Hybrid Power Plant Analysis (Photovoltaic-Microhydro) to get to the Energy Independent Village in Surabaya

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Abstract

This study presents an analysis of a hybrid power generation system that combines photovoltaic (PV) and microhydro technology as a sustainable energy solution towards energy independence in rural communities in Surabaya. The study explores the potential of solar energy, utilizing high levels of year-round insolation, and microhydro energy from local water sources. The integration of renewable energy sources aims to improve the reliability and stability of electricity supply, reducing fluctuations due to weather conditions. By optimizing technology integration and implementing supportive policies, this hybrid system shows the potential to effectively meet the energy needs of rural areas of Surabaya. This analysis underscores the importance of sustainable energy development in achieving local energy autonomy and contributing to broader environmental goals.

Keywords: ***Performance; Quality Monitoring; Wireless Sensor Network***

Introduction

Indonesia is an archipelagic country that has abundant natural resources and great potential in developing renewable energy. The city of Surabaya, as one of the metropolitan cities in Indonesia, faces great challenges in meeting the increasing energy needs. To achieve sustainable development goals, especially in creating energy-independent villages, the use of renewable energy technology is very important. Solar energy has great potential in Indonesia because it is located in tropical areas that get sunlight all year round. In addition, the wealth of rivers in Indonesia can be used as a source of microhydro energy. By utilizing these natural resources and existing technology, a Hybrid Power Plant (PLTH) was formed that combines photovoltaic and microhydro.

Surabaya has a wide range of renewable energy potentials, including solar and water energy. Surabaya's geographical and climatic conditions that get a lot of sunlight throughout the year make photovoltaic (PV) technology very relevant and potential. On the other hand, several areas around Surabaya have water sources that can be used for microhydro power plants. Combining these two energy sources in one hybrid system can maximize the utilization of local resources and improve energy efficiency.

Hybrid power plants that combine photovoltaic (PV) and microhydro have several advantages, including:

1. Reduce dependence on fossil fuels and utilize renewable natural resources.
2. The combination of PV and microhydro can provide a more stable and sustainable supply of electricity, even in the rainy season when sunlight is reduced, microhydro can make up for the energy shortage.
3. The use of renewable energy significantly reduces greenhouse gas emissions, supporting climate change mitigation efforts.
4. Developing hybrid power plants can empower local communities by providing more reliable and affordable access to electricity.

Despite its great potential, the development of hybrid power plants in Surabaya also faces several challenges, such as:

1. The initial investment for PV and microhydro installations is quite high, although the operating costs are low.
2. Advanced technology and adequate supporting infrastructure are needed for the integration of these two energy sources.
3. Support from the government in the form of regulations and incentives is essential to encourage investment in this sector.

To realize an energy-independent village in Surabaya, a holistic approach is needed that involves an in-depth analysis of the potential and technical and economic feasibility of hybrid power plants. The active participation of the community in the development and maintenance of renewable energy systems is also very important. Cooperation between the government, the private sector, academics, and local communities is key to the success of this project. Against this background, the analysis of hybrid power plants (photovoltaic-microhydro) is a strategic step towards an energy-independent village in Surabaya, contributing to increasing energy security.

The hybrid power generation system is designed to produce electrical energy that is able to serve consumers in remote areas optimally so that there is no longer an area in Indonesia that is not connected to electricity. PLTH is a power generation system that combines several types of power plants with the aim of combining their respective strengths and covering their respective weaknesses to condition certain situations so that the overall system can operate more economically and efficiently.

Energy Independent Village (DME) is a program that was first launched by the President of the Republic of Indonesia in 2007 to meet the energy needs of several villages in Indonesia. The DME criterion is that villages are able to meet at least 60% of their total energy needs (electricity and fuel) by empowering the potential of local resources and the growth of productive activities to improve the village economy as a result of local energy availability. With the existence of DME, people's dependence on the use of subsidized energy sources from the government can be minimized.

Literature Review

2.1 Photovoltaic

The sun is the main source of energy that emits an unusually large amount of energy to the earth's surface. In sunny weather, the earth's surface receives about 1000 watts of solar energy per square meter. The use of solar energy in Indonesia has been directed towards the provision of electricity in rural areas or areas that are difficult to reach by conventional electricity installations. The sun's radiant energy is converted into electrical energy by using solar power plants or photovoltaic technology made from semiconductor materials, called solar cells. This technology, in addition to coming from an unlimited energy source (sunlight), is also known to be environmentally friendly so it has a high usability.

