Visual Studio Application for Generation Power System Reliability Calculations

Ikrima Alfi, Rifqi Fauzan Kusmayana
Department of Electrical Engineering, Universitas Teknologi Yogyakarta, Yogyakarta, Indonesia

ARTICLE INFORMATION

Article History:

Submitted 18 December 2022
Revised 17 January 2023
Accepted 04 February 2023

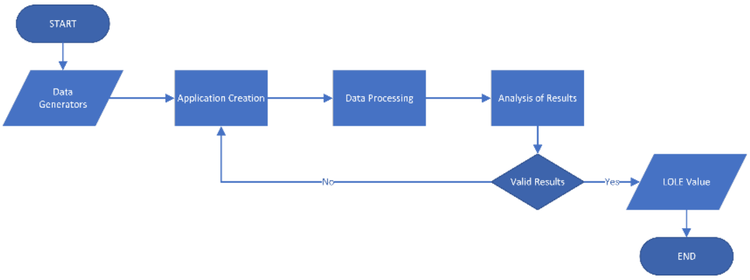
Keywords:

Reliability;
Loss of Load Expectation;
Power Generation;
Visual Studio

Corresponding Author:

Ikrima Alfi,
Department of Electrical Engineering,
Universitas Teknologi Yogyakarta,
Yogyakarta, Indonesia.
Email: ikrima.alfi@uty.ac.id

ABSTRACT



Power system reliability is affected by the reliability of its sub-systems, including generator reliability. The reliability of a power plant can be seen, among others, based on the LOLE (Loss of Load Expectation) index. Processing and calculating data using excel or matlab will take a lot of time and effort. This is unfavorable for system evaluation which is a routine activity. The contribution of this research is to create an easy data processing method with a user-friendly display using Java programming-based Visual Studio. The research data uses generator operating data in 2018 and 2019 Hydroelectric Power Plant Ir. H. Djuanda. Calculations using visual studio have been validated with calculations using Excel. LOLE calculation results in 2018 was 0.17356748092842464 days/year and for 2019 it produced a LOLE of 0.006204969593183424 days/year. The results obtained did not exceed the PLN standard, namely 1 days/year, in other words, in 2018 and 2019 Hydroelectric Power Plant Ir. H. Djuanda has a good level of reliability.

Document Citation:

I. Alfi and R. F. Kusmayana, “Visual Studio Application for Generation Power System Reliability Calculations,” *Buletin Ilmiah Sarjana Teknik Elektro*, vol. 5, no. 1, pp. 56-66, 2023, DOI: 10.12928/biste.v5i1.7076.

1. INTRODUCTION

Stages in the operation management of the electric power system are operational planning, implementation and control of operations as well as analysis of operations. Operational planning of the electric power system is a matter of how the electric power system will be operated for a certain period of time, while the analysis of operations is an analysis of the results of operations to provide feedback for planning operations as well as for the implementation and control of operations [1].

System reliability calculations are required in the planning process and the operation process. During planning, reliability calculations are needed to determine system design criteria or requirements and identify areas or weak points that require modification or reinforcement [2]. During system operation, reliability calculations are required to monitor system performance.

The reliability of the electric power system is the level of availability and service of electric power from a system to consumers/loads. The reliability of the power system is influenced by the reliability of its subsystems, including the reliability of the power plant. The reliability of a power plant can be seen, among others, based on the index of LOLP (Loss of Load Probability) [3]-[9], LOLE (Loss of Load Expectation) [5], [6], [9]-[13], EENS (Expected Energy Not Served) [3], [11], [14]-[19], Equivalen Availability Factor (EAF) [20], Net Capacity Factor (NCF) [3], [20], Generating Availability Data System (GADS) [21], Failure Mode Effect Analysis (FMEA) [22], [23], Method of Bayesian Network [24], Monte Carlo Simulation [25], [26]. Some researchers use heuristic methods in analyzing generator reliability, including using a genetic algorithm [27].

In calculating the reliability index, some researchers use Matlab software [4], [6], [10], [11], [13], [15], [18], and excel [4], [15], [25], [26]. Data processing using excel or matlab will require a lot of time and energy. This is especially unfavorable for system evaluation, which is a routine activity.

Visual Studio is a graph-based software. The use of graph-based software makes it easier for users to calculate reliability indices. This research will create a Loss of Load Expectation (LOLE) calculation program using Visual Studio 2019. The contribution of this research is to create an easy way of processing data with a user-friendly display using visual studio based on java programming. The data of this research is the generator operation data of Ir. Juanda Hydroelectric Power Plant in 2018 and 2019.

