Loss of Load Probability Calculation for West Java Power System with Nuclear Power Plant Scenario

I D Azizah¹, A G Abdullah*, W Purnama¹, A B D Nandiyanto² and M A Shafii³

¹Departemen Pendidikan Teknik Elektro, Fakultas Pendidikan Teknologi dan Kejuruan, Universitas Pendidikan Indonesia.

²Departemen Pendidikan Kimia, Fakultas Pendidikan Matematika dan Ilmu Pengetahuan Alam, Universitas Pendidikan Indonesia.

³Department of Physics, Andalas University, Padang, West Sumatera, Indonesia

*ade_gaffar@upi.edu

Abstract. Loss of Load Probability (LOLP) index showing the quality and performance of an electrical system. LOLP value is affected by load growth, the load duration curve, forced outage rate of the plant, number and capacity of generating units. This reliability index calculation begins with load forecasting to 2018 using multiple regression method. Scenario 1 with compositions of conventional plants produce the largest LOLP in 2017 amounted to 71.609 days / year. While the best reliability index generated in scenario 2 with the NPP amounted to 6.941 days / year in 2015. Improved reliability of systems using nuclear power more efficiently when compared to conventional plants because it also has advantages such as emission-free, inexpensive fuel costs, as well as high level of plant availability.

1. Introduction
The reliability of the system is important process of operating a power generation unit. Failure is often the case can cause blackouts in power systems and generator concerned will suffer financial losses [1]. Therefore, the reliability of the system at the power plant has always been a major concern in the planning of the electrical system [2]. Research on the reliability of the system has often done in the last decade [3]. Loss of Load Probability (LOLP) method is method that often used in the industry to evaluate the reliability of a power plant to meet the load demand when the system is not able to supply the existing load [4]. LOLP value is affected by load growth, the daily load curve, forced outage rate (FOR) plant, number and capacity of generating units [5].

In general, nuclear power plants is a plant that have high capacity, but in the level of security to be tightened because it is sensitive to outside interference [6]. The capacity factor of any nuclear power plant generator unit approximately 90%, which is higher than the value of other plants [7]. In the industrial world, NPP serves as a sample of technological development, because of advantages such as very low emissions, high efficiency level, and effective in providing sustained power [8]. Nuclear power plants are very stable due to start mining uranium to fuel in the form of distributed processing by countries with stable political conditions. To fuel it takes very little for a very long period, which only requires 130 tons of uranium to 1 GW by the boiling water reactor for 4 years where other plants with fossil fuels requires one metric ton a year operation [9].
2. Load Forecasting

One thing to consider in the security management system is the load forecasting power because it is very important to all parts of the electrical systems such as generation, transmission, distribution, and marketing of energy [10]. Load forecasting is necessary to fix the schedule, planning and operation of power system [11]. On the other hand, when the economic growth continues, the power industry is gradually entering the world of business. So that the accuracy and reliability of load forecasting increasingly needed [12]. The level of accuracy of load forecasting has a significant effect on the operation of power systems and power production costs [13]. So if the results exceed the estimate of the needs of the operating costs will increase [14]. Load forecasting is divided into short-term (from 1 hour to 1 week), mid-term (1 week to 1 year) and long term forecasting (1 year up to one decade) [10].

Load and peak energy has a non-linear equation and relate on many variables, either by natural factors and economic. In the case of a variable nature, usually caused by several factors such as climate, temperature, and more. While the economic variables such as the amount of energy consumed, the number of population, gross domestic product (GDP), gross national product (GNP), and oil prices per unit are also often considered. To natural factors in the short-term load forecasting, oil and electricity prices are usually taken into account. While the long-term forecasting of economic factors, GDP and GNP is more influential than the natural factors [15].