2.2 Main Components of Photovoltaic

Photovoltaic modules, or commonly called solar modules, are devices made up of semiconductor materials such as silicon, gallium arsenide, cadmium telluride, and others that convert direct sunlight into electricity. When solar cells absorb sunlight, free electrons and holes are formed, creating a positive/negative connection. When connected to a DC load, an electric current will flow to the load.

These devices play a crucial role in converting solar energy into usable electrical energy, making them an ideal solution for electricity supply in remote and rural areas that are difficult to reach by conventional power grids.

Figure 1. Photovoltaic Module
Source: Kurniawan - 2023

$$\text{Charge Controller Capacity} = \frac{\text{Demand watt X Safety Factor}}{\text{System Voltage}} \quad \ldots\ldots\ldots \quad (1)$$

2.3 Solar Charge Controller

Solar Charge Controller is a control device that functions to regulate the voltage and current emitted from the solar module, carry out the battery charging process, prevent the battery from overcharging, and control the discharge process. The capacity of the charge controller is determined by the following formula:

Figure 2. Solar Charge Controller
Source: Kurniawan - 2023

2.4 Battery

The battery serves to temporarily store the electricity generated by the solar module, so that it can be used when solar energy is not available. For the energy that can be accommodated by this battery itself, it can be searched using the following equation:

E bat = Ibat x .... system (2)

Figure 3. Battery
Source: Kurniawan - 2023

2.5 Inverter

An inverter is a device to convert direct current into non-direct current, and the voltage is adjusted to the required voltage. The charge capacity of the inverter is determined by the following formula:

Inverter Capacity = Demand Watt x safety factor... (3)

Where the safety factor is determined at 1.25.

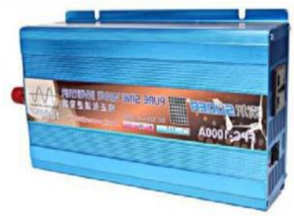

Figure 4. Inverter
Source: Kurniawan - 2023

2.6 Calculating Array Areas

The power (wattpeak) generated by solar power plants to meet energy needs from the calculation of the array area, the amount of power generated by solar power (wattpeak) can be calculated with the following formula:

PWattpeak = PV Area x PSI x ηPV [Watt] .... (4)

Where:

PV Area = surface area of solar panels
PSI = peak solar insulation is 1,000 W/m2
ηPV = Solar panel efficiency [%]

2.7 Performance Ratio

Performance ratio is a measure of the quality of a Solar Power Plant (PLTS) that is independent of location, and is therefore often described as a quality factor. Performance ratio (PR) is expressed in percent and describes the relationship between the actual energy output and the theoretical energy output of solar PV. Thus, the PR shows the proportion of energy that is actually available to be delivered to the grid after deducting energy losses (e.g. thermal losses and conduction losses) and energy consumption for operations.

$$PR = \frac{Eyield}{Eideal} \quad (5)$$

Where:

PR = Performance Ratio (%)
Ideal = Ideal energy (KWh/year)
Eyield = Solar energy generated by solar PV (KWh)

Energy Generated

Solar PV components cannot operate 100% in total due to losses. Assuming a loss on components of 20%, then the amount of energy generated by solar panels can be calculated using the following formula: 60 solar panels x 260 Wp = 15,600 Watts = 15.6 Kw
With a loss of 20%, the output power from solar power is:

Pi = power used x (100% - 20%) ....(6)

If using the lowest solar radiation data, the energy produced by the solar panel can be calculated using the following formula:

Pout = Pi x lowest solar radiation.................... (7)
If using the highest solar radiation data, the energy produced by the solar panel can be calculated using the following formula:
Pout = Pi x highest solar radiation .... (8)
If you want to calculate the energy generated per year, the data used is the average irradiation value or PSH
Pout = Pi x PSH .... (9)
For energy per year (Energy yield) the following formula is used: Ey = Pout x 365 days ....(10)
For the ideal energy produced by solar PV uses the following formula: Htilt = PSH x 365 days .... (11)
Ideal energy = Pmax PV x Number of pv x Htilt .... (12)

2.8 Area array (PV area)

As it is known that every 1°C increase in temperature (from the standard temperature) on the solar panel, it will result in the power produced by the solar panel will be reduced by about 0.5%. The maximum temperature data for the Surabaya area in 2024 is 25.8°C. This temperature data shows that there is a temperature increase of 0.8°C from the standard temperature (25°C) required by the solar panels.

