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Value of Loss Load Analysis of Java-Bali System Based on Macro Economic Data

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Abstract **--** Industrial and business sectors have a big influence on the gross domestic product in some regions (GDP). Besides that, GDP is influenced by electricity consumption. That statement is the reason why the value of loss load (VOLL) had to be calculated. This research calculates VOLL for getting the value of outage cost, efficiency, and productivity industrial and business sector in each Area Pengaturan Beban (APB) and the entire Java-Bali region. VOLL is calculated by macroeconomic analysis because this method has more time efficiency than survey analysis. VOLL forecasting in 2016-2023 is calculated, also in this research. After that, the outage cost forecasting in hierarchical level 1 (HL 1) can be gotten if expected energy not supplied (EENS) from HL 1 is calculated. Before EENS calculation is held, analysis of another reliability indices such as loss of load expectation (LOLE) and loss of load probability (LOLP) was calculated. The calculation results show that VOLL in 2017 is 35,100.67 Rp/kWh, and EENS in HL 1 is 7.25 MWh. The total outage cost from the calculation is 289 million rupiahs.

Keywords:
Value of Loss Load
GDP
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I. Introduction

The electric power system is a very complex. The main focus of the electronic power system is to ensure that the supply of electrical energy is reliable, and the cost is economical to meet the needs of consumers [1]. In Indonesia, the Java-Bali power system is the largest and most complex electrical system. In 2016-2025, the electricity demand expected increase from 216.8 TWh in 2016 to 457.0 TWh in 2025, growing at an average 8.6% per year [2]. Besides, the Java-Bali power system is expected to have a low outage rate and a proper evaluation of the reliability index of increasing generators capacity planning. Small outages will significantly affect electricity customers, primarily in the industrial and business sectors. These two sectors are most significant sectors that contribute to gross domestic product (GDP). GDP produced by the majority of industries and businesses requires a large amount of electricity consumption. The relationship between GDP and energy consumption can be used to see the productivity and efficiency of industry and business in particular region. Besides, the chance of economic loss due to power outage, which is represented as a value of loss load (VOLL), can also be obtained. VOLL can be defined as the average cost that customers must pay for each loss of 1 MWh for every 1 hour [3]. The projection of VOLL in 2016-2023 can be calculated based on the projection results from the GDP and electricity consumption in a particular year. The projected total outage cost can be calculated based on VOLL projection results by first calculating the EENS reliability index. EENS reliability index can be obtained by analyzing and calculating loss of load expectation (LOLE) and the loss of load probability (LOLP), whether it is following PLN standards. So, this study purpose to estimating VOLL, then estimating outage costs to evaluate the reliability index for plans to increase power capacity in 2016-2023 of 43.4 GW or an additional capacity of an average of 4.3 GW per year [2].

II. Basic Concept of GDP and Reliability Index

A. Gross Domestic Product (GDP)

Gross domestic product (GDP) is the sum of value of the goods and services produced from all economic activities in a country [4]. At the same time, gross regional domestic product (GRDP) is the total value of GDP in a particular region. In general, the GRDP value of a specific country is reported every year. All products and services depend on the electric energy supply, where the value of GRDP will decrease as long as there are outages [5]. Calculating Forecasting Errors choose the best GRDP forecasting model and Tracking Signals in the form of mean absolute deviation (MAD), mean squared error (MSE), and mean absolute percent error (MAPE) in the (1), (2), (3) respectively.

$$\text{MAD} = \frac{\sum_{t=1}^{N} |d_t - d_t'|}{N} \tag{1}$$

$$\text{MSE} = \frac{\sum_{t=1}^{N} |d_t - d_t'|^2}{N} \tag{2}$$

$$\text{MAPE} = \frac{100}{N} \sum_{t=1}^{N} \left[\left| \frac{d_t - d_t'}{d_t} \right| \right] \tag{3}$$

Models with the lowest MAD, MSE, and MAPE values are used for forecasting [6].

B. Electric Energy Consumption

Electric energy consumption is the amount of electrical energy used by a country or region for its daily needs. Forecasting the electricity consumption of an area can be obtained using long-range energy alternatives planning (LEAP) software. The electricity consumption projection uses the demand analysis function [7].

