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Reliability Analysis of a Micro Hydro Power Plants System at Lombok with Expected Energy Not Supplied Method

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ABSTRACT

In the context of this research, understanding the reliability of a power generator is essential as a criterion for assessing its suitability for use or the need for further development. The method used in this study is reliability analysis, known as "Expected Energy Not Supplied (EENS)." The initial step of this method is to calculate the FOR (Forced Outage Rate) to determine the level of disturbances in the generator unit. The subsequent process involves calculating individual probabilities, analyzing the generator load curve, determining the EENS values of three generators, and comparing them with the EENS standards established by the National Electricity Market. These standards stipulate that EENS should not exceed 0.002% of the total energy consumption in the region. This research marks a significant milestone as the first endeavour conducted on Lombok Island within this specific context. The study was conducted by analyzing three operational Micro-Hydro Power (MHP) units on Lombok Island. The research findings indicate that the EENS metric for MHP on Lombok Island stands at 2.822%. This result suggests that the reliability of MHP on Lombok Island falls below the established criterion, which is less than 0.002% annually. In practical terms, these findings imply that MHP plants located on Lombok Island may not be relied upon as the primary source to meet the electricity demands of the Lombok region in 2022. This research provides valuable insights into the challenges of energy reliability on Lombok Island and serves as a crucial foundation for further considerations in the development of renewable energy sources in the region.

1. INTRODUCTION

1.1 Background

In recent years, there has been a significant increase in the implementation of renewable energy sources in the Indonesian electricity industry. The promotion of renewable energy is actively taking place in the provinces of Nusa Tenggara and Sulawesi, making this trend highly important. It is projected that by 2030, the Nusa Tenggara region will have a renewable energy capacity 71% larger than any other region. The implementation of policies that encourage the use of renewable energy sources is crucial to reduce dependence on non-renewable energy sources and mitigate the negative impacts of climate change. Micro-hydroelectric power plants are a promising option for renewable energy in Indonesia as they harness energy from small water streams without the need for fuel [1]-[4].

The Indonesian government has implemented strategies to tap into the potential of hydropower as a renewable energy source for electricity generation, aligning with their efforts to create a sustainable and environmentally friendly national energy mix. Different types of hydropower plants, such as centralized micro-hydro power plants (MHPP), micro-hydro power plants, and larger hydroelectric power plants, are being constructed in various regions of Indonesia. These actions are consistent with the government's commitment to optimize the use of natural resources while minimizing waste production. The provision of sustainable energy is crucial to meet Indonesia's energy demands and reduce the negative environmental impacts [5].

Recognizing the importance of private sector involvement in advancing renewable energy, the government is working to implement policies that incentivize private participation in this sector. These strategies not only promote economic development but also benefit society as a whole, aligning with Indonesia's goal of achieving energy sustainability [6], [7].

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1.2 Aim and Contribution

This study is significant as it is the first research conducted on Lombok Island. Furthermore, analysis on the reliability of power generation is rarely performed, especially regarding new renewable energy sources. The commonly used methods in Indonesia to evaluate reliability are SAIDI SAIFI, and LOLP (Loss of Load Probability), so it is expected that this research can provide another parameter for assessing reliability, particularly from the perspective of power generation. Another objective of this study is to assess the reliability of the MHPP system in the Nusa Tenggara region using the Expected Energy Not Supplied (EENS) approach. The implementation of Extreme Value Theory (EVT) with the EENS methodology is rarely seen in reliability studies related to Micro Hydro Power Plants (MHPP) in Indonesia. The EENS approach was chosen because it can enhance the reliability of micro-hydro systems, provide more accurate results in dynamic scenarios, and consider factors such as weather conditions, power consumption, and resource availability.

Therefore, conducting a reliability analysis of micro-hydro systems to evaluate the likelihood of system failures, ensure customer satisfaction, and modify generator capacity planning.

To ensure accurate and reliable results, this study will utilize empirical measurements and simulation data generated by computer software. The findings of this research will have beneficial implications for the micro-hydro industry in Indonesia and globally [8]-[10].

Evaluating the performance of micro-hydro systems through reliability analysis is a crucial step in assessing the possibility of system failures in customer service and optimizing production capacity planning. Through this reliability analysis, adjustments to generator capacity planning can be made, and the probability of system failures during customer service can be evaluated. The Energy Expected Not Supplied (EENS), which is based on reliability standards set by the National Electricity Market (NEM), is a commonly used metric in determining the reliability index of generators. EENS calculates the energy that a generator cannot produce and is greatly influenced by the number of generators operating in the system at any given time. A reliability analysis of micro-hydro systems is essential to ensure reliable customer service, optimize generator capacity planning, and consider critical aspects such as Energy Not Supplied (EENS). This study aims to conduct a reliability analysis of micro-hydro systems using the EENS approach to evaluate the probability of system failures and optimize generator capacity planning [11].