The amount of power that is reduced when the temperature around the solar panel increases by 0.8°C from its standard temperature, calculated as follows:
P when t rises to t °C = 0.5% x Pmmpx Temperature rise ....(13)

For the maximum output power of solar panels when the temperature rises by 25.8°C, the calculation formula uses the following equation:

Pmmp when rising to 25.8°C = $P_{mmp} - P_{\text{when t rises °C}}$ .... (14)

Based on the results of the calculation of the maximum output power of the solar panel when the temperature rises to 25.8°C, the TCF (Temperature Correction Factor) value uses a calculation formula with the following equation:

$$TCF = \frac{P_{\text{mmp saat naik menjadi t°C}}}{P_{mmp}} \quad (15)$$

For the area of the array is calculated by the equation :

$$\text{Area}=\frac{\text{kWp}}{\text{Efisiensi Modul Surya}} \qquad (16)$$

2.9 Hybrid Power Plants

Hybrid Power Plants (PLTH) are defined as power generation systems that combine two or more plants with different energy sources. It is generally used for isolated grids, so that synergies are obtained that provide economic and technical benefits.

HOMER (Hybrid Optimization Model for Energy Renewable)

HOMER is a simulation software (program) that optimizes power generation systems, both off-grid (standalone) and grid-connected. This system can consist of a combination of photovoltaic, microhydro, batteries, and other new and renewable energy sources to serve electrical loads as well as thermal loads.

Net Present Value (NPV) Method

Net Present Value or net value now is a comparison between the present value of net cash (PV of Proceed) and the present value of investment (Capital Outlays).

$$NPV = \sum_{i=0}^{n} \frac{CF_t}{(1-k)^t} - IO$$

$$NPV = \sum_{(n)}^{n} CF_t\,(PVIF_{k3}) - IO \qquad (27)$$

Information:

CFT = annual free cash flow over a period of time

Discounted Payback period (DPP) DPP is a period or period of time with the present value of investment expenditure of the investment life.

$$\text{Last year ACCPV Negativee+ACCPV+} \frac{\textit{Tahun terahir negatif}}{\textit{PV tahun terahir negatif}}$$

$$PI = \frac{\sum_{i=0}^{n} \frac{CF_t}{(1-k)^t}}{IO} \qquad (28)$$

Information:

CFT = annual free cash flow over a period of time

k = need for yield rates or IO capital costs

= Cash advance N

= expected project time frame

Pi = The profitability index is located in Dosay Village, West Sentani District, Jayapura Regency, Papua.

Results And Discussion
3.1 Homer Simulation

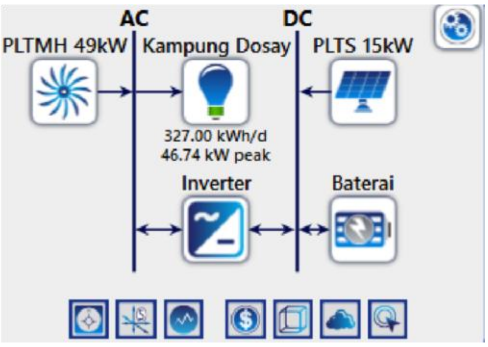

Figure 5. PLTH Design Display in Homer

The results of the simulation provide several configurations that can supply the load continuously in one year. The results are presented in the image below. The resulting system configuration is based on the economic problem of the system, namely NPC. The simulation results put the system with the smallest NPC considered optimal to meet load needs.

Table 1. NPC Fee Summary Table

Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	1,207,500	0.00	234,108.66	0.00	0.00	1,441,608.66
Battery	80,750	54,491.68	13,258.38	0.00	(10,581.11)	137,918.95
Converter	4,648,771.8	1,635,529.45	265,767.46	0.00	(271,696.39)	6,278,372.4
PLTD	0.00	0.00	8,943,431.08	44,835,758.36	0.00	53,779,189.45
PLTB	720,000	0.00	1,802.89	0.00	0.00	721,802.89
System	6,657,021.8	1,690,021.13	9,458,368.49	44,835,758.36	(282,277.5)	62,358,892.35

From the Calculations Above: The PLTH system costs $62,358,890 by adding up the entire cost required, which consists of:

1) The total price of PLTH components is $6,657,021.88
2) Replacement and component installation value of $1,690,021.13
3) Fuel cost of $44,835,758.36
4) Operating and maintenance costs of $9,458,368.9

a. Levelized Cost of Electricity (LCOE)

$$LCOE = \frac{Total\ Annual\ Cost}{Total\ Energi\ yang\ dihasilkan}$$

$$LCOE = \frac{5{,}453{,}870.5}{23.255.942\ kWh} = \$0.\frac{23}{kWh}$$

b. Payback Period: As a result of the calculation above, it takes 11.6 years to return the entire investment capital. With an electricity tariff of $0.23/kWh generated by PLTH, the total investment cost can be covered long before the useful life of the PLTH system, which is 25 years.

c. Net Present Value (NPV): The above calculation of net present value (NPV) is positive at $35,589,268.96, the positive value indicates that the revenue earned is greater than the value of the investment.
d. Profitability Index (PI): the result of the calculation above, the project is declared feasible and accepted because the Profit Index value is 7.53. In accordance with the existing standard value, that is, if the PI value is ≥ 1, the project is declared feasible and accepted.
e. Internal Rate of Return (IRR): The result of the above IRR calculation is 37.38%. From the results of these calculations, the investment can be recognized as feasible because the value is greater than the standard IRR, which must be more than or equal to 10%.

Hybrid Power Plant Configuration Results

Based on Figure 8, the results of the most optimal hybrid power plant configuration based on the lowest Net Present Cost (NPC) value consist of:

1) Solar Power Plant (Solar Power Plant) of 20 kW
2) PLTMH (Micro Hydro Power Plant) of 49 kW
3) Battery of 105 units
4) 24 kW inverter

The total NPC of this configuration is Rp. 4,651,357,000. The cost of electricity generation (Cost of Energy) is Rp. 3,014.70 per kWh. The electrical energy produced by this system in a year is 207,207 kWh.

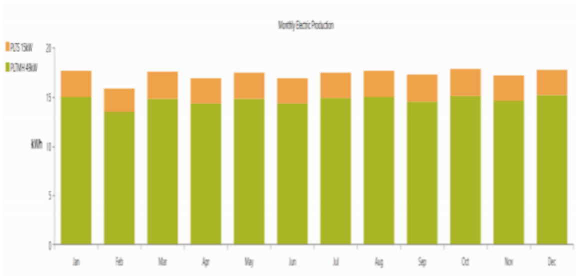

Figure 5. Graph of Average Energy Output Per Month PLTH
Source: processed data - 2024

3.2 Electrical Energy Generated by Solar Power Plants

Solar Power Plants (Solar Power Plants) in this system can produce energy of 31,553 kWh per year or 15.2% of the total annual energy production. The average energy that can be generated is 86.4 kWh per day, with an average output of 3.60 kW and a maximum output of 19.4 kW. This solar power plant has a capacity factor of 26.4% with a levelized cost of 5,571 Rp/kWh.

3.3 Electrical energy produced by PLTMH

The installed PLTMH has a capacity of 49 kW, with a planned discharge of 3,247 m3/s, producing electrical energy of 175,654 kWh/year. The average energy that can be generated is 20.1 kW and the maximum power that can be generated is 20.3 kW. It has a levelized cost of 995 Rp/kWh. The figure below shows the power generated in a year by PLTMH.

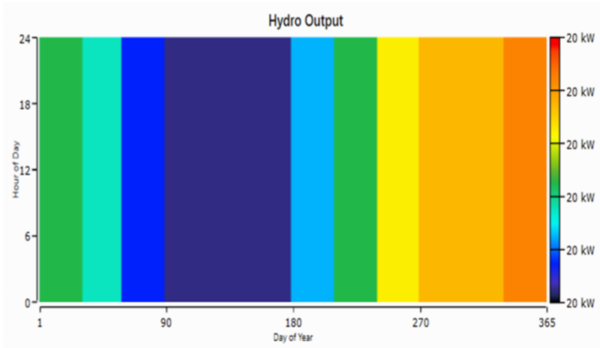

Figure 6. PLTMH Monthly Energy Profile Graph
Source: processed data – 2024

Investment Feasibility Analysis and Economic Studies

The cost parameters inputted in the HOMER software for PV, microhydro, battery and converter systems consist of capital costs, component replacement costs, and operational and management (O&M) with an average lifetime of 25 years.