The demand analysis function is a function that determines what the characteristic of demand value calculation will be. In this study, demand is calculated based on two variables, namely energy intensity, and customer. The energy intensity variable contains the fundamental values of energy intensity that are formulated as in (4) and the average energy intensity growth that is formulated as in (5). Customer variables contain customer data, and the average customer growth is formulated in (6) [7].

$$\text{Energy Intensity (EI)} = \frac{\text{Energy consumption}}{\text{Costumer}} \tag{4}$$

$$\text{Average growth of EI} = \frac{\sum_{t=1}^{n} \text{EI}}{\text{n}} \tag{5}$$

$$\text{Average growth of costumer} = \frac{\sum_{t=1}^{n} \text{Costumer}}{\text{n}} \tag{6}$$

In the Final Demand Analysis section of LEAP software, input expressions are given according to their categories. For example, the customer sector category, the input expression, is *Key \ Customer Business [Customer] * Key \ Energy Intensity Business [MWh / Customer]*. Then the projected output of energy consumption is obtained [7].

C. Value of Loss Load (VOLL)

VOLL is defined as the average cost that customers must pay for each loss of 1 MWh for every 1 hour [3]. VOLL is a useful and essential measurement in the electricity market. VOLL represents customer’s willingness to pay for electricity services or prevent energy not supplied [5]. VOLL is obtained from calculating of GDP data and electricity consumption (EC) data in the electricity sector in Java-Bali. The VOLL used as a unit of Rp / MWh. The value of lost load or VOLL can be represented as a function of customer damage. The function can be developed into (7) below.

$$VOLL = \frac{GDP_t}{EC_t} \tag{7}$$

where t is the related year.

D. Reliability Index in Power System

A power plant unit is expected to supply the load demand during operation. However, sometime the generator could not supply the load or an outage. This outage causes the system not to be able to supply the load fully. Therefore it is necessary to calculate the probability of outages. Two techniques state this calculation, namely forced outage rate (FOR) for evaluating long-term reliability and outage replacement rate (ORR) for evaluating short-term (daily) reliability [8]. In this study, the FOR technique is used because the reliability evaluation used is included in the long-term category. Then the FOR is used as data to calculate the load loss probability using the capacity outage probability table (COPT). COPT calculations are formulated in (8).

$$P_j = \frac{N!}{j!\,N - j!} \times A^{N-j} \times U^j \quad (8)$$

where j is the outage condition, P_j is the probability of outage j, N is the number of generator units, A is the availability of generator unit, and U is the generator unit's unavailability.

COPT results are used as parameters for the calculation of individual and cumulative probabilities. Both of these probabilities are used to obtain the reliability index LOLE, LOLP, and EENS. The first reliability index to look for is the LOLE reliability index. The LOLE index is a case where an individual's daily peak load can be used in combination with COPT to get the number of days in a specified period when the daily peak load will exceed available capacity. The LOLE index is obtained through (9) [8].

$$LOLE = \sum_{i=1}^{n} P_i(C_i - L_i) \ \text{ days/period} \quad (9)$$

where C_i is the available capacity at day i, L_i is the projected peak load at day i, $P_i(C_i\text{-}L_i)$ is the probability of loss load at day i.

The LOLE index can be used to obtain the LOLP index by dividing it by a total of 365 days and expressed as a percentage. The LOLE and LOLP index is compared with the PLN standard, whether the LOLE value is below one day/year, and the LOLP value is below 0.247%. If the LOLE and LOLP index is good, the EENS index is calculated. The EENS index states the estimated energy cannot be supplied by power generation systems [8]. EENS also means the sum of the load in MW that cannot be supplied at a certain time due to load demands that exceed the available capacity each hour. The basic concept of expected energy curtailed is used to determine the expected energy produced by each unit in a system [8]. Equation (10) represents the EENS function by using generator data in a region.

$$EENS = \sum_{k \in s} E_k P_k = \sum_{k \in s} 8760\ \mathrm{L}C_k P_k \ \text{ (MWh/year)} \quad (10)$$

where P_k is the individual probability of system k, E_k is the energy curtailed of system k, LC_k is the load curtailment of system k.