Although national energy markets generally offer a high level of reliability, concerns regarding intermittent reliability can arise when the supply-demand balance in a region becomes fragile [4], [12]. Various factors, such as adverse weather conditions or unforeseen disruptions in the power system, can contribute to such issues. Therefore, it is important to establish reliability requirements to ensure efficient electricity supply in a region. The Energy Networks and Energy Services (EENS) organization sets reliability criteria based on the National Electricity Market (NEM) [13].

These criteria specify that the energy unavailable in a year should not exceed 0.002% of the total energy consumed in the research area. This statement highlights the importance given by EENS to guarantee the reliability of electrical infrastructure in a region, as evidenced by their dedication to providing consistent and secure power resources. It should be noted that each area has different characteristics that can influence the reliability of existing electrical infrastructure. Further research is needed to validate the suitability of reliability criteria used for the unique conditions and characteristics of each geographical region. Thus, efforts to ensure the reliability of electrical infrastructure in specific regions can be maintained and enhanced in line with demand and advancements [14]-[16].

2. MATERIALS AND METHODS

2.1 Reliability

The generator unit is a critical component of a power generation system that produces electricity to meet the energy needs of a community. However, like any other technological component, generators may experience disruptions or malfunctions in their operation. These issues can range from disconnection from the grid to physical damage, resulting in a halt in the electricity flow to consumers [8], [9].

The Forced Outage Rate (FOR) ratio is a key metric used to assess the reliability of a generator by measuring the frequency of disruptions it experiences. Several variables can impact a generator's dependability, including scheduled maintenance, physical condition, and fuel usage techniques. Therefore, regular maintenance is essential to ensure its reliability. Additionally, factors such as power plant type, capacity, reliability of producing units, fuel usage, and investment costs must be considered when analyzing the power generation system. Maintaining reserve capacity is also crucial to accommodate fluctuations in power demand, increased peak loads, and potential malfunctions in power-producing units.

In this context, a practical and reliable power generation system plays a vital role in meeting energy needs and ensuring the long-term sustainability of the electrical energy supply. This can be achieved through planned maintenance, proper fuel usage, and adequate planning for spare capacity to meet these objectives.

2.2 Available Power

To ensure a consistent power supply for consumers, it is crucial to consider the available power in the electrical system. The availability of power is influenced by various factors, such as the installed power capacity of production units and their operational availability. However, certain factors can affect the availability of backup power in the system, including malfunctions or routine maintenance performed on power generation units[10]-[12].

The Forced Outage Rate (FOR) is a measure used to assess the reliability of the electrical system in meeting consumer power needs. It quantifies the frequency at which generating units experience outages. The FOR can be calculated using the following formula [13], [14]:

$$Availability = 1 - FOR \tag{1}$$

To find the FOR value itself, here is the formula:

$$FOR = \frac{Number\ of\ uninterrupted\ (hours)}{Number\ of\ operates + number\ of\ uninterrupted} \tag{2}$$

In the context of generating units, the FOR value, or operational reliability factor, can be an important indicator in assessing the reliability of production units. Using a FOR value of 0.05 as an example, it can be seen that the probability of the unit being impaired is 0.05 or 5% in each operation. In contrast, the probability of such a unit operating successfully is 1 - 0.05 = 0.95 or 95%. It should be noted that a smaller FOR value provides a higher level of assurance of production unit operation as the probability of the unit experiencing disruption becomes smaller. In this case, the size of the FOR value can be a determining factor in assessing the level of operational reliability of a production unit.

However, poor maintenance of the generating unit can cause the FOR value to be lower, thereby reducing the guarantee of the unit's operation. Conversely, more frequent disturbances in the generating unit can result in a higher recorded FOR value. Therefore, good and proper maintenance of the generating unit is essential to maintain the optimal FOR value and optimize its operational reliability.

2.3 Load Curve

Load curves are useful for displaying variations in generator load in kilowatts (kW) over time, whether on a daily, weekly, monthly, or even annual scale. This investigation focuses on only one day per year, and only daily data was collected. Creating a load duration curve involves sorting the daily load power, from day one to day 365, from greatest to least. This load duration curve will demonstrate the generator's ability to supply power throughout its operating period [15], [16].

It is beneficial to know whether the generator can maintain a consistent power supply on a particular day of the year. This information can help decision-makers plan production strategies and identify potential power system problems over time. However, it is important to create this load curve carefully and exhaustively to avoid errors and biases. Therefore, employing appropriate analysis techniques and relying on dependable data sources are crucial for producing accurate and reliable results [17]-[19].