Load forecasting method used is multiple regression method. Multiple regression analysis was used to measure the effect of more than one dependent variable, multiple regression equations of general formula obtained by forming the Sum of Square Error equation (SSE) [16].

\[ \text{SEE} = \sum_{i=1}^{n} e_i^2 = \sum_{i=1}^{n} (y_i - b_0 - b_1x_{1i} - b_2x_{2i})^2 \] (2.1)

Then equation 1 will differentiation to find the regression coefficient \( b_1 \), \( b_2 \), and \( b_0 \) as follows:

\[ \sum_{i=1}^{n} y_i = nb_0 + b_1 \sum_{i=1}^{n} x_{1i} + b_2 \sum_{i=1}^{n} x_{2i} \] (2.2)

\[ \sum_{i=1}^{n} x_{i}y_i = b_0 \sum_{i=1}^{n} x_{1i} + b_1 \sum_{i=1}^{n} x_{1i}^2 + b_2 \sum_{i=1}^{n} x_{1i}x_{2i} \] (2.3)

\[ \sum_{i=1}^{n} x_{2i}y_i = b_0 \sum_{i=1}^{n} x_{2i} + b_1 \sum_{i=1}^{n} x_{1i}x_{2i} + b_2 \sum_{i=1}^{n} x_{2i}^2 \] (2.4)

The results of the calculation of the equation (2.2), (2.3) and (2.4) are inserted into the following general equation regression:

\[ Y_R = b_0 + b_1x_{1i} + b_2x_{2i} \] (2.5)

With

\( Y_R \) = Dependent variable

\( b_0 \) = Constants

\( b_1, b_2 \) = Regression coefficients

\( x_{1i}, x_{2i} \) = variables

3. Loss of Load Probability

In the industrial world power, Loss of Load Probability method has been accepted as a method to evaluate the reliability of a system [4]. Method Loss of Load Probability (LOLP) is a method used to determine the reliability of a system by considering the system load exceeds the generating capacity available so that the system is not served [17]. During a state of lack of capacity (power loss), the demand cannot be met because of the forced outage [18].

LOLP equation can be presented in equation (3.1) [19]:

\[ \text{LOLP} = \sum \frac{P_{f,i}}{100} \] (3.1)
where:

\[ P_j = \text{The probability of occurrence of a load equal to or greater than the available power.} \]

\[ t_j = \text{The time when the load is not served} \]

Reliability criteria used is the index Loss of Load Probability (LOLP) is smaller than 0.274%. This means the possibility / probability of occurrence of peak loads exceed available generation capacity is smaller than 0.274% (LOLP 0.274% is equivalent to one day of the year probability of peak load cannot be met by existing capacity power systems) [20].

Calculating index LOLP of power system starting from search force outage rate (FOR) value [18]. At each power plant unit, will face the problem of aging on existing components. This aging will increase the probability of outage system with certain times that will increase the value of forced outage rate (FOR). As a result the available capacity of the power system at given time is difficult to predict and affect a reliability system. [21].

The equation used to find the value in the FOR seen from equation (3.2) [22]:

\[ FOR = \frac{FOH}{SH + FOH} \] (3.2)

Where:

\[ FOH = \text{Forced Outage Hours} \]
\[ SH = \text{Service Hours} \]

Forced outage rate calculated for varying periods of time, ranging from 1 day, 1 month or 1 year (365 days). FOR is equal to unavailability [19].

4. Methods

LOLP calculations performed using the help of Microsoft Excel. The calculation is repeated until the condition of the load demand in 2018. However, every year there is a change amount of power available from existing plants in accordance with the plan to increase the number and generating capacity by PLN. Plants are built, has a different FOR. For planning purposes, FOR used can be seen from Table 1 [23]:

| No | Type of Plants          | Unit Size  | FOR (%) |
|----|-------------------------|------------|---------|
| 1  | hydro power             | All        | 1       |
| 2  | gas power plants        | All        | 7       |
| 3  | geothermal power plants | All        | 5       |
| 4  | Steam power plant fuel oil | 25-100 MW | 8.5     |
|    |                         | >100 MW    | 9       |
| 5  | steam power plant coal  | 400 MW     | 10      |
| 6  | diesel power plants     | All        | 5       |
| 7  | Combined Cycle          | All        | 9       |

The economic growth of West Java province stated in Gross Regional Domestic Product (GDP) over the last 6 years that have increased average increase of 12.14 per year with details of every year as shown in Table 2.
Table 2. Economic Growth in West Java (Billion Rupiah)

| Year | GRDP(billion Rp) | growth GDRP (%) |
|------|-----------------|-----------------|
| 2009 | 784.678,84      |                 |
| 2010 | 906.685,75      | 15,54864281     |
| 2011 | 1.013.824,50    | 11,81652519     |
| 2012 | 1.120.038,32    | 10,47654895     |
| 2013 | 1.244.460,82    | 11,10877171     |
| 2014 | 1.390.828,74    | 11,7615531      |

The increase in economic growth was also followed by a growth in the number of electricity customers and power consumption from 2009-2014 year in a row as shown in Table 3 and Table 4.

