Performance Evaluation of 3x1 MW Mini Hydro Power Plant in Malili District, East Luwu Regency

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***Abstract*— One form of simple renewable energy that is widely used is water energy (hydro power). one form of water energy utilization is the MiniHydro power plant,. MHP was chosen as an alternative energy because it has several advantages over other power plants, such as being environmentally friendly, more durable, smaller operating costs and suitable for remote areas. The purpose of this research is to evaluate the performance of the plant in terms of continuity of service and analyze the factors that affect the continuity of service of the plant and analyze the level of reliability of the plant based on the value of energy availability produced by the MHP. the methods in this research are literature study, observation, data collection and processing. Based on the results of the study, it is known that the electrical energy produced by the Ussu Malili MHP for one year (2023) amounted to 16,439,486 kWh and the resulting energy efficiency reached 67%. The resulting operating time is 81%, maintenance time reaches 3.9%, and disruption time is 21%, while the reliability of the power system based on the availability of energy at the Ussu Malili MHP is 79%.**

Keywords—PLTM; Electrical Energy Efficiency; Reliability of Electric Power System

I. Introduction

The State Electricity Company (PLN) as the operator appointed by the government to handle the electricity sector in Indonesia has still not been able to meet the electricity needs of the community as a whole. The geographical conditions of Indonesia as an archipelago, the spread and uneven distribution of electricity load centers, and the low level of electricity demand in several regions are factors that hinder the provision of electricity on a national scale. [1].

Mini hydro power plant (PLTM) is a hydroelectric power plant with a power scale of 100 kW - 5 MW. PLTM is chosen as one of the alternative energy because it has several advantages compared to other power plants, such as being environmentally friendly, more durable, lower operational costs and suitable for remote areas. In addition, PLTM mechanical maintenance is easier.

In the process of generating electricity, there are many components needed, and each component must work optimally, but there is also the possibility of failure in operation. Internal factors, such as short circuit faults in the rotor winding, and external factors, such as human error, animals, and natural conditions, can cause system components to fail. This has an impact on reliability as one measure of the quality of the system and equipment.

This study aims to evaluate the performance of the Ussu Malili PLTM in producing electrical energy to meet consumer needs and to determine the reliability of the electric power system based on the performance of the generator, whether it is optimal and efficient.

II. Research Methodology

A. *Mini hydro power plant (PLTM)*

Mini-hydro power plants (PLTM) are hydroelectric power plants with a power scale of 100 kW - 5 MW. PLTM is chosen as one of the alternative energies because it has several advantages compared to other power plants, such as being environmentally friendly, more durable, lower operational costs and suitable for remote areas. In addition, PLTM mechanical maintenance is easier.).

B. *Working principle of mini hydro power plant*

The working principle of the Mini Hydro Power Plant (PLTM) is basically the same as the PLTA, only different in capacity or the amount of power generated. The Mini Hydro Power Plant (PLTM) has a working principle, which utilizes the height (head) - the fall of water and the flow of water. Technically, the Mini Hydro Power Plant

(PLTM) has three main components, namely water (hydro), turbines, and generators.

C. Components of a Hydroelectric Power Plant

In a MiniHydro power plant location, a system can be mapped which aims to channel water from the river to the penstock. Several civil structures are required, including a dam and all its equipment, intake structure, sand trap, carrier channel, stilling tank, penstock, and power house.

1. Weir

   A dam is a structure that functions as a river flow interceptor, regulates the entry of water into the delivery channel, and prevents riverbed sediment and garbage from entering the delivery channel because it will reduce the volume of water that can be accommodated by the delivery channel (Hafis et al., 2022).

2. Penstock

   Penstock in the Mini Hydro Power Plant (PLTM) system is an important component that functions to direct the flow of water from the intake (water intake) with high pressure to the turbine. This pressure is generated from the height (head) or the decrease in water elevation from the system.