III. Methodology

This study uses 2012-2015 GRDP data from Badan Pusat Statistik (BPS), energy consumption data from Indonesian Electricity Statistic book 2016 [9], plans to increase generating capacity sourced from Electricity Power Supply Business Plan PT PLN 2016-2025 [2], daily peak load data from PT PLN, and some data from the document Operation Evaluation Yearly Report 2015 [10]. The research flow diagram used is represented in Figure 1.

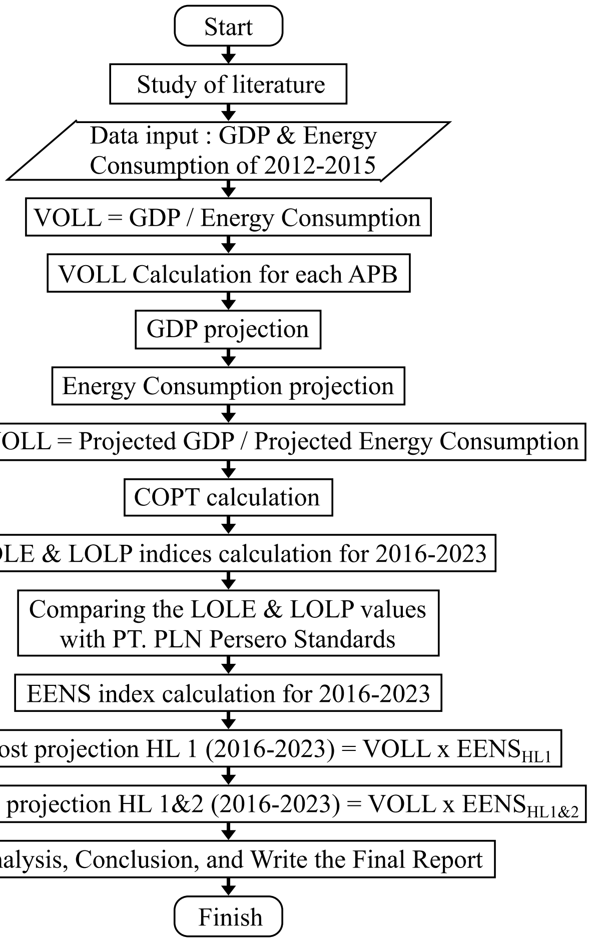

FIGURE 1.
The research flow diagram

A. VOLL Calculation for 2012-2015

Indonesia's GDP has 17 business sectors. The VOLL calculation begins with the classification of the constant 2010 GDP prices in 2012-2015 for which business sectors are affected by electricity. The GDP constant price sector in 2010 was affected by electricity, namely the manufacturing sector, electricity, gas, clean water, commerce, hotels, restaurants, finance, rentals, and services [4]. GDP classification results obtained as in Table I. The customer group used to obtain VOLL based on macroeconomic data, namely industrial and business customer groups [11]. Classification of electrical energy consumption for industrial and business customers for 2012-2015 in the Java-Bali region in Table II.

TABLE I
GDP Constant Price of Java-Bali Affected by Electricity

No	Sector	GDP Constant Price (Trillion Rupiah)			
		2012	2013	2014	2015
1	Industry	1,309.15	1,392.54	1,472.99	1,541.52
2	Electricity and gas	18.78	19.32	20.14	19.37
3	Water	3.74	3.88	4.02	4.19
4	Commerce	740.68	781.51	817.20	851.77
5	Accommodation	195.76	207.31	222.12	237.16
6	Finance	208.90	227.06	237.52	259.89
7	Business	103.19	111.64	121.46	130.72
8	Education	157.47	167.73	180.13	193.41
9	Health	45.18	48.07	52.43	56.72
10	Other services	94.52	101.35	109.27	117.03
Total		2,877.34	3,060.42	3,237.28	3,411.77

TABLE II.
GDP and Energy Consumption Each APB

APB	GDP (Trillion Rupiah)	Energy Consumption (GWh)
DKI Jakarta & Banten	1,137.69	29,248.86
Jawa Barat	851.07	25,322.86
Jawa Tengah & DIY	540.26	10,049.01
Jawa Timur	818.02	16,912.07
Bali	64.74	2,394.16

B. VOLL Calculation for Each Area Pengaturan Beban(APB)

In Indonesia, electrical energy is distributed and regulated by Area Pengaturan Beban (APB) located in each region. Java-Bali APBs are classified into 5 APBs, namely DKI Jakarta and Banten APB, Jawa Barat APB, Jawa Tengah, and DIY APB, Jawa Timur APB, and Bali APB. The calculation begins by grouping GDP data by the province in 2015, shown in Table III.