2.4 Individual Probability (IP)

Determining the probability of occurring or individual probability after obtaining a combination of plants can be calculated using the following equations [14]:

$$y_n = \{(y_{n-1} + x)\ and\ (y_{n-1} + 0)\} \tag{3}$$

The probability of power occurring after the n=th unit for the power numbers in the equation is as follows:

$$P_n\{(y_{n-1} + x) = P_{n-1}(y_{n-1})(1 - q_n) \tag{4}$$

$$P_n\{(y_{n-1} + 0) = P_{n-1}(y_{n-1})q_n \tag{5}$$

To calculate the probability of a forced power interruption in an electric power system with n generating units, it is possible to use predetermined formulas. By deriving individual probabilities from the power values associated with using one unit, two units, *etc*., this calculation method helps determine the reliability of a generating system [20].

For a system with one generating unit, for instance, the following circumstances can be identified:

a. The probability of this event occurring is zero if the quantity of kW power on outage does not equal the power of the generating unit.
b. If the kW power on outage is zero, the probability that this will occur is one minus the FOR (probability of forced outage).
c. If the kW power on outage is equivalent to the generating unit's power, then the probability of this happening is equal to the probability of forced outage (FOR).

Probability calculations for systems with two generating units can be performed as follows:

a. If the kW value on outage in both units is zero, the probability of occurrence is the product of (1-FOR1) and (1-FOR2).
b. If the highest kW value during the outage is the sum of the most significant kW values for each unit, then the probability of occurrence is the product of FOR1 and FOR2.
c. If the value of kW on outage is between zero and the maximum value of kW, the probability of kW on outage can be calculated based on the following scenarios Scenario 1, The probability of occurrence is equal to the non-zero table value multiplied by the (1-FOR) of the unit with a value of 0. Scenario 2, If each unit has a value of zero, the probability of occurrence in the resulting table will also be zero.

If the system consists of three generating units, such as unit 1 = FOR1, unit 2 = FOR2, and unit 3 = FOR3, the procedures below can be used to create a new table of possible occurrences:

a. If the kW on outage value from the previous table with two units is equal to that from the table with three units, then the probability of occurrence must be multiplied by (1-FOR3).
b. kW on outage in a table with three generating units is the result of kW on outage in a table with two units multiplied by Zero in this instance, the probability of occurrence is multiplied by (1-FOR3).

The kW value in units is 3, and the probability will be multiplied by FOR3.

c. If there are s identical units in the system, the probability of kW on outage will be calculated using the sum of the s elements for s kW value on the outage.

Using the above equations, it can be concluded as follows:

$$\text{Tabel n unit} = \{\text{Tabel (n} - 1 \text{ unit} + 0\} \quad \{\text{Tabel (n} - 1 \text{ unit } R_n\} \tag{6}$$

While the column of possible occurrence, namely:

Table (n-1) units + 0 = probability of occurrence in table (n-1) units times (1-FORn),

Table (n-1) units + Rn = probability of occurrence in table (n-1) units times FORn.

2.5 Loss of Load Probability (LOLP)

The unreliability of a system in this context is seen as its inability to meet the daily peak load. Loss of load occurs whenever the system load exceeds the available generating capacity. The overall probability of a power shortage (loss of load) is referred to as Loss-of-Load Probability or LOLP. It is typically expressed in terms of days per year, hours per day, or as a percentage of time. When expressed as the expected accumulated amount of time during which a power shortage is experienced, this measurement is more accurately referred to as the loss of load expectation (LOLE). LOLP measurement was first introduced by Calabrese in 1947.

$$LOLP = \sum_J P_j t_j$$

2.6 Expected Energy Not Supplied (EENS)

EENS, or Expected Energy Not Supplied, is a commonly used calculation method in the world of electricity for determining the amount of prospective energy a generator cannot supply when required. This method of calculation takes into account multiple variables, such as the number of generators operating at any given time and the reliability of the electrical system [21].

Several variables significantly impact the value of EENS in practice, including generator size and type, system capacity, environmental conditions, and government policies regarding the development of the electricity infrastructure. Therefore, EENS calculations must be meticulously performed to ensure reliable results that accurately reflect the electrical system's ability to meet energy demands. The NEM (National Electricity Market) has established reliability criteria for EENS, stating that annual energy availability must exceed 0.002% of the region's total energy consumption [22], [23]. This demonstrates the usefulness of EENS in evaluating system dependability and maintaining the stability of the local energy supply [14], [24].

The EENS value is obtained by multiplying the energy value by the probability of the generator operating at the current level. The bound energy is calculated using the area under the long load curve, while the generator's operating value is used to identify specific portions of the site.

$$\text{EC} = \int_{\text{Xn}}^{\text{Xn+1}} \text{f(x)dx} \tag{7}$$

Several stages of the calculation procedure must be executed with care in order to minimize the energy value of the fine. First, the load curve equation corresponding to the system's integral limits must be chosen. The value of the confined energy can then be calculated using a flat build formula that calculates the area formed by the intersection of the value of the generator in service and the old load curve [25].