3. Turbin

   The turbine functions to convert potential energy into mechanical energy. The force of falling water that pushes the propeller causes the turbine to rotate. A water turbine can be interpreted as a prime mover whose working fluid is water. The turbine functions to convert the potential energy of the fluid into mechanical energy in the form of shaft rotation which is then converted back into electrical energy in the generator (Hafis et al., 2022)

4. Generator

   A generator is a device the functions to convert mechanical energy into electrical energy as its output. Mechanical energy comes from the rotation of the shaft on the turbine which is connected through a clutch system that transmits mechanical energy from the turbine to the generator.

D. Turbine Mechanical Power

The turbine in the PLTM converts the potential and kinetic energy of water into mechanical power. The mechanical power generated by the turbine is the result of a combination of the height of the water fall and the flow velocity. In general, the mechanical power (Pmechanics) generated or the turbine input power can be calculated using the formula.

$$P_{mechanic} = \rho \times g \times Q \times H \quad (1)$$

Meanwhile the turbine output power can be calculated using the equation

$$P_{Turbin} = P_{Mekanik} \times \eta_{turbin} \quad (2)$$

Dimana :

Pmekanik = daya mekanik turbin (W)

Pturbin = daya turbin (kW)

ρ = massa jeni air (kg/m^3)

g = percepatan gravitasi (9,8 m/s^2)

H = tinggi jatuh air (m)

Q = debit (m^3/s)

η = efisiensi turbin (%)

E. Power Generators

After the mechanical power is received by the generator, this power is converted into electrical power through the electromagnetic principle where the rotation of the rotor produces a magnetic field that induces an electric current in the stator coil. The electrical power produced by the generator (P_(out gen)) can be calculated by taking into account the efficiency of the generator. The formula for electrical power is calculated with the following equation

$$P_{Generator} = P_{Turbin} \times \eta_g \quad (3)$$

Dimana :

Pgenerator = daya generator (kW)

Pturbin = daya turbin (kW)

η_g = Efisiensi generator (%)

F. electrical energy

The electrical energy produced by the PLTM can be calculated by multiplying the electrical power produced by the operating time. This calculation involves factors such as turbine and generator efficiency.

G. Transformator

In Mini Hydro Power Plants, transformers are used to change the electrical output produced by the generator for distribution or transmission needs. Transformers can increase (step up) or decrease (step down) the voltage according to the system. In transmission lines, transformers can increase energy efficiency by reducing energy losses on long-distance lines.

H. Reliability of the generating system

Reliability is the opportunity for a piece of equipment to operate as planned within a certain time interval and under certain operating conditions. Observations of the operating conditions of a component of an electric power system are carried out within a certain time interval, generally within a period of one year (Rumbay, 2020). The concept of reliability contains the terms availability and unavailability which are the results of observations over a certain time interval of an operating condition in the power system.

The following is an equation for determining the reliability of an electric power system:

$$Availability = \frac{jumlah\ jam\ operasi}{jumlah\ jam\ operasi + jumlah\ jam\ unit\ terganggu} \quad (4)$$

$$Unavailability = \frac{jumlah\ jam\ operasi}{jumlah\ jam\ operasi + jumlah\ jam\ unit\ terganggu} \quad (5)$$

Availability and unavailability are the results of observations over a certain period of time on an operating condition in a power system. Operational performance is determined by several factors as follows: (Prasetyo, 2011).