While the energy consumption data uses data specifically for industrial and business customers for each APB is shown in Table III. GDP and energy consumption per APB are used to calculate VOLL for each APB.

TABLE III.
Energy Consumption for Industry and Business

No	Customer	Energy Consumption (GWh)			
		2012	2013	2014	2015
1	Industry	53,873.72	57,709.84	58,990.84	56,980.08
2	Business	22,444.30	24,418.77	26,689.18	26,946.88
Total		76,318.02	82,128.61	85,680.02	83,926.96

C. Reliability Index for the Planning Period

Modeling of generating units to evaluate the plant's reliability index is carried out by processing FOR data to obtain the value of the probability of load loss represented by COPT. The table of FOR assumptions used for COPT simulations during the planning period is shown in Table IV. The calculation begins by finding the load duration curve (LDC). LDC in time function is obtained from the 2014 daily peak load data. The highest daily peak load in the Java-Bali system occurred on October 21, 2014, with a peak load reaching 23,900 MW. Daily peak load data of 2014 is used as a basis for the projected peak load of 2015-2023, with an average peak load growth of 8.4% per year [2].

TABLE IV.
For Value Assumption for The Planning Period

Generator Type	Capacity (MW)	Forced Outage Rate (%)
Steam	1000	12
	600	12
	200	12
	100	12
	50	10
	25	10
Geothermal	0 - 110	5
Hydro	All size	1
Gas	25 – 200	7
Gas engine	All size	7
Combine cycle	0 – 750	10

COPT results from simulation using MATLAB are cumulative and individual probabilities at certain capacity values. These two probabilities are used to calculate LOLE, LOLP, and EENS indices in the 2016-2023 planning period. COPT simulation also uses additional generating capacity planning data in 2015-2023.

IV. RESULT AND DISCUSSION

A. VOLL Calculation for 2012-2015

The results of the VOLL calculation using (7) is obtained in Table V. The results show VOLL in Java-Bali 2012-2013 decreased 1.16%, 2013-2014 increased1.39%, and 2014-2015 it increased again 7.59%.

Thus, from 2012 to 2013, the efficiency of electricity use and productivity of the industrial and business sectors is lower than in the period of 2013 to 2014 and 2014 to 2015. VOLL can also be used to see how important the electrical energy supply of an industrial country, represented as the average cost that must be paid by the customer for each outage [3]. The greater the VOLL, the total outage cost will be even greater during the outage because VOLL is proportional to the energy not supplied. So that, in 2013-2015 will have high total outage costs if energy not supplied is also large.

TABLE V.
VOLL Calculation Results For 2012-2015

Year	GDP (Billion Rupiah)	Energy Consumption (GWh)	VOLL (Rp/kWh)
2012	2,877,342.45	76,318.02	37,702.01
2013	3,060,422.84	82,128.61	37,263.78
2014	3,237,281.78	85,680.02	37,783.39
2015	3,411,769.84	83,926.96	40,651.66

B. VOLL Analysis of each APB

VOLL calculation results for each APB using (7) produce data such as Table VI. Bali is in the lowest position because the Bali APB is the only APB with higher electricity consumption for business customers than for industrial customers, as shown in Figure 2. Besides, Jawa Tengah and Yogyakarta APB have the largest VOLL in Java island because none of the nine largest electricity consumer companies in Indonesia as shown in Figure 3. High VOLL indicates high industrial and business productivity and efficiency, so outages must be avoided so that total outage costs can be prevented.