Consequently, the energy limit of the system will equal the region formed beneath the load's ageing curve. Additionally, the Expected Energy Not Supplied (EENS) value can be calculated by transferring energy values constrained by the generator's operation probability. Therefore, caution and foresight are required when calculating the energy value of the fine in order to select the appropriate load curve equation and calculate the probability of the generator operating so that the resultant calculation results are accurate and scientifically valid.

$$EENS = EC \ x \ P \tag{8}$$

3. RESULT AND DISCUSSION

Through approximately three weeks of observations, literature research, and interviews at MHPP Narmada, Pengga, and Santong, several data were effectively gathered and can be processed according to the researcher's objectives. The EENS (Expected Energy Not Supplied) method will be used to analyze the data. In order to obtain accurate results using the EENS method, multiple calculation steps must be performed.

In the first step of the EENS method, the FOR (Forced Outage Rate) is calculated to determine how frequently a generating unit experiences interference. After successfully obtaining the FOR value, the next stage is calculating the individual probabilities. This stage attempts to determine the likelihood of a forced outage affecting a combination of plants with varying power values.

The generating load curve must be analyzed after the individual probability values have been effectively calculated. At this juncture, it is intended to demonstrate the relationship between the power supply capability (watts) and the service life of the generation unit (years). Thus, researchers will be able to acquire more comprehensive information regarding the capacity of plants to satisfy electricity demands at a given time.

After effectively analyzing the plant load curve, the EENS value of the three studied plants will be determined. After effectively calculating the EENS percentage value, researchers will evaluate the Narmada, Pengga, and Santong MHPP plants' dependability. This is accomplished by comparing the obtained EENS value to the standards established by the National Electricity Market. The standard stipulates that the EENS value cannot exceed 0.002% of the region's total energy consumption.

3.1 Built-in Power

Each MHPP Narmada, Pengga, and Santong has a unique generating capacity. MHPP Narmada has a 100 kW generating capacity, MHPP Pengga has a 400 kW generating capacity, and MHPP Santong has a 100 kW generating capacity. Therefore, the total installed capacity of the three power facilities is 1,500 kW.

After obtaining each generating unit's capacity and all three units' total capacity, it is necessary to determine the possible system operation configurations by examining the power supply. In this instance, there are three generating units, so the value of n, or the number of generating units, is three.

In determining possible combinations, it is also necessary to consider the Forced Outage Rate (FOR) value, which can impact the system's overall operation. Therefore, it is necessary to conduct a thorough evaluation to ensure that the system can operate effectively and proficiently and withstanding the possibility of interruptions or outages.

3.2 Forced Outage Rate (FOR) Value

The micro hydro power plant units utilized in this investigation were Narmada MHPP, Pengga MHPP, and Santong MHPP. This study employs three teams with capacities of 100 kW, 400 kW, and 1000 kW for a total power of 1500 kW. When calculating the number of units utilized, it is determined that three units were utilized.

In the calculations performed for this study, the number of active generating units in the system was represented by n. There are eight possible combinations of all three units given the value of n in this context, which is three. This study employs the FOR (Forced Outage Rate) method to calculate the probability of each individual or combination.

Calculating the FOR value requires a year's data on each generating unit's faults. The disruptions in question encompass internal faults, external faults, as well as maintenance. This research analyzed disturbances in three micro hydro power plant units (MHPP) during 2022. These units were MHPP Narmada, MHPP Pengga, and MHPP Santong. According to the results of the analysis, the Narmada MHPP experienced disruptions for 170 hours and 23 minutes, the Pengga MHPP for 290 hours and 24 minutes, and the Santong MHPP for 274 hours and 05 minutes.

To calculate the FOR value of each unit, a predetermined FOR value is applied: 0.0191 for Narmada MHPP, 0.0321 for Pengga MHPP, and 0.0303 for Santong MHPP. The number of disturbances occurring in each generating unit and the likelihood of these units operating during the operating time (1-FOR) can be determined by obtaining this FOR value.

In this study, the FOR value is crucial for determining the individual probability and total power generated by the three micro hydro power plant units. This study can calculate the individual probability and total power generated by a system consisting of one unit, two units, and three units of the power plant using the FOR method. This provides a deeper comprehension of the performance and potential power of the MHP utilized in this study [26].

3.3 Individual Probability (IP) Value of Generator

Finding individual probabilities is the next stage. Each computation will know the kW value from zero to installed power during the blackout. The likelihood of the unit operating is 0.9809 at the Narmada MHPP because the individual probability is (1-FOR 1) 1-0.0191 = 0.9809. In contrast, the individual probability is FOR1, which is 0.9809, which indicates the potential of the unit encountering interference, when the interference is 100 kW or more in power.