1. Service factor

Service factor is the ratio between the length of operating time (t_op) for one year (8760 hours). The higher the service factor (100%), the better the reliability of the generating unit. In practice, the service factor cannot reach 100%, because during 8760 hours (1 year) there is a maintenance outage time for the generating unit. This means that the operating time of the generating unit does not reach 8760 hours (less than 8760 hours or less than 100%).

$$SF = \frac{t_{op}}{8760} \quad (6)$$

2. Maintenance Factor

Maintenance outage factor is the ratio between the length of maintenance time (t_mn) during one year (8760 hours). The lower the maintenance outage factor (MOF) (0%), the better the reliability of the generating unit.

$$MOF = \frac{t_{mn}}{8760} \quad (7)$$

3. Force Outage Factor

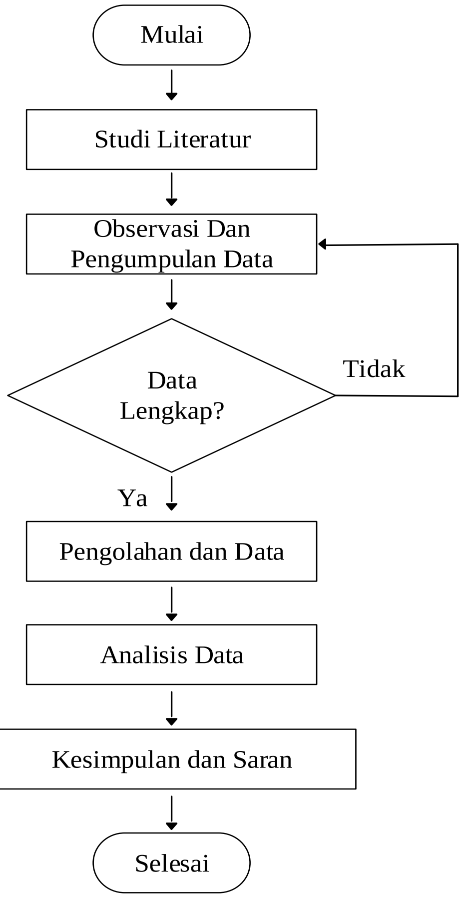
The forced outage factor is the ratio between the length of the outage (t_fo) during one year (8760 hours). The smaller the value of the forced outage factor (FO) (0%), the higher the operating time and the better the reliability of the generating unit.

$$FOF = \frac{t_{fo}}{8760} \quad (8)$$

III. Research Metods

In Data collection in the thesis on the performance evaluation of the 3x1 MW capacity mini-hydro power plant in Malili District, East Luwu Regency was carried out at the mini-hydro power plant in Ussu Village, Malili District, East Luwu Regency, South Sulawesi Province.

This research is described in stages according to the performance evaluation process at the Ussu Malili PLTM. The stages in the process that will be carried out in this research are described in several steps that can be seen in the research flow diagram as shown in the flow diagram.



Gambar 1. Diagram alir penelitian

To clarify the research diagram in Figure 1, here are the steps of the research procedure

1. Literature study to assist in writing the thesis requires a lot of theory about the MiniHydro power plant process, types of power plant components and how to evaluate the performance of PLTM.
2. Observation and data collection are carried out to facilitate the research process. The data needed in this study are technical data of the Ussu Malili PLTM, turbine and generator specification data, energy production data, operating time data, maintenance time data and disruption time data.
3. Data processing is carried out after the required data is complete, the data is processed by referring to the literature review.
4. The research data obtained was calculated and analyzed to determine the performance of the PLTM.
5. From the data processing process, results and discussions are obtained, so that a conclusion can be drawn as a result of the evaluation.

IV. Results and Discussion

Technical Data of Components of the Ussu Malili Hydroelectric Power Plant.

Table 1. Technical data of the Ussu Malili PLTM dam

Data Rancangan	Ukuran
Debit rencana 3 turbin	3,6 m^3/s
Lebar mercu	10,5 m
Tinggi mercu	2 m
Tinggi air diatas mercu	2 m
Lebar pilar penguras	1 m
Lebar pintu penguras	1,25 m
Panjang apron	20 m
Tinggi dinding banjir	2 m
Panjang kolam olak	4,2 m

Table 2 penstock PLTM Ussu Malili

Data Rancangan	Ukuran
Panjang	250 m
Diamter pipa	1,260 m
Material	baja
Branch	2 bh
Anchor block	9 bh
Saddle block	22 bh
Drain 10	1 bh
Drain 3	6 bh