TABLE VI
VOLL Calculation Results for Each APB in 2015

APB	DKI & Banten	Jawa Barat	Jawa Tengah & DIY	Jawa Timur	Bali
VOLL (Rp/kWh)	38,896.9	33,608.7	53,762.2	48,368.8	27,039.8

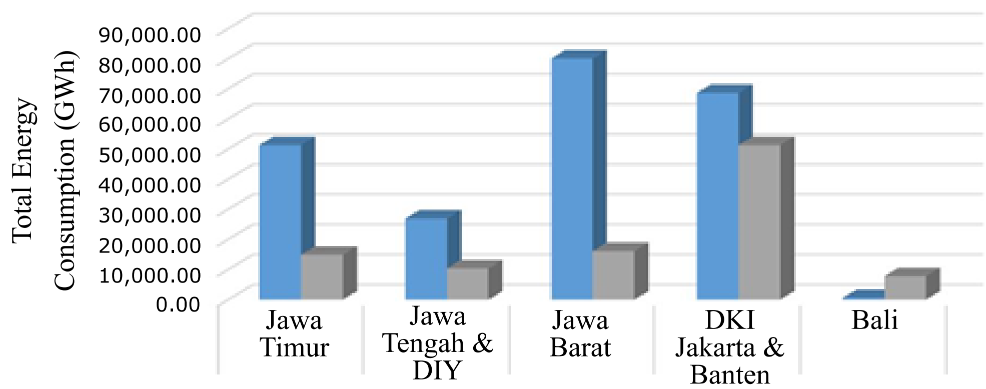

FIGURE. 2.
Comparison of total energy consumption for each APB in 2012-2015

FIGURE 3.
Distribution map of the nine largest energy consumption companies

C. Java-Bali VOLL Projection for 2016-2023

VOLL projection is obtained by making GDP projection using Minitab 17 software and projection of energy consumption using LEAP software. GDP projection begins with determining the periodic series method to be used. GDP is categorized as long-term secular value increases (trend patterns), then the periodic series method used for forecasting is the trend analysis method. Then the forecasting model is determined by calculating forecasting error parameters, namely MAPE, MAD, and MSD. Simulation results show that the smallest value is in the quadratic model, as shown in Table VII. So that the best GDP forecasting model used is a quadratic trend model. Minitab 17 simulation results GDP projection is formulated by 2,690,929 + 188,755t - 2,148t^2. The quadratic trend formula obtained projection of GDP on Table VIII with trillions of rupiah and the results of Minitab 17 shown in Figure 4.

TABLE VII.
Calculation Result of MAPE, MAD, and MSD

Parameter	Linear	Quadratic	Exponential	S Curve
MAPE	0	0	0	0
MAD	2,148	385	7,204	1,285
MSD	4,799,595	185,336	52,170,858	6,606,642

TABLE VIII.
GDP Projection Results for 2016-2023

Year	GDP	Forecast	Fit	Growth
2012	2.877,34	-	2.877,54	-
2013	3.060,42	-	3.059,85	182,31
2014	3.237,28	-	3.237,86	178,01
2015	3.411,77	3.407,92	3.411,58	173,72
2016	-	3.572,34	-	160,57
2017	-	3.730,53	-	158,20
2018	-	3.882,50	-	151,97
2019	-	4.028,26	-	145,75
2020	-	4.167,79	-	139,53
2021	-	4.301,09	-	133,31
2022	-	4.428,18	-	127,09
2023	-	4.549,05	-	120,87