Table 3. Electricity Costumer Growth (Individual)

| Costumer            | 2009          | 2010          | 2011          | 2012          | 2013          | 2014          |
|---------------------|---------------|---------------|---------------|---------------|---------------|---------------|
| household           | 7.227.573     | 7.740.066     | 8.204.884     | 8.935.978     | 9.698.695     | 10.354.332    |
| industry            | 10.636        | 11.201        | 10.778        | 11.404        | 12.039        | 12.584        |
| business            | 299.853       | 266.358       | 290.079       | 310.838       | 328.638       | 341.152       |
| social              | 158.784       | 176.771       | 189.274       | 203.449       | 216.443       | 229.740       |
| Government offices  | 9.836         | 10.362        | 10.776        | 11.404        | 12.039        | 12.584        |
| Street lighting     | 25.116        | 29.824        | 33.276        | 38.636        | 44.508        | 49.586        |
| Total               | 7.731.798     | 8.206.806     | 8.699.814     | 9.471.789     | 10.276.128    | 10.969.431    |
| growth (%)          | 19            | 19.34         | 18.96         | 19.02         | 19.03         | 19.08         |

Table 4. Growth Use Electricity

| Year | Use Electricity |
|------|-----------------|
| 2009 | 28.379,47       |
| 2010 | 30.720,99       |
| 2011 | 34.053,60       |
| 2012 | 36.653,31       |
| 2013 | 38.881,66       |
| 2014 | 42.885,92       |

In the use of multiple regression approach, looking for value $b_0$, $b_1$ and $b_2$ can be done by inputting the data in Table II to Table IV Those variables will be incorporated into the YR equation so that the growth of electricity consumption West Java undetermined until 2018. Later in the composition plants used in the calculation LOLP, FOR value will be added to any conditions established a number of $2^n$ where $n$ is the number of plants so that the cumulative probabilities can be calculated.

At the time of the calculation, the results of load forecasting to be changed in the form Load Duration Curve. In making the curve, the available power of each state combined with a curve that will be visible intersection. The results of the intersection will be determined value of $t$, where $t$ is the time interval system cannot meet demand.
5. Findings and Discussion

Table 5. The Calculation of Multiple Regression Results Forecasting Growth in West Java of Electricity Use

| Year | X1     | X2     | Yr    | Growth |
|------|--------|--------|-------|--------|
| 2015 | 1559708,845 | 13066420,56 | 46728,80789 | 8,960721585 |
| 2016 | 1749095,062 | 15564284,62 | 51259,95413 | 9,696687007 |
| 2017 | 1961477,327 | 18539657,03 | 56340,73811 | 9,911799686 |
| 2018 | 2199647,913 | 22083821,47 | 62037,79344 | 10,11178682 |

The percentage of average growth amounted to 10.276%, is assumed to get the average growth rate from 2015 to 2018 years the daily load of the power system of West Java in order to get the daily load pattern as in figure 1.

![Figure 1. Curve Average Daily Expenses West Java Year 2015-2018](image)

The results will form the pattern of load forecasting in accordance with the data taken as a sample, ie per-30 minutes for 24 hours with the data used is the load on 1 January 2014. Sampling data on that date because it considers the often rising power demand during public holidays so minimize the lack of power when the load exceeds the available capacity. In the sample data, the smallest load occurred at 13:00 pm with the power of 2407.95 MW and the largest load occurs at 19:30 with a power of 3357.26 MW. Through the resulting pattern, load forecasts to 2018 obtained the largest peak load value of 4964.93 MW.

![Figure 2. Load Duration Curve West Java 2015-2018](image)
In the sample used, the peak load that occurs is equal to 3357.260 MW, bringing the total power generating composition which is used to calculate the index LOLP must exceed the existing peak load. In this study, plants used include most types of plants, so it will be visible the impact of the use of each plant on the reliability of a system. For 2014, the composition of the plant which is used as shown in Table 6.