1.1. Electrical Power System Reliability

Power outages that are too frequent with long outages are a reflection of the poor reliability of the electric power system. Reliability can be interpreted as the level of availability and service of electric power from an electric power system. The level of reliability can be seen from several things, namely:

a. How often does the system experience outages or interruptions.
b. How long the outage or interruption lasted.
c. How fast is the time needed to recover from the blackout or disturbance that has occurred.

The reliability of system operation does not only depend on the power reserve available in the system but also on the size of the FOR (Forced Outage Rate) of the operating generating u nits. FOR is a measure of whether a generator is frequently disturbed, a generator can be said to have good reliability if the generator is able to provide electricity at any time or does not often go out, while a generator can be said to have poor reliability if the level of energy availability is low or the generator is often not operating. To get the FOR value stated in Equation (1).

$$FOR = \frac{Disruption\ hours}{Operating\ hours + Disruption\ hours} \tag{1}$$

1.2. Availability

Availability can be defined as the characteristic of an equipment which is expressed by the probability that the equipment will operate according to its function under stated conditions in a certain moment of time. Availability is the complement of unavailability. The probability of a unit failure is the forced outage rate (FOR) or the unavailability of the unit. The probability of a unit's success is the unit's availability stated in Equation (2) [28].

$$Availability = 1 - FOR \tag{2}$$

1.3. Loss of Load Probability (LOLP)

Loss of Load Probability (LOLP) expresses the value of the possibility of a loss of load because the available power capacity is equal to or less than the system load. The loss of one generating unit results in the expected risk of loss of power supply E(t), which is defined in Equation (3) [28].

$$E_i(t) = p_i t_i \tag{3}$$

With,
p_i is the probability of capacity loss, and t_i is the duration of loss of capacity in percent.
The system-wide load loss probability is defined as the sum of all expectations for all units.

$$LOLP = \sum_{i=1}^{n} p_i t_i \quad (4)$$

1.4. Loss of Load Expectation (LOLE)

Expected loss of load indicates the possibility that the plant is not able to cover the required power consumption. The term LOLE is closely related to the term LOLP. The time interval used for LOLP is in percentage values, while the time interval used for LOLE is in days [28]-[30]. The possibility of losing this load is a risk faced in operating a power system and needs to be formulated, to formulate this it requires a load duration curve that describes the length of time each load value lasts as shown in Figure 1.

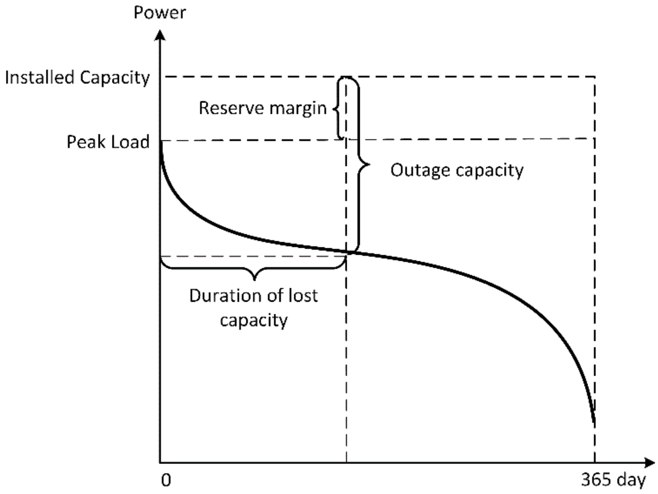


Figure 1. Load duration curve [28]

LOLE can be expressed as in the Equation (5) [1].

$$LOLE = \sum_{t=1}^{t=365} P \times t \quad (5)$$

Where,
P is the cumulative probability of system capacity < load, and t is time ranging from 1 to 365 days (one year).

The reliability standard used by PLN is Loss of Load Probability (LOLP) smaller than 0.274% or equivalent to the probability of outage 1 day a year [31].

2. METHODS

The research was conducted in several stages as shown in Figure 2.