Table 3. Ussu Malili PLTM turbine specifications

Parameter	Keterangan
Daya Turbin	1064 kW
Tinggi rata-rata	100 m
Frekuensi	50 Hz
Debit terukur	1.2 m^3/s

Efisiensi Turbin	90 %
Putaran	1000 r/min
Maks. Kecepatan putaran	1.631r/min
Dorongan air maksimal	42 kN

Table 4. Specification of Ussu Malili PLTM generator

I. Parameter	Keterangan
Daya Nominal	1000 kW/1250 kVA
Tegangan Nominal	6300 V
Arus nominal	114,6
Frekuensi	50 Hz
Phasa	3 phasa
Faktor daya	0,8
Efisiensi generator	96 %
Tegangan ekstitasi nominal	15 V
Arus eksitasi nominal	205 A

Analisis Data :

From the technical data of components and specifications of turbines and generators, the power produced by the Ussu Malili PLTM can be theoretically calculated.

- **Daya mekanik turbin**

$P_{mechanic}$= ρ×g×Q×H

= 1000 kg/m^3 × 9,8 m/s^2×1000 m×1,2m^3/s

= 1176.0 kW

The power that comes into the generator is the same as the power produced by the turbine (Pin generator = Pturbin) because the turbine and generator are coupled and work together

Unit 1

P_{Turbin} = $P_{Mekanik}$×η_{turbin}

= 1176.0 kW × 0.90

= 1058.4 kW

So the total turbine power produced by the Ussu Malili PLTM is 3 × 1058.4 = 3,175.2 kW or 3 MW

The power generated by the generator rotated by the turbine is calculated by the equation

$P_{Generator}$= P_{Turbin}×η_g

= 1058.4 × 0.96

= 1016.06 kW

So the total power generated by the Ussu Malili PLTM generator is 3 × 1016.06 = 3,048.1 kW or 3 MW

In table 5. The results of energy production produced in 2023 are displayed in theory and in table 6. The production results in 2023 are displayed according to reality.

Table 5. 2023 power output and energy production data (theory)

No	Bulan	Debit Rata-rat (m^3/s)	Daya Output (kW)	Waktu Operasi (Jam)	Produksi Energi (kWh)
1	Januari	3.6	3048	684	2.084.832
2	Februari	3.6	3048	612	1.865.376
3	Maret	3.6	3048	684	2.084.832
4	April	3.6	3048	660	2.011,680
5	Mei	3.6	3048	684	2.084.832
6	Juni	3.6	3048	660	2.011,680
7	Juli	3.6	3048	684	2.084.832
8	Agustus	3.6	3048	684	2.084.832
9	September	3.6	3048	660	2.011,680
10	Oktober	3.6	3048	684	2.084.832
11	November	3.6	3048	660	2.011,680
12	Desember	3.6	3048	684	2.084.832
	Jumlah		26.726	7.998	16,439.486

Tabel 6. Data daya output dan produksi energi tahun 2023 (nyata)

No	Bulan	Debit Rata-rat (m^3/s)	Daya Output (kW)	Waktu Operasi (Jam)	Produksi Energi (kWh)
1	Januari	2.25	2053	672	1.379,946
2	Februari	1.96	2004	521	1.044,097
3	Maret	2.68	2445	671	1.641,164
4	April	3.06	2629	690	1.812.595
5	Mei	3.37	2809	735	2.064.351
6	Juni	3.19	2841	698	1.983.109
7	Juli	3.15	2807	695	1.951.274
8	Agustus	2.47	2692	564	1.518.349
9	September	1.42	1885	476	897.512
10	Oktober	1.01	1433	430	616.203
11	November	0.88	1212	428	518.968
12	Desember	1.64	1916	528	1.011.918
	Jumlah		26.726	7.998	16,439.486

From the data above, the highest output power produced by the Ussu Malili PLTM is real in May, which is 2809 kW at a discharge of 3.37 m3/s and has a fairly high operating time, which is 735 hours out of 744 hours (31 days×24 hours) resulting in energy production of 2,064,351 kWh. Meanwhile, the lowest output power occurred in November, which was 1212 kW at a discharge of 0.88 m3/s and had a fairly low operating time, which was 428 hours out of 720 hours (30 days × 24 hours), so that the energy production produced was also small, which was 518,968 kWh.