Table 6. Composition of Electricity Generating System in West Java 2014

| Power Plant | Type                  | power (MW) | FOR  |
|-------------|-----------------------|------------|------|
| Cirata      | hydropower            | 1008       | 0.015|
| Pelabuhan Ratu | Steam power plants  | 1050       | 0.1927|
| Saguling    | hydropower            | 701        | 0.057|
| Muara Tawar | gas power plants      | 1138       | 0.0192|
| Muara Tawar | Combined Cycle        | 874        | 0.081|
| Drajat      | geothermal power plants| 180       | 0.066|

With a total power of 4951 MW, is basically the power supply that is able to meet peak demand in 2014. However, due to the load continues to grow every year, then the composition of the plant in 2015-2018 added some plants in accordance with Table 7.

Table 7. Existing Power Plant 2015-2018

| Year | Power Plant | Type                  | power (MW) | FOR  |
|------|-------------|-----------------------|------------|------|
| 2015 | Kamojang    | geothermal power plants| 90         | 0.0013|
| 2016 | Peaker Jawa-Bali 4 | Combined Cycle | 300      | 0.09 |
| 2017 | Peaker Jawa-Bali 1 | Combined Cycle | 400      | 0.09 |
| 2018 | Jawa 1      | Combined Cycle        | 1600       | 0.09 |

In accordance with the purpose of the study, the nuclear plant is entered into the system each year, has the power and FOR accordance with Table 8.

Table 8. Description of nuclear power plant on Scenario 2

| Year | Power Plant         | Type    | power (MW) | FOR  |
|------|---------------------|---------|------------|------|
| 2014-2018 | Nuclear Power Plant | BWR     | 1537       | 0.04 |

When calculating scenario 2, the composition of the same generation as scenario 1, except plants port power plant with 1050 MW queen is replaced by the NPP due to differences in power plants installed between the two power generators are small and have a very large value FOR.

After all the data is entered as described above, then execute him, finally obtained value LOLP (loss of load probability) for each year, from 2014 to 2018. Table 9 will show the value LOLP (loss of load probability).

Table 9. Result of LOLP Calculation on Scenario 1

| Year | Peak Load (MW) | Capacity of the Plant (MW) | LOLP (days/year) |
|------|----------------|---------------------------|-----------------|
| 2014 | 3357,260       | 4951                      | 16,65938        |
| 2015 | 3702,260779    | 5041                      | 31,04208        |
| 2016 | 4082,714737    | 5341                      | 61,5576         |
| 2017 | 4502,265134    | 6391                      | 71,60904        |
| 2018 | 4964,929623    | 7991                      | 39,18609        |
In the first year, the index LOLP generated at 16.65938 days/year. This is a number that exceeds the provisions of PLN is less than 1 day/year. But in subsequent years, the reliability of the system decreases to figure 71.60904 days/year in 2017 and in 2018 returned improved to 39.18609 days/year. This is due to the high value of FOR in several plants with a high of 19.27% in Pelabuhan Ratu plant (power plant). But in scenario 2, the index LOLP have improved since the NPP has a value of 0.04 FOR with the results as shown in Table 10.

| Year | Peak Load (MW) | Capacity of the Plant (MW) | LOLP (days/year) |
|------|----------------|---------------------------|------------------|
| 2014 | 3357.260       | 5258                      | 10.73305         |
| 2015 | 3702.260779    | 5348                      | 6.940895         |
| 2016 | 4082.714737    | 5648                      | 14.44181         |
| 2017 | 4502.265134    | 6698                      | 15.71932         |
| 2018 | 4964.929623    | 8298                      | 8.95312          |

Reliability index in 2015 is the best reliability index of other years. This is because the existing plants for the year have amounted to 0.0013 FOR. Whereas in 2017, the index reached 15.72 LOLP days/year. This is due to the addition of capacity at Muara Tawar power plant with a total power of 650 MW by 1524 FOR 0.09. The value of this FOR the plant with great power, would lead to a worsening of the reliability system although more power is available.

If seen Figure 5, the index calculation LOLP with nuclear power plants are in the electrical system of the West Java provides positive results. This can be known with the index declining LOLP which means improved reliability. The best result was in 2015 with the index of 6.940895 in scenario 2. The composition of plant on sample data that LOLP index <1 day/year.