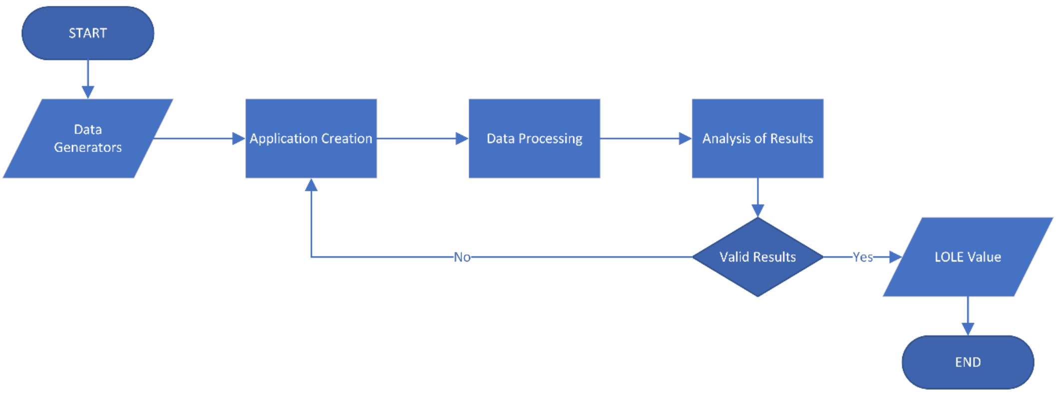


Figure 2. Flowchart of research stage

- Data Generators
  The generator data needed is data on the number of interruptions, the length of interruptions, the amount of maintenance and the length of maintenance of each generator unit and the length of time the generator unit is standby or ready to be operated per year. The data that will be used for this research is taken from Perum Jasa Tirta II, which includes disturbance data on generator units 1 to 6 for the last 2 years, namely 2018 and 2019.
- Application Creation
  The create applications using visual studio with java-based programs. In the application there are several results that will be determined including the length of time the generating unit operates, FOR, availability, individual probability, cumulative probability, load loss time expressed in days/year and also LOLE.
- Data Processing
  Data processing is done after the application is completed.
- Analysis of Results
  The results of data processing from Visual Studio will be analyzed by comparing the results of the LOLE calculation using Excel software. If the error is within the desired tolerance limit, then the program made is valid and the LOLE value obtained is the desired output value.

3. RESULTS AND DISCUSSION

3.1. Generator Operation Data in 2018

Details regarding data on the number of disturbances, duration of disturbances, number of maintenance and duration of maintenance of each generator unit in 2018 at the Ir. H. Djuanda Hydroelectric Power Plant are shown in Table 1.

Table 1. Generator operation data in 2018

Generator Units	Amount of Interruption	Interruption Duration (hour)	Amount of Maintenance	Maintenance Duration (hour)
Unit 1	6	2.44	8	62.33
Unit 2	30	11.36	22	162.18
Unit 3	25	10.77	17	410.48
Unit 4	25	9.66	13	1,572.53
Unit 5	10	3.56	14	296.27
Unit 6	25	10.74	17	987.4
Total	**121**	**48.53**	**91**	**3,491.19**

3.2. Generator Operation Data in 2019

Details regarding data on the number of disturbances, duration of disturbances, number of maintenance and duration of maintenance of each generator unit in 2019 at the Ir. H. Djuanda Hydroelectric Power Plant are shown in Table 2.

Table 2. Generator operation data in 2019

Generator Units	Amount of Interruption	Interruption Duration (hour)	Amount of Maintenance	Maintenance Duration (hour)
Unit 1	8	3.07	10	261.95
Unit 2	16	6.87	19	1,239.74
Unit 3	32	12.77	32	1,256.66
Unit 4	34	13.88	25	620.9
Unit 5	24	9.64	21	1,274.44
Unit 6	14	6.25	18	359.94
Total	**128**	**52.48**	**125**	**5,013.63**

3.3. Program Display in Visual Studio Applications

The making of this program uses the Visual Studio 2019 application which is based on the Java programming language, as seen in Figure 3. There are several parameters in this program including generator interruption and maintenance hours, generator operating hours, FOR, availability, individual probability, cumulative probability, t (day/year) and LOLE value as well as 3 buttons which are used to calculate, delete text and also stop the program.

To run this program, it is enough to enter data about the length of interference in the generator and also data (t) based on the load duration curve, after the two parameters are entered the next step is to press the equal button (=) then all the results of the parameters in the program layout will automatically appear and display fairly accurate results.