The number 0 (zero) at MHPP Pengga denotes a 0 kW disturbance. The likelihood of the unit operating is 0.9679 since the individual probability is (1-FOR2), which is 0.0321. Comparatively, the individual probability of FOR2, or the likelihood of the unit suffering interference, is 0.9679 when it suffers interference of 400 kW or more power than the generating unit.

Individual probability in the Santong MHPP is (1-FOR3) or 0.0303, so the probability of the unit operating is 0.9697. Similarly, FOR3, or 0.0303, indicates the unit's susceptibility to interference when the interference is 1000 kW or higher in Santong MHPP. Calculate the individual probabilities of the system by combining the Narmada and Pengga MHPP plants, where a value of zero represents a generating unit enduring a forced outage and a value of one represents a generating unit that is operational. If the Narmada and Pengga MHPP are normally operational or if there is no interference, then the individual probability of both units is 1. The following is an individual probability calculation, IP(0kW) = (1-FOR1)(1-FOR2) = (0.9809) (0.9679) = 0.9494. Other conditions are displayed in Table 1. Calculating the individual probabilities of the three generating units is the next step. Table 2 displays the individual probability calculations for the three generating units. The calculation for three generators is divided into two sections. In the table, the incoming power in kilowatts is determined by:

a. For (n-1) units plus zero equals the probabilities of each individual in the table (n-1) times units (1-FORn).
b. For (n-1) units + Pn = individual probabilities in table (n-1) units times FORn.

With the knowledge that (n-1) units plus zero represent kW during outages used in previous calculations (table 4.7), namely 0 kW, 100 kW, 400 kW, and 500 kW. Simultaneously, (n-1) units + Rn is 1000 kW at the outage that must be added or units that have not been added to the probability calculation for two generating units.

Table 1. Calculation for two generating units with individual probability (IP) calculation.

Group Name		In Service (kW)	Out Service (kW)	Formula	Probability
Narmada	Pengga				
1	1	0	500	$(1-\mathrm{FOR1})(1-\mathrm{FOR2})$	0.949479236
1	0	100	400	$(1-\mathrm{FOR1})(\mathrm{FOR2})$	0.031458545
0	1	400	100	$(\mathrm{FOR1})(1-\mathrm{FOR2})$	0.018450896
0	0	500	0	$(\mathrm{FOR1})(\mathrm{FOR2})$	0.000611323
Total					1

Table 2. Calculation for three generating units with individual probability (IP) calculation.

Group Name			In Service (kW)	Out Service (kW)	Formula	Probability
Narmada	Pengga	Santong				
1	1	0	1000	500	$(1-\mathrm{FOR1})(1-\mathrm{FOR2})\mathrm{FOR3}$	0.028802673
1	0	0	1400	100	$(1-\mathrm{FOR1})(\mathrm{FOR2})(\mathrm{FOR1})$	0.000954302
0	1	0	1100	400	$(\mathrm{FOR1})(1-\mathrm{FOR2})(\mathrm{FOR3})$	0.000559712
0	0	0	1500	0	$(\mathrm{FOR1})(\mathrm{FOR2})(\mathrm{FOR3})$	1.85446E-05
1	1	1	0	1500	$(1-\mathrm{FOR1})(1-\mathrm{FOR2})(1-\mathrm{FOR3})$	0.920676563
1	0	1	400	1100	$(1-\mathrm{FOR1})(\mathrm{FOR2})(1-\mathrm{FOR3})$	0.030504243
0	1	1	100	1400	$(\mathrm{FOR1})(\mathrm{FOR2})(1-\mathrm{FOR3})$	0.017891184
0	0	1	500	1000	$(\mathrm{FOR1})(\mathrm{FOR2})(1-\mathrm{FOR3})$	0.000592778
Total						1

3.4 Plant Load Curve

This study used a load curve that depicts the variation in generator load in kW as a function of time to conduct a reliability analysis. The scales at which this time position can be used include daily, weekly, monthly, and even yearly. However, by gathering the essential information every day for this study, we could focus on only one day of the year.

To obtain a more detailed load curve, it is recommended to utilize the identical time function from day one to day 365 for arranging the power load in descending order. The load length curve depicted in Figure 1 elucidates the intrinsic correlation between power delivery capacity and the duration required to provide optimal service in the present scenario. The visual representation facilitates a lucid comprehension of the correlation between the energy input and the duration of efficient service. Subsequently, an endeavour is made to generate a load length curve by arranging the load power values in descending order. The duration curve of the electrical load supplied by the micro-hydropower (MHP) system in the year 2022 is depicted in Figure 2. The load length curve is subsequently employed to ascertain the t-value, which is contingent upon the prevailing operational circumstances and the energy resources at hand.

An illustration of optimal system performance can be demonstrated by considering a scenario where the operating power is 1500 kW and the power during an outage is 0 kW. In such a case, the system is deemed to be functioning optimally and has the capacity to operate at the specified power of 1500 kW. At present, the t value stands at 0 due to the absence of the load value of 1500 kW on the previous load curve. Table 3 provides comprehensive information on t-values across diverse load conditions. This study offers an enhanced comprehension of the dependability of the MHPP system in providing electrical power.