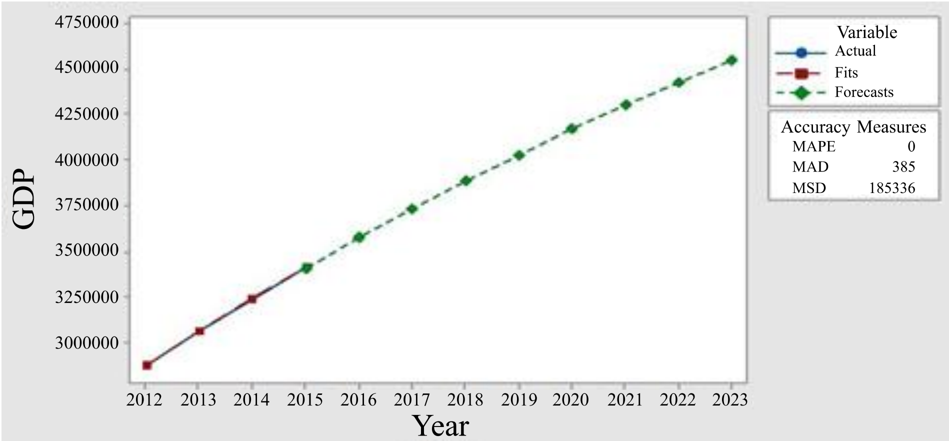

FIGURE. 4.
GDP projection with a quadratic trend model

Then the energy consumption projection requires data on energy consumption and the number of customers from each sector. The calculation is carried out using all sectors and bases for a minimum of 5 years (2010-2015) for the projected year (2016-2025), even though the results used are only the industrial and business sectors for 2016-2023. Other LEAP software input parameters are the percentage of energy intensity and customer growth obtained from calculations using (5) and (6). The overall percentage of growth in both energy intensity and customers is shown in Table IX. The energy consumption projection is obtained in the Final Demand Analysis section of the LEAP software with the output shown in Figure 5.

TABLE IX.
Growth of Energy Intensity and Costumer

EI (%)	House hold	Industry	Busi ness	Social	Govern ment	Public light
	0,40	-0,47	-0,76	2,83	5,00	-3,57
Costu mer (%)	House hold	Industry	Busi ness	Social	Govern ment	Public light
	6,63	5,24	8,03	6,37	8,55	10,30

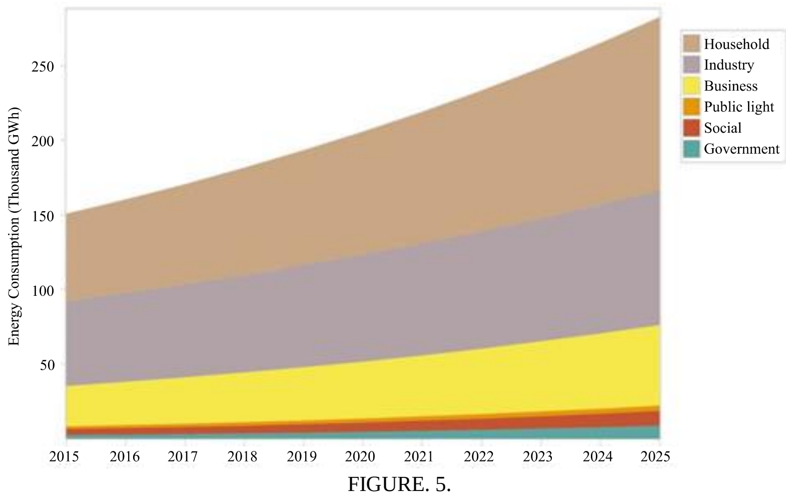

FIGURE. 5.
Energy consumption projection using LEAP

Then from the results of the energy consumption projections, the data is reclassified for the industrial and business sectors in the 2016-2023 projection year, as shown in Table X.

TABLE X.
Energy Consumption Projection for 2016-2023

Sector	Energy Consumption (TWh)							
	2016	2017	2018	2019	2020	2021	2022	2023
Industry	59.7	62.5	65.5	68.6	71.8	75.3	78.8	82.6
Business	28.9	31	33.2	35.6	38.2	40.9	43.9	47

Both projection results of GDP and electricity consumption are used for the VOLL projection for the period of 2016-2023. VOLL calculation uses (7) so that the result value is shown in Table XI.

TABLE XI.
VOLL Projection Results for 2016-2023

Year	GDP (Billion Rupiah)	%	Energy Consumpti on (TWh)	%	Forecasting VOLL (Rp/kWh)
2016	3,572,335	-	88.60	-	40,319.81
2017	3,730,530	4.4%	93.50	5.5%	39,898.72
2018	3,882,503	4.1%	98.70	5.6%	39,336.40
2019	4,028,255	3.8%	104.20	5.6%	38,658.88
2020	4,167,785	3.5%	110.00	5.6%	37,888.95
2021	4,301,094	3.2%	116.20	5.6%	37,014.58
2022	4,428,181	2.9%	122.70	5.6%	36,089.49
2023	4,549,047	2.7%	129.60	5.6%	35,100.67

In Table XI, the VOLL projection has a decreasing trend, indicating the efficiency and productivity of industrial and business customers are expected to decrease. This condition occurs because industrial and business sector customers produce less GDP but have high electricity usage. Therefore, the development of industries and businesses with high GDP and efficient energy consumption needs to be implemented.