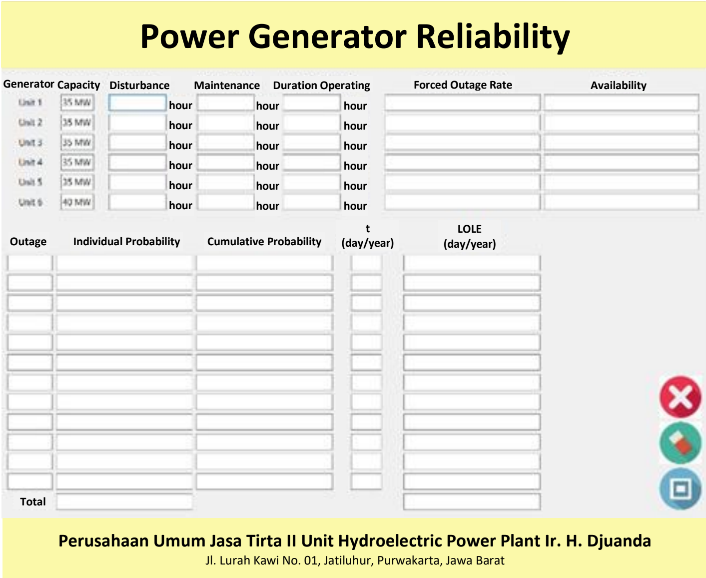


Figure 3. Layout of the program to calculate reliability

3.4. FOR (Forced Outage Rate) in 2018

The data used to find FOR is data on disturbances that occur in generators in 1 year, including how long the generator experiences interference/maintenance that causes the unit to not operate and also the time of the generator unit operating in 1 year.

a. FOR Generator Unit 1

$$FOR = \frac{2.44}{8{,}695.23 + 2.44} = 0.000281$$
$$Availability = 1 - 0.000281 = 0.999719$$

b. FOR Generator Unit 2

$$FOR = \frac{11.36}{8{,}586.46 + 11.36} = 0.001321$$
$$Availability = 1 - 0.001321 = 0.998679$$

c. FOR Generator Unit 3

$$FOR = \frac{10.77}{8{,}338.75 + 10.77} = 0.001290$$
$$Availability = 1 - 0.001290 = 0.998710$$

d. FOR Generator Unit 4

$$FOR = \frac{9.66}{7{,}177.81 + 9.66} = 0.001344$$
$$Availability = 1 - 0.001344 = 0.998656$$

e. FOR Generator Unit 5

$$FOR = \frac{3.56}{8{,}460.17 + 3.56} = 0.000421$$
$$Availability = 1 - 0.000421 = 0.999579$$

f. FOR Generator Unit 6

$$FOR = \frac{10.74}{7{,}761.86 + 10.74} = 0.001382$$
$$Availability = 1 - 0.001382 = 0.998618$$

3.5. Load Duration Curve in 2018

To obtain the LOLE value of the power system, it is necessary to have a load duration curve expressed in days/year as shown in Figure 4 is the load duration curve during 2018, this load duration curve data is needed to be able to calculate LOLE.

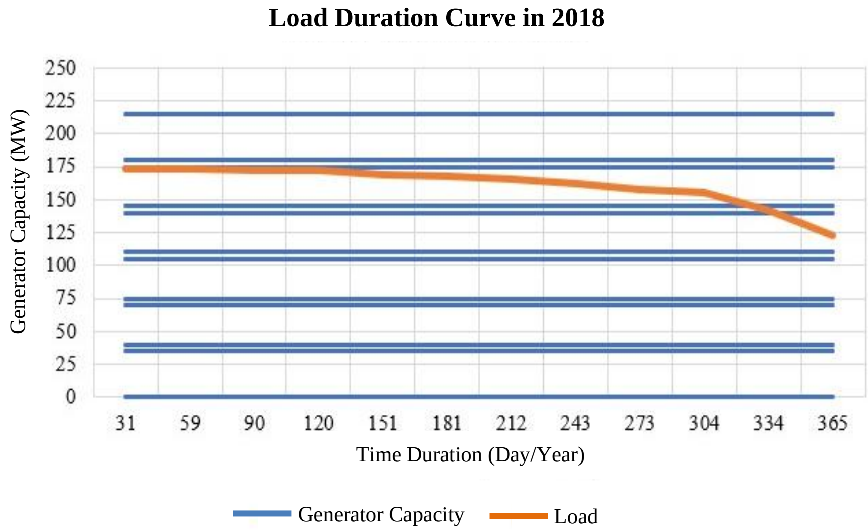


Figure 4. Load duration curve in 2018

3.6. Probability of System Operation in 2018

The Ir. H. Djuanda Hydroelectric Power Plant has 6 generator units consisting of 5 units with a capacity of 35 MW (units 1 to 5) and 1 unit with a capacity of 40 MW (unit 6). Based on this, there will be 26 combinations that can occur in system operation as shown in Table 3 in the form of an accumulation of 64 combinations (individual probabilities) and cumulative probabilities.