3.5 Calculation of Expected Energy Not Supplied (EENS)

In general, to ensure a stable and reliable energy supply, electrical system operators should consider the possibility of generator failure. One way to evaluate the reliability of an electrical system is to use EENS (Expected Energy Not Supplied) values. This EENS is an estimate of energy that is expected to be unavailable due to the failure of generators operating at a given time.

However, this EENS's value does not remain constant throughout time. This is caused by the variety of generators that are always in operation. As a result, the operating circumstances of the generator in the electrical system at that time had a significant impact on this EENS number. The value of the bounded energy (EC or Energy Curtailment) and the likelihood that the current generation will be put into service must be multiplied to determine the value of EENS. The EC itself is derived from the region produced under the previous load curve, whereas the share is derived from the value of the operating or operating generator. The load length curve equation is also necessary to guarantee accurate EC calculations.

Therefore, as an electrical system operator, it is important to understand how to calculate the EENS value and the factors that influence it, such as generator operating conditions and load curves. This will help in planning and optimizing the use of electrical systems more effectively and efficiently.

Table 3. Time data (t) on three plants in 2022.

Out Service	In Service	Time (t)
0	1500	0
100	1400	0
400	1100	17
500	1000	59
1000	500	162
1100	400	189
1400	100	361
1500	0	0

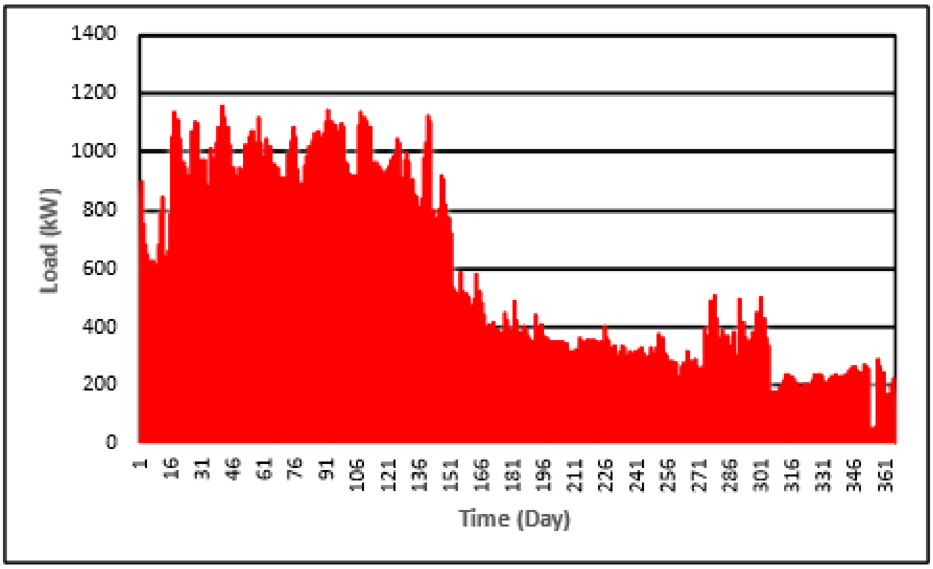

Fig. 1. Results of Energy curtailed calculations in 2022.

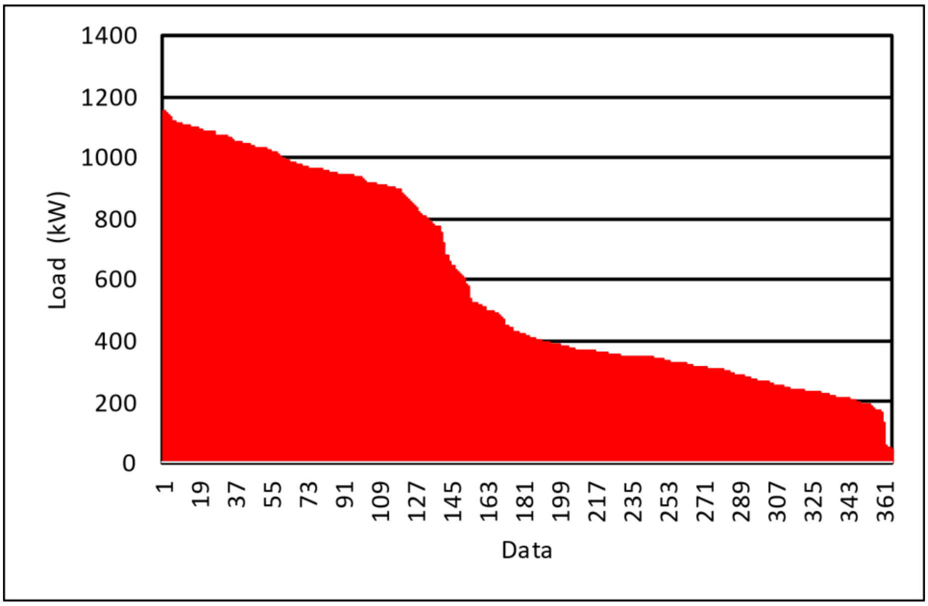

Fig. 2. Long load curve of MHPP Narmada, Pengga, Santong.

