption of 374,902 kWh. These findings indicate that solar energy is the primary contributor to renewable electricity generation at the site, while wind energy provides supplementary support.

From an economic perspective, the system is financially feasible, with a Net Present Cost (NPC) of IDR 457.7 million, a Levelized Cost of Electricity (LCOE) of IDR 1,648/kWh, a Return on Investment (ROI) of 9%, and an Internal Rate of Return (IRR) of 13.1%. The simple and discounted payback periods are 6.97 and 9.24 years, respectively. Although the renewable energy contribution remains relatively modest, the proposed hybrid configuration represents a practical and economically viable approach for increasing renewable energy utilization in institutional-scale buildings.

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