Table 3. Individual and cumulative probabilities in 2018

Power Quantity Off	Individual Probability	Cumulative Probability
0 MW	0.99397642575130200000	1
35 MW	0.00463371635672077000	0.00602357424869763000
40 MW	0.00137535420795647000	0.00138985789197687000
70 MW	0.00000807448304982590	0.00001450368402040040
75 MW	0.00000641162217189965	0.00000642920097057454
105 MW	0.00000000639515653116	0.00000001757879867489
110 MW	0.00000001117257306305	0.00000001118364214373
140 MW	0.00000000000221683549	0.00000000001106908068
145 MW	0.00000000000884890750	0.00000000000885224519
175 MW	0.00000000000000026991	0.00000000000000333769
180 MW	0.00000000000000306741	0.00000000000000306778
215 MW	0.00000000000000000037	0.00000000000000000037

3.7. Loss of Load Expectation (LOLE) in 2018

Loss of Load Expectation (LOLE) states the value of the possibility of losing load because the available power capacity is equal to or less than the system load, expressed in days/year. The data used to calculate LOLE is the result of cumulative probability and data based on the old load curve in 2018 as shown in Table 4.

Tabel 4. LOLE in 2018

Power Quantity (MW)		Cumulative Probability	load> Operating power (days/year)	LOLE (days/year)
Outage	Operational			
0	215	1	0	0.00000000000000000000
35	180	0.00602357424869763000	0	0.00000000000000000000
40	175	0.00138985789197687000	120	0.16678294703722400000
70	145	0.00001450368402040040	319	0.00462667520250773000
75	140	0.00000642920097057454	334	0.00214735312417190000
105	110	0.00000001757879867489	365	0.00000641626151633485
110	105	0.00000001118364214373	365	0.00000408202938246145
140	75	0.00000000001106908068	365	0.00000000404021444820
145	70	0.00000000000885224519	365	0.00000000323106949435
175	40	0.00000000000000333769	365	0.00000000000121825685
180	35	0.00000000000000306778	365	0.00000000000111973970
215	0	0.00000000000000000037	365	0.00000000000000013505
Total				0.17356748092842500000

Figure 5 is the result of the LOLE calculation using the visual studio application.

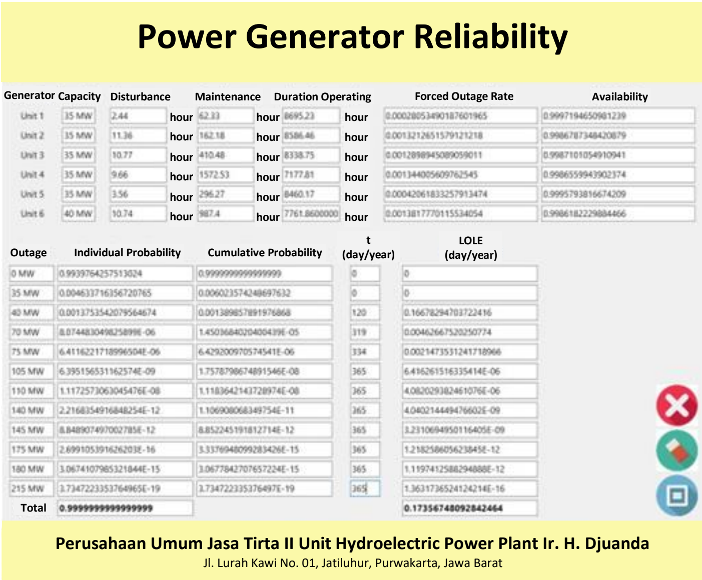


Figure 5. Calculation of LOLE in 2018 using the Visual Studio 2019 application

LOLE calculation using Ms. Excel gets a result of 0.173567480928425 days/year, while the results of calculations using the Visual Studio application are 0.17356748092842464 days/year for 2018.