However, suggestions for increasing efficiency and productivity will also increase outage costs for every 1 kWh loss (Rp / kWh). So , this suggestion can be made with consideration of the proper planning of additional generating capacity. A good plan can be seen from the evaluation results of the LOLP index are less than 0.274% or equivalent to the LOLE index that is less than one day/year.

D. Evaluation of Reliability Index in the Planning Period

The reliability index calculation in the planning period is assumed to have two state operating characteristics, with the scope of the calculation only limited to HL1. The calculation results of the Java-Bali region's reliability index without considering the uncertainty of forecasting load in 2015 obtained a LOLE of 7.19×10^{-9} days/year and a LOLP of 5.79×10^{-9}%. In contrast, the LOLE and LOLP reliability index values of the Java-Bali region without considering the uncertainty of load forecasting for the 2016-2023 planning period are shown in Table XII.

TABLE XII.
Reliability Indices Without LFU for 2016-2023

Year	LOLP (%)	LOLE (day/year)	EENS (MWh)
2016	3.77×10^{-07}	1.38×10^{-06}	4.86×10^{-03}
2017	2.48×10^{-05}	9.07×10^{-05}	3.01×10^{-01}
2018	7.39×10^{-09}	2.70×10^{-08}	1.20×10^{-04}
2019	4.01×10^{-15}	1.46×10^{-14}	1.28×10^{-10}
2020	2.96×10^{-13}	1.08×10^{-12}	1.72×10^{-08}
2021	8.80×10^{-11}	3.21×10^{-10}	4.69×10^{-06}
2022	8.89×10^{-08}	3.24×10^{-07}	4.37×10^{-03}
2023	2.43×10^{-05}	8.87×10^{-05}	$1.11 \times 10^{+00}$

The calculation results of the LOLP and LOLE reliability indices already fulfill the reliability criteria standards of PT PLN Persero, where the LOLE index is smaller than one day/year, and the LOLE index is smaller than 0.274% [2]. Because the LOLE and LOLP indices have fulfilled PLN criteria standards, the additional generator capacity planning data obtained from the RUPTL can be used to find the smallest EENS reliability index on the HL1 (generator side). The EENS calculation in 2015 obtained a value of 2.73 $\times 10^{-5}$ MWh / year, while the EENS calculation for the 2016-2023 planning period is shown in Table XIII.

TABLE XIII.
Reliability Indices with LFU for 2016-2023

Year	LOLP (%)	LOLE (day/year)	EENS (MWh)
2016	8.14×10^{-05}	2.97×10^{-04}	3.02×10^{-01}
2017	2.14×10^{-03}	7.81×10^{-03}	$7.25\times10^{+00}$
2018	1.83×10^{-06}	6.69×10^{-06}	8.89×10^{-03}
2019	1.27×10^{-12}	4.64×10^{-12}	1.31×10^{-08}
2020	4.94×10^{-09}	1.80×10^{-08}	3.58×10^{-05}
2021	9.83×10^{-09}	3.59×10^{-08}	8.22×10^{-05}
2022	4.03×10^{-06}	1.47×10^{-05}	2.94×10^{-02}
2023	5.22×10^{-04}	1.91×10^{-03}	$3.36\times10^{+00}$

E. Evaluation of Reliability Index in the Planning Period by considering Load Forecasting Uncertainty (LFU)

The reliability index with considering the uncertainty of the load is calculated by modeling it in a normal distribution with seven classes of intervals. A normal distribution curve represents uncertainty with a mean of 0 and a standard deviation σ. The standard deviation is obtained from the projected and realization percentage, which is 2.8%. The standard deviation calculation based on uncertainty is presented as follows.

$$\sigma = \frac{\%\, uncertainty \times forecast\ load}{100} = \frac{2.8\,\% \times 24258}{100} = 692.86\ MW$$