Table 2. Investment Feasibility Analysis and Economic Studies

Component	Capital	Replacement Fee	O&M
20 kW solar power plant	IDR 2,014,000,000	-	IDR 20,000,000
PLTMH 49 kW	IDR 2,000,000,000	-	IDR 20,000,000
105 pcs battery	IDR 726,320,000	IDR 100,000,000	IDR 50,000,000
Inverter 24 kW	IDR 478,000,000	IDR 100,000,000	-

3.4 Testing and Calculation

The data used in this research was obtained from a solar panel with a capacity of 1000 WP with a 200 Ah battery as a storage medium for electrical power. The Micro Hydro Power Plant (PLTMH) with a capacity of 5 kW uses water from the river in the Energy Independent Village in Surabaya, which is flowed to the turbine through a rapid pipe (penstock) by utilizing the height of the water fall (head). Data collection was carried out on Sunday, June 12, 2024, at the Energy Independent Village in Surabaya.

3.5 Testing PLTMH with Load

After collecting data on the PLTMH, a series of PLTMH components were designed ranging from the intake channel where water enters to the generator as an electricity producer. The PLTMH design process begins from the input of data obtained based on field observations, including voltage and current data to determine the power generated by the PLTMH.

The test was carried out using 50% and 70% loads to determine the amount of voltage generated by the PLTMH. The following are the results of the no-load test obtained from this study.

3.6 PLTMH Testing with Initial Load (50% Load)

PLTMH testing is carried out using loads to find maximum voltage and current, so that the output power produced by PLTMH can be known.

Table 3. PLTMH Test Results with 50 % Load

Yes	Hour	PLTMH (V)	PLTMH (A)	PLTMH (kW)
1	01.0	208 V	52.57 A	10.93 kW
2	02.0	208 V	53.70 A	11.17 kW
3	03.0	208 V	52.38 A	10.89 kW
4	04.0	208 V	52.23 A	10.86 kW
5	05.0	208 V	52.71 A	10.96 kW
6	06.0	208 V	53.94 A	11.22 kW
7	07.0	208 V	53.68 A	11.16 kW
8	08.0	208 V	52.63 A	10.94 kW

This table records PLTMH (Micro Hydro Power Plant) data at a given hour, with measured voltage (V), current (A), and power (kW). With a graph showing the difference in voltage, current, and power generated by the PLTMH with the initial load (50% load). The following is a summary of the results of the PLTMH test with a load of 50%:

a. The rated average voltage (Vpanel) is 208 V.
b. The average current value (Ipanel) is 52.98 A.
c. The maximum power generated is 11,220 kW (11,220 W).

3.7 Testing of PLTMH with medium load (70%)

Testing of Microhydro Power Plants using loads to find maximum voltage and current to determine the output power produced by PLTMH. The results obtained from the PLTMH research using a 70% load can be seen in table 4.

These results show that PLTMH at 50% load produces an average voltage of 208 Volts with an average current of 52.98 A, and reaches a maximum power of 11,220 W.

Table 4. Testing Results of PLTMH with 70% Load

Yes	Time	PLTMH Voltage	PLTMH Current (A)	Power Plant (KW)
1	09.00	216 V	65.62 A	14,174 KW
2	10.00	216 V	67.80 A	14,645 KW
3	11.00	216 V	65.44 A	14,135 KW
4	12.00	216 V	65.28 A	14,100 KW
5	13.00	216 V	65.84 A	14,144 KW
6	14.00	216 V	67.95 A	14,677 KW
7	15.00	216 V	67.83 A	14,651 KW
8	16.00	216 V	65.71 A	14,193 KW

This table includes the measurement time, PLTMH voltage, PLTMH current, and PLTMH power according to the data you provided. If there is anything that needs to be added or improved, please let me know.

Average Current & Voltage Value at PLTMH with 70% Load

Vpanel average value	= Vtotal / 8
	= 216 / 8
Average	= 216 V
Average score of Ipanel	= Total / 8
	= 531.49 / 8
Power Average	= 66.43 A
P	= V x I
	= 216 x 67.95
	= 14.677 KW

From the results of the PLTMH test using a 70% load, an average voltage of 216 Volts with an average current of 66.43 A, and the maximum power produced is 14,677 kW. Based on the measured capacity, micro-hydro power plants (PLTMH) are able to distribute loads of up to 50% and 70% for the people of energy independent villages in Surabaya. For 100% load, the system will switch to solar power plants (PLTS).