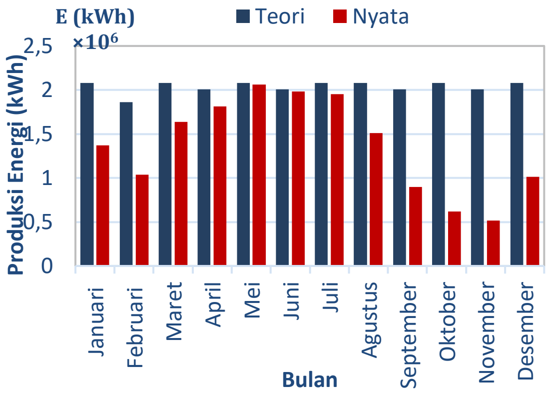


Figure 2. Comparison of real-state and theoretical energy production

The comparison data obtained theoretically with real data is then calculated to determine the level of efficiency of the Ussu Malili PLTM in producing energy for one year (2023).

Efisiensi Energi $= \frac{hasil\ nyata}{hasil\ teori} = \frac{14.439,486}{24.505.920} = 0,67\%$

In the data analysis, it was found that the efficiency value produced by the Ussu Malili PLTM in 2023 was 67%. Efficiency cannot reach 100% due to the influence of decreased water discharge in the dry season and scheduled maintenance and disruption due to component failures that affect the plant in producing electrical energy

Electric Power System Reliability

the reliability level of the Ussu Malili PLTM electric power system by calculating the value of the availability factor (Availability) and unavailability (Unavailability) in equation 4 and equation 5 as follows:

Availability $= \frac{jumlah\ jam\ operasi}{jumlah\ jam\ operasi + jumlah\ jam\ unit\ terganggu}$

$= \frac{7108}{7108 + 1890}$

$= \frac{7108}{8998}$

$= 0.79 = 79\%$

Unavailability $= \frac{jumlah\ jam\ operasi}{jumlah\ jam\ operasi + jumlah\ jam\ unit\ terganggu}$

$= \frac{1890}{7108 + 1890}$

$= 0.21$

$= 21\%$

The results of the calculation above show that the reliability of the Ussu Malili PLTM electric power system has an availability percentage of 79%, meaning that during operational hours, the Ussu Malili PLTM can operate properly and provide electricity according to its capacity. Meanwhile, an unavailability of 21% indicates that during operational hours, the Ussu Malili PLTM is unable to generate electricity or operate due to interruptions, maintenance, or other conditions that hinder normal operations

The 79% availability percentage and 21% unavailability indicate that the Ussu Malili PLTM has a fairly reliable performance, but there are problems in operational reliability that need to be improved to ensure a more stable electricity supply.

V. Conclusion

1. The month of May showed the best performance with an output power of 2809 kW with an operating time of 735 hours, a discharge of 3.37 m3/s and an energy production of 2,064,351 kWh, while in November there was a decrease in performance which was seen from the low output power of 1212 kW, operation time of 428 hours, discharge of 0.88 m3/s and energy production of 518,968 kWh.The 79% availability percentage and 21% unavailability indicate that the Ussu Malili PLTM has a fairly reliable performance, but there are problems in operational reliability that need to be improved to ensure a more stable electricity supply.
2. The energy availability of the Ussu Malili PLTM in 2023 is 79%. This value was obtained from the operational performance which had a great influence on the reliability of the plant with three assessment factors, namely the service factor, the maintenance exit disturbance factor, and the forced exit disturbance factor.

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