The results of 692.86 MW range the difference between one interval with another, so it produces a new daily peak load. The new daily peak load is used to obtain the new LOLE index. The LOLE results by considering the uncertainty of the load have a value greater than the LOLE index without considering the uncertainty of the load because when using LFU, there is a higher load estimate. Because the LOLE and LOLP indices also fulfill PT. PLN criteria standards, the EENS reliability index on the HL1 (generator side), by considering the uncertainty of the load can be used. The results of LOLE, LOLP, and EENS indices with LFU in 2016-2023 calculated in the same way are shown in . The fluctuation in LOLE, LOLP, and EENS results is affected by the size of the reserve margin for each year shown in Table XIV.

TABLE XIV.
Reserve Margin (RM) for 2016-2023

Year	2016	2017	2018	2019	2020	2021	2022	2023
RM (%)	21.2	18.8	25.5	40.6	37.9	34.4	29.7	24.8

F. Projection of Total Outage Costs

The projection of total outage costs is the result of the multiplication of the VOLL projection with EENS HL 1, which was done earlier. The calculation results show fluctuations with high differences due to the EENS HL 1 highly affected by reserve margins, and it is expected that energy will not be supplied due to the outage on the generator side is small. Whereas if compared with the calculation of total outage costs with EENS up to HL II, which is a combination of the generation system and the transmission system in 2016-2018 [12] and 2019-2022 [13], the results are also shown on Table XV. These results indicate that the total outage costs due to outage in HL 2 (generator and transmission) are greater than in HL 1 (generator). The majority of these outages come from transmission lines.

TABLE XV.
Comparison of Total Outage Costs in HL 1 and HL 2

Year	VOLL (Rp/kWh)	EENS (MWh)		Outage Cost (Rupiah)	
		HL 1	HL 2	HL 1	HL 2
2016	40,319.81	3.02×10^{-01}	17,171.62	$1.22\times10^{+07}$	$6.92\times10^{+11}$
2017	39,898.72	$7.25\times10^{+00}$	13,432.09	$2.89\times10^{+08}$	$5.36\times10^{+11}$
2018	39,336.40	8.89×10^{-03}	11,637.70	$3.50\times10^{+05}$	$4.58\times10^{+11}$
2019	38,658.88	1.31×10^{-08}	5,771.39	5.08×10^{-01}	$2.23\times10^{+11}$
2020	37,888.95	3.58×10^{-05}	5,418.39	$1.35\times10^{+03}$	$2.05\times10^{+11}$
2021	37,014.58	8.22×10^{-05}	6,782.25	$3.04\times10^{+03}$	$2.51\times10^{+11}$
2022	36,089.49	2.94×10^{-02}	8,774.71	$1.06\times10^{+06}$	$3.17\times10^{+11}$
2023	35,100.67	$3.36\times10^{+00}$	-	$1.18\times10^{+08}$	-

V. Conclusion

Based on this study's results, it can be seen that the value of VOLL and outage cost is related to the productivity and effectiveness of the industry. The highest VOLL value from 2012-2015 occurred in 2015 amounted to 40,651.66 Rp / kWh. The APB with the highest VOLL in the Java-Bali region is the Central Java & DIY APB of 53,762.2 Rp / kWh because the majority of the industry produces GDP with efficient energy consumption (high productivity). If there is an outage with the same EENS in all APBs, Central Java & DIY will suffer the greatest loss. The highest VOLL projection results in 2016 amounted to 40,319.81 Rp / kWh and decreased to 35,100.67 Rp / kWh in 2023, so a reliable capacity addition plan is needed, so that the EENS is small. The largest reliability index value without using LFU was in 2023, obtained LOLE 8.87×10^{-5} days/year, LOLP 2.43×10^{-5}%, and EENS 1.11 MWh / year. The largest reliability index value using the LFU was in 2017, obtained LOLE 7.81×10^{-3} days/year, LOLP 2.14×10^{-3}%, and EENS 7.25 MWh / year. The highest total outage cost in HL I in the 2016-2023 planning period occurred in 2017, amounting to 289 million rupiahs. The lowest reserve margin value of 18.8% is the main reason. The total outage costs in HL II is greater than in HL I because the majority of outage occurs in transmissions.

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