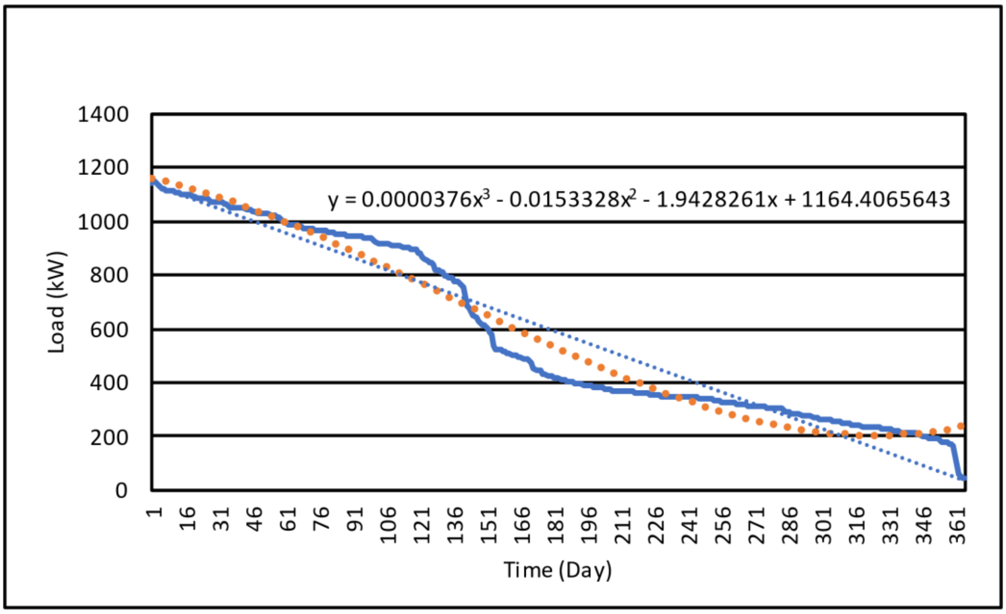

Fig. 3. Equation line of the load length curve of MHPP Narmada, Pengga, Santong in 2022.

Based on the load length curve above, the resulting line equation is $y = 0.0000376x^3 - 0.0153328x^2 - 1.9428261x + 1164.4065643$. This equation is used to find the value of the constrained energy. The formula used to find EC is according to Equation (7).

Based on the formula, the next step is to calculate the out-of-service condition based on Table 3. The power value is a variable x. The summary results of the calculation can be seen in Table 4**.**

Table 4. Results of Energy curtailed calculations in 2022.

In service (kW)	Time (t)	EC (Energy Curtailed)
0	0	0
100	0	0
400	17	789.84
500	59	5382.66
1000	162	66884.59
1100	189	87261.39
1400	361	176850.10
1500	0	0

Table 5. EENS MHPP in 2022.

EENS for MHPs 1,2 and 3				
Out service (kW)	In service (kW)	Probability	Collected energy (kWh)	EENS (kWh)
0	1500	1.85446E-05	0	0
100	1400	0.000954302	0	0
400	1100	0.000559712	789.84	0.442084714
500	1000	0.028802673	5382.66	155.0350308
1000	500	0.000592778	66884.59	39.64772754
1100	400	0.030504243	87261.39	2661.842508
1400	100	0.017891184	176850.10	3164.057653
1500	0	0.920676563	0	0
		EENS 1,2,3		6021.025004

Table 6. LOLP MHPP in 2022.

LOLP for MHPs 1,2, and 3			
Out service (kW)	In service (kW)	Probability	LOLP (Day)
0	1500	1.85446E-05	0
100	1400	0.000954302	0
400	1100	0.000559712	0.000370587
500	1000	0.028802673	0.082807215
1000	500	0.000592778	0.006007761
1100	400	0.030504243	0.451267365
1400	100	0.017891184	5.499995006
1500	0	0.920676563	0
	Total		6.040447933

The determination of the EENS value involves the multiplication of the energy-constrained with the probability of the generator's operation subsequent to the chosen EC value. The results of the calculations are presented in Table 5. Based on the results of the calculations, it has been determined that the MHPP Energi Harapan Unsupplied (EENS) on Lombok Island produces a cumulative energy output of 270,003 kWh. This value can also be expressed as a percentage. Divide the EENS value by the number of 1-year generation load data values and then multiply the result by 100%. From the formula produced an EENS percentage on Lombok Island of 2.82%