3.8. FOR (Forced Outage Rate) in 2019

The data used to find FOR is data on disturbances that occur in generators in 1 year, including how long the generator experiences interference/maintenance that causes the unit to not operate and also the time of the generator unit operating in 1 year.

a. FOR Generator Unit 1

$$FOR = \frac{3.07}{8{,}494.98 + 3.07} = 0.000361$$
$$Availability = 1 - 0.000361 = 0.999639$$

b. FOR Generator Unit 2

$$FOR = \frac{6.87}{7{,}513.39 + 6.87} = 0.000914$$
$$Availability = 1 - 0.000914 = 0.999086$$

c. FOR Generator Unit 3

$$FOR = \frac{12.77}{7{,}490.57 + 12.77} = 0.001702$$
$$Availability = 1 - 0.001702 = 0.998298$$

d. FOR Generator Unit 4

$$FOR = \frac{13.88}{8{,}125.22 + 13.88} = 0.001705$$
$$Availability = 1 - 0.001705 = 0.998295$$

e. FOR Generator Unit 5

$$FOR = \frac{9.64}{7{,}475.92 + 9.64} = 0.001288$$
$$Availability = 1 - 0.001288 = 0.998712$$

f. FOR Generator Unit 6

$$FOR = \frac{6.25}{8{,}393.81 + 6.25} = 0.000744$$
$$Availability = 1 - 0.000744 = 0.999256$$

3.9. Load Duration Curve in 2019

To get the LOLE value of the power system, it is necessary to have a load duration curve expressed in days/year as shown in Figure 6 is the load duration curve during 2019, this load duration curve data is needed to be able to calculate LOLE.

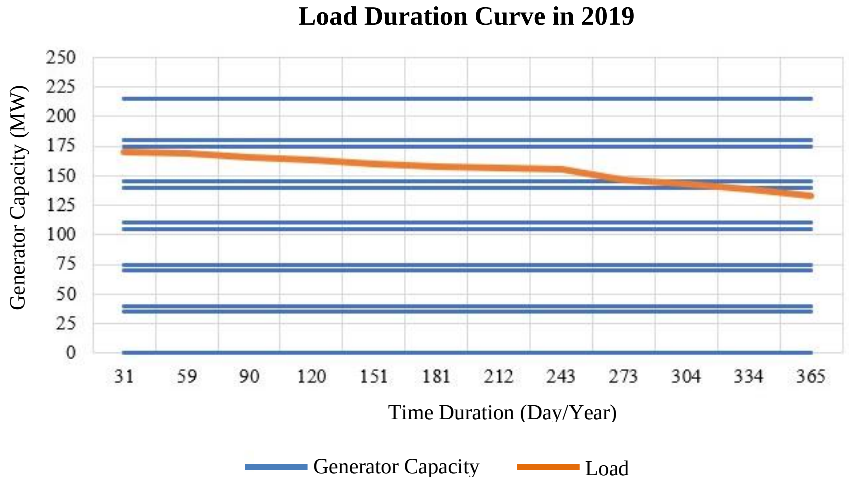


Figure 6. Load duration curve in 2019

3.10. Probability of System Operation in 2019

The Ir. H. Djuanda Hydroelectric Power Plant has 6 generator units consisting of 5 units with a capacity of 35 MW (units 1 to 5) and 1 unit with a capacity of 40 MW (unit 6). Based on this, there will be 26 combinations that can occur in system operation as shown in Table 5 in the form of an accumulation of 64 combinations (individual probabilities) and cumulative probabilities.

Table 5. Individual and cumulative probabilities in 2019

Power Quantity Off	Individual Probability	Cumulative Probability
0 MW	0.99330411895106900000	1
35 MW	0.00593827247189115000	0.00669588104893151000
40 MW	0.00073961058725944200	0.00075760857704036000
70 MW	0.00001355172420415980	0.00001799798978091780
75 MW	0.00000442161580370770	0.00000444626557675799
105 MW	0.00000001454121602760	0.00000002464977305029
110 MW	0.00000001009056391269	0.00000001010855702269
140 MW	0.00000000000715920988	0.00000000001799311000
145 MW	0.00000000001082733588	0.00000000001083390012
175 MW	0.00000000000000123260	0.00000000000000656424
180 MW	0.00000000000000533072	0.00000000000000533164
215 MW	0.00000000000000000092	0.00000000000000000092

3.11. Loss of Load Expectation (LOLE) in 2019

The loss of load expectation value in 2019 using Excel can be seen in Table 6. LOLE calculation using visual studio application can be seen in Figure 7.