3.8 Solar Panel Testing

Testing of Solar Panels with Peak Load (100% load)

In this study, solar panels are a very important component, this is because the greater the input power produced by solar panels, the greater the electricity produced by solar panels. Electrical energy is the amount of derivatives generated from voltage and current, so the value of the voltage and current produced is the electrical value that the solar panel has. Testing of solar panels with 100% load to find the maximum voltage and current to determine the output power produced by the solar cells. This test was carried out on the same day, on Sunday, June 12, 2024 at the Energy Independent Village in Surabaya. The results obtained from the research of solar panels using loads can be seen in table 5.

Table 5. Solar Panel Testing Results With 100% Load

Yes	Time	Inverter Voltage	Inverter Current (A)	Inverter Power (KW)	Solar Voltage Panel	Solar Power Panel (A)	Solar Power Panel(KW)
1	17.00	14,50	1,70	24,65	210	48,47	10,179
2	18.00	15,20	2,22	33,74	210	49,60	10,416
3	19.00	13,55	1,53	20,73	210	48,26	10,135
4	20.00	13,50	1,48	19,98	210	48,18	10,118
5	21.00	14,90	1,90	28,31	210	48,58	10,202
6	22.00	16,80	2,38	39,98	210	49,70	10,437
7	23.00	16,20	2,28	36,93	210	49,63	10,423
8	24.00	14,80	1,78	26,34	210	48,50	10,185

This table includes the measurement time, inverter voltage, inverter current, and inverter power, as well as the voltage, current, and power of the solar panel according to the data you provided. If there is anything that needs to be added or improved, please let me know. Based on the results of the above research test, a graph of current voltage, power, solar panels can be obtained shown in figure 8.

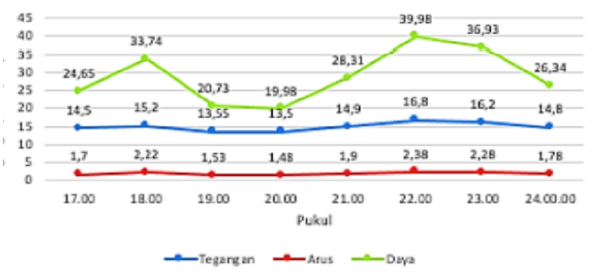

Figure 7. Graph of Voltage, Current, and Power of Solar Panels

Figure 8. Graph of Voltage, Current, and Power of Solar Panels Using 100% Load
Figure 8 is a graph showing the difference in voltage, current, and power generated by solar panels with 100% load. This is tempered by the intensity of sunlight shining on the solar panels. The image above also shows that the generated current is unstable every time the solar panel is tested.

Average Current and Voltage Values at Solar Power Plants

Vpanel average value	= Vtotal / 8
	= 119.45 / 8
Average	= 14.93 V
Average score of Ipanel	= Total / 8
	= 15.27 / 8
Power Average	= 1.90 A
P	= V x I
	= 16.80 x 2.38
	= 39.98 Watts

From the results of the solar panel research test using a 50% load, an average voltage of 14.93 Volts can be found with an average current output of 1.90 A and a maximum power of 39.98 W.

Average Value of Inverter Current and Voltage at Solar PV

Vpanel average value	= Vtotal / 8
	= 1,680 / 8
Average	= 210 V
Average score of Ipanel	= Total / 8
	= 390.92 / 8
Power Average	= 48.86 A
P	= V x I
	= 210 x 49.70
	= 10.437 Watts

From the results of the inverter research test on solar panels using 100% load, it can be found that an average voltage of 210 Volts with an average current output of 48.86 A with a maximum power output of 10,437 W.

Conclusion

Based on the power plant design system, after designing the solar and microhydro power plants and operating properly, the next step is to design an automatic switch system to move solar power plants with PLTMH using smart relays.

There are many influences of Hybrid power plants (photovoltaic-microhydro) on the supply of electrical energy in the Energy Independent Village in Surabaya. Residents in the village can enjoy electrical energy for lighting and other needs, which previously only relied on candles and flashlights for lighting at night.

In Surabaya, the potential of renewable energy sources such as solar energy and water energy promise sustainable solutions to meet energy needs. Solar energy has great potential with fairly high solar insolation throughout the year, allowing the installation of solar panels in various buildings to generate electricity efficiently. Meanwhile, water energy from microhydro and hydropower plants can be utilized around areas that have sufficient water flow, albeit on a smaller scale. The implementation of a hybrid system that combines these two energy sources is expected to improve the reliability of electricity supply, despite the challenges of varying weather conditions. Thus, further development and integration of supporting technologies and policies are key to maximizing the potential of renewable energy in Surabaya to support energy sustainability in the future.

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