The findings of the study indicate that the aforementioned value falls short of the benchmark established by the National Electricity Market (NEM), which stipulates an annual proportion of less than 0.002% of the overall energy usage in the area. Thus, it can be inferred that the micro hydropower plants situated on Lombok Island are confronted with numerous challenges and hindrances that necessitate resolution prior to their complete dependability. In order for micro hydro power plants to make a substantial contribution towards fulfilling the energy requirements of the region, it is imperative to enhance the system's maintenance, efficiency, and resilience. Furthermore, it is imperative to take into account the enhancement of infrastructure and the advancement of technology to ensure the optimal and sustainable functioning of micro hydropower plants on Lombok Island. Sustaining the energy independence of Lombok Island necessitates persistent and comprehensive endeavors to enhance the caliber and dependability of micro hydropower facilities.

From Table 6, it can also be analyzed that the LOLP (Loss of Load Probability) value for micro-hydro power plants (PLTMH) is 6.040447933 days per year, which means that based on this value, it can be stated that the PLTMH generator is not reliable. Because the established standard is 3 days per year.

From the two methods mentioned above, it can also be seen that the EENS method has advantages, including having richer information. The EENS table provides more comprehensive information about the impact of various conditions of non-operation of micro-hydro power generators (MHP) on unavailable energy (EENS) and the accumulated energy. This provides a better understanding of the consequences of load loss risk. In a business context, EENS includes the amount of accumulated energy in specific non-operational situations, which is more relevant from a business perspective. This can help calculate potential losses that may occur due to power supply failures. This method is more useful in the context of energy resource planning and management.

The EENS table also includes the total EENS for all calculated conditions, which is 6021.025004 kWh. This is a measure of the overall impact of load loss risk in 2022. Meanwhile, the LOLP method provides the probability of load loss in days, but it does not provide information about the amount of energy lost or its consequences in a business context. Therefore, in this case, the EENS method is more relevant and useful for measuring the risk and impact of load loss in the operation of micro-hydro power generators (MHP) in 2022.

4. CONCLUSIONS

This study used the EENS method to evaluate and quantify the reliability of Micro-Hydro Power Plants (MHP). The research involved verifying three MHP generating unit operations, namely MHP Narmada, MHP Pengga, and MHP Santong, to determine the EENS value. The EENS calculation process began with a FOR analysis, followed by the estimation of Individual Probability (IP) and load curve analysis. The results of the analysis indicate that the EENS metric for MHPP in Lombok Island, with a particular focus on Narmada MHP, Pengga MHP, and Santong MHP, remained unsatisfactory in 2022 as it exceeded the threshold established by the National Electricity Market. According to the established norm, the annual energy supply must not exceed 0.002% of the overall energy usage within the given locality. Therefore, it is crucial to evaluate and improve the performance of MHP.

Furthermore, computational analysis has also shown that the EENS value of MHP in Lombok Island, including Narmada MHP, Pengga MHP, and Santong MHP, reached 2.82% in the year 2022. The standards set by the National Electricity Market are not yet met by the

MHP system due to its current level of reliability. According to the regulations of the National Electricity Market, the annual energy supply must not exceed 0.002% of the overall energy consumption within the area.

From the research, it can also be concluded that the EENS method has advantages over other methods, such as LOLP, including having richer information. The EENS table provides more comprehensive information about the impact of various conditions of non-operation of Micro-Hydro Power Generators (MHP) on unavailable energy (EENS) and the accumulated energy. This provides a better understanding of the consequences of load loss risk. In a business context, EENS includes the amount of accumulated energy in specific non-operational situations, which is more relevant from a business perspective. This can help calculate potential losses that may occur due to power supply failures. This method is more useful in the context of energy resource planning and management.

The study's findings suggest that enhancing and augmenting the dependability of the MHP system on Lombok Island should be prioritized. The objective is to adhere to the regulations established by the National Electricity Market and ensure that the Economic Energy and Network Support (EENS) does not surpass pre-established thresholds. This measure is expected to improve energy accessibility within the region and establish a more dependable functioning of the MHP in the long run.

NOMENCLATURE

y_n	Amount of power after the n-unit
y_{n-1}	Amount of power before the n-unit
x	Power from the n-unit
q_n	Forced outage rate n-unit
p_n	Probability after the n-unit
P_{n-1}	Probability before the n-unit exists
R_n	Capacity of the n-unit
kW	Power unit
kWh	Energy unit

Abbreviations

MHPP	Micro Hydro Power Plant
FOR	Forced Outage Rate
IP	Individual Probability
EC	Energy Curtailed
NEM	National Electrical Market
EENS	Expected Energy Not Supplied
LOLP	Loss of Load Probability
P	Probability

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