Table 6. LOLE in 2019

Power Quantity (MW)		Cumulative Probability	load> Operating power (days/year)	LOLE (days/year)
Outage	Operational			
0	215	1	0	0
35	180	0.00669588104893151000	0	0
40	175	0.00075760857704036000	0	0
70	145	0.00001799798978091780	265	0.00476946729194322000
75	140	0.00000444626557675799	320	0.00142280498456256000
105	110	0.00000002464977305029	365	0.00000899716716335585
110	105	0.00000001010855702269	365	0.00000368962331328185
140	75	0.00000000001799311000	365	0.00000000656748515000
145	70	0.00000000001083390012	365	0.00000000395437354380
175	40	0.00000000000000656424	365	0.00000000000239594760
180	35	0.00000000000000533164	365	0.00000000000194604860
215	0	0.00000000000000000092	365	0.00000000000000033580
		Total		0.00620496959318343

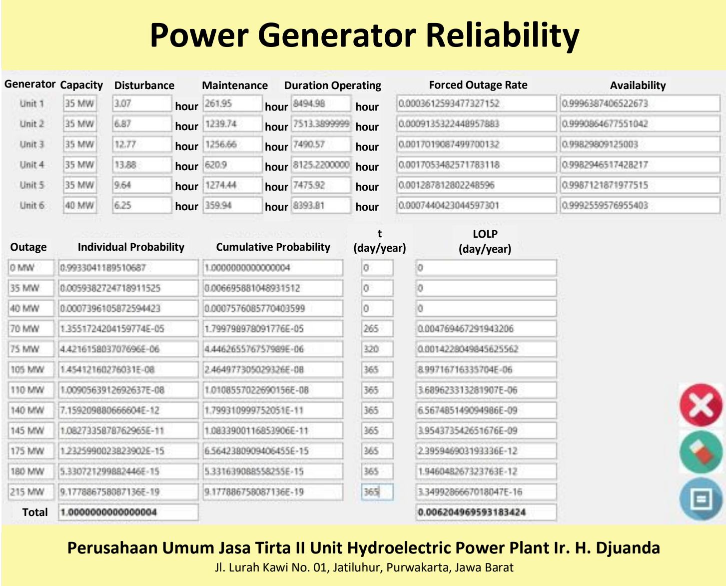


Figure 7. Calculation of LOLE in 2019 using Visual Studio 2019 application

LOLE calculation using Ms. Excel obtained a result of 0.00620496959318343 days/year, while the calculation results using the visual studio application obtained 0.006204969593183424 days/year for 2019.

4. CONCLUSION

As a step to simplify the calculation of the reliability level of the Ir. H. Djuanda Hydroelectric Power Plant, the researcher created a reliability calculation program using the Visual Studio 2019 application which uses the java programming language. With this program, the reliability level of the Ir. H. Djuanda Hydropower Plant can be directly known by entering data on the length of time the generator unit does not operate for a year and also data from the load duration curve for a year, then other data such as FOR, availability, individual probability, cumulative probability to LOLE can be directly known. The reliability level of the Ir. H. Djuanda Hydroelectric Power Plant for 2 years has relatively good reliability, for 2018 the reliability level of the Ir. H. Djuanda Hydroelectric Power Plant based on the LOLE index is 0.173567480928425 days/year, while for 2019 the LOLE index of the Ir. H. Djuanda Hydroelectric Power Plant is 0.00620496959318343 days/year. To develop this research, it can describe in more detail about the kinds of disturbances that often cause generator units to not operate and add ways to overcome the disturbances that occur. Can add several other parameters besides LOLE to determine the reliability level of a power plant in Indonesia, especially the Ir. H. Djuanda Hydroelectric Power Plant.

REFERENCES

[1] D. Marsudi, *Operasi Sistem Tenaga Listrik*, 2 ed. Yogyakarta: Graha Ilmu, 2006.

[2] O. H. Abdalla, "Security and Reliability Criteria For Electricity Generation and Transmission System Planning," *Journal of the Egyptian Society of Engineers*, vol. 61, no. 1, pp. 3–10, 2022, https://doi.org/10.21608/egsen.2022.247103.

[3] A. Senen and R. Z. Akbar, "Aplikasi Pengunaan Visual Basic Pada Perhitungan Indeks Keandaan Pembangkit," *Elektron Jurnal Ilmiah*, vol. 11, no. 2, pp. 63–68, 2019, https://doi.org/10.30630/eji.11.2.127.