6. Conclusions

Based on the results of load forecasting, load demand until 2018 is met by additional generators annually by reference to PLN RUPTL 2015-2024. Based on the results of calculations in accordance with the plan to increase power plants by PLN began in 2015 until 2024, the Loss of Load Probability value obtained is still not meet the standards is below 1 day/year. This is due to the value of Forced Outage Rate of conventional plants either already in operation or are still in the planning stages for the sources cited, the value of the plant FOR relatively large. LOLP index to improve a system, try to always small value FOR especially in large plants.
After the NPP entered into the system, LOLP index experienced significant improvement. In addition to its value FOR smaller nuclear plants, conventional power plants are replaced by the NPP has a large Forced Outage Rate, is 0.1927.

References

[1] L. Weingarth, “Dynamic Positioning Power Plant System,” 2011.
[2] K. M. Rabb, M. Ahmed, P. Pea, and M. Rabbani, “Reliability Assessment of Bangladesh Power System Using Segmentation Method,” 2013.
[3] H. Jang, B. Kim, and S. Lee, “Including Combined-Cycle Power Plants in Generation System Reliability Studies,” no. September, 2011.
[4] H. T. Spears, K. L. Hicks, and T. Case, “Load for Three Areas,” no. 4, pp. 521–526, 1970.
[5] R. Firmansyah, S. Budi, and E. S. Amitayani, “Peran PLTN dalam Meningkatkan Indeks Keandalan Loss Of Load Probability (LOLP) Sistem Kelistrikan bangka,” no. September, pp. 169–179, 2015.
[6] D. Liu and H. Luo, “Study on Nuclear Power Plant Dynamic Response Characteristics and Impact of Power Quality Problems,” no. Ciced, pp. 5–6, 2012.
[7] J. S. Giraldo, D. J. Gotham, D. G. Nderitu, P. V Preckel, and D. J. Mize, “Fundamentals of Nuclear Power,” no. December, 2012.
[8] L. I. N. Yu-fan, “Simple analysis about the environment protection and design of nuclear power plant,” pp. 233–235, 2011.
[9] Y. Ichihara and S. Member, “A Perspective on Nuclear Power Generation in the Future Electric Power Industry — For Nonspecialists in the Electric Power Related Industries,” vol. 89, no. 12, pp. 1793–1807, 2001.
[10] N. Cetinkaya, “Long-term Electrical Load Forecasting based on Economic and Demographic Data for Turkey,” pp. 219–223, 2013.
[11] X. Du, J. Bai, and Q. Fan, “Study of the Medium-Long Load Forecasting Based on the Identical Dimension Addition Grey Model,” pp. 700–703, 2011.
[12] Y. Min, Z. Min, and W. Dongyue, “Research on Mid-long Term Load Forecasting based on Combination Forecasting Mode,” no. 5, 2015.
[13] A. Laouafi, M. Mordjaoui, and F. Laouafi, “An Evaluation of Conventional and Computational Intelligence Methods for Medium and Long-Term Load Forecasting in Algeria,” 2010.
[14] J. Zhu, “The Optimization Selection of Correlative Factors for Long-term power load Forecasting,” pp. 241–244, 2013.
[15] P. Atsawathawichok and P. Teekaput, “Long term Peak Load Forecasting in Thailand using Multiple Kernel Gaussian Process,” no. 1, pp. 1–4, 2014.
[16] R. L. Bunden, Numerical Analysis ninth edition. 2005.
[17] G. Gambirasio, “Computation of Loss-of-Load Probability,” no. 1, pp. 54–55, 1976.
[18] L. Wang, “the Effects of Uncertainties in Forced Outage Rates and Load Forecast on the Loss of Load Probability,” no. 6, pp. 1920–1927, 1977.
[19] H. F. Boroujeni, M. Eghtedari, and M. E. B. Abdollahi, “Calculation of generation system reliability index: Loss of Load Probability,” vol. 9, no. 4, pp. 4903–4908, 2012.
[20] PT PLN Persero, “Rencana Usaha Penyediaan Tenaga Listrik,” pp. 1–515, 2015.
[21] A. A. Oka, “Demand Not Supplied, Loss of Load Probability Reliability Indices for Industrial Costumers,” pp. 602–607, 2000.
[22] R. Billinton, L. Fellow, and J. Ge, “A Comparison of Four-State Generating Unit Reliability Models for Peaking Units,” vol. 19, no. 2, pp. 763–768, 2004.
[23] D. Marsudi, Operasi Sistem Tenaga Listrik. Yogyakarta: Graha Ilmu, 2006.