[4] A. Cekum, Junaidi, and Purwoharjono, "Studi Keandalan Pembangkit Listrik Tenaga Diesel (PLTD) Sukaharja Kabupaten Ketapang," *Jurnal Teknik Elektro Universitas Tanjungpura*, vol. 2, no. 1, pp. 1–10, 2019, https://jurnal.untan.ac.id/index.php/jteuntan/article/view/34966.

[5] M. S. Alvarez-Alvarado and D. Jayaweera, "Aging Reliability Model for Generation Adequacy," *2018 IEEE International Conference on Probabilistic Methods Applied to Power Systems (PMAPS)*, pp. 1-6, 2018, https://doi.org/10.1109/PMAPS.2018.8440529.

[6] A. N. Widiastuti, Sarjiya, K. A. Pinanditho, and E. T. Prastyo, "Evaluasi Keandalan Perencanaan Pembangkit Wilayah Jawa-Bali dengan Mempertimbangkan Ketidakpastian Peramalan Beban," *Jurnal Nasional Teknik Elektro Dan Teknologi Informasi*, vol. 6, no. 2, pp. 230–234, 2017, https://journal.ugm.ac.id/v3/JNTETI/article/view/2861.

[7] P. F. Ferdinant, L. Nurdiana, and A. Irman, "Evaluation of Power Plant Reliability Using Index Loss of Load in the Suralaya Power Plant," in *IOP Conference Series: Materials Science and Engineering*, vol. 909, no. 1, pp. 1–9, 2020, https://doi.org/10.1088/1757-899X/909/1/012070.

[8] G. Slipac, M. Zeljko, and D. Šljivac, "Importance of Reliability Criterion in Power System Expansion planning," *Energies*, vol. 12, no. 9, pp. 1–18, 2019, https://doi.org/10.3390/en12091714.

[9] I. Apriliyanto, E. D. Malia, A. R. Uspa, A. D. Bhaswara, and F. Rahman, "Studi Analisa Keandalan Pada Pembangkit Listrik Tenaga Uap (PLTU) Embalut Kalimantan Timur Menggunakan Perhitungan LOLP (Loss of Load Probabilty) dan LOLE (Loss of Load Expectation)," *PoliGrid*, vol. 3, no. 2, pp. 52–56, 2022, https://doi.org/10.46964/poligrid.v3i2.1706.

[10] L. T. Al-Bahrani, W. Saaed, and M. Al-Kaabi, "Generation Reliability Enhancement based on Reliability Indices," *Journal of Physics: Conference Series*, vol. 1844, no. 1, pp. 1–10, 2021, https://doi.org/10.1088/1742-6596/1844/1/012010.

[11] A. Hidayati, Supriyatna, and A. B. Muljono, "Analisis Kontingensi terhadap Unjuk Kerja dan Keandalan Komposit Pembangkit dan Transmisi pada Sistem Kelistrikan Lombok," *Jurnal Dielektrika*, vol. 3, no. 2, pp. 95–104, 2016, http://dielektrika.unram.ac.id/index.php/dielektrika/article/view/143.

[12] I. S. Qamber, "Loss of Load Expectation Calculation for Power Plant," *IET Conference Publications*, vol. 2019, no. CP758, 2019, https://doi.org/10.1049/cp.2019.0213.

[13] U. Albab and D. Y. Sukma, "Upaya Peningkatan Indeks Keandalan Sistem Pembangkit dengan Peningkatan Kapasitas Sistem Pembangkit," *Jurnal Online Mahasiswa Fakultas Teknik*, vol. 6, no. 2, pp. 1–6, 2019, https://jnse.ejournal.unri.ac.id/index.php/JOMFTEKNIK/article/view/25738.

[14] R. Syahputra, F. Noor, and F. Mujaahid, "Analisis Indeks Keandalan Pembangkit Listrik Tenaga Hibrid Angin-Surya Menggunakan Metode EENS," *Semesta Teknika*, vol. 23, no. 1, pp. 92–105, 2020, https://journal.umy.ac.id/index.php/st/article/view/9602.

[15] R. A. Putra and I. T. Yuniahastuti, "Perhitungan Keandalan Pembangkit Loss of Load Probability (LOLP) untuk N Pembangkit," *Jurnal Electra*, vol. 1, no. 2, pp. 13–19, 2021, https://doi.org/10.25273/electra.v1i2.8960.

[16] R. A. Putra, I. T. Yuniahastuti, and R. D. Laksono, "Skenario Perbaikan Nilai Keandalan Loss of Load Probability pada PLTH Pantai Baru Pandansimo," *Jurnal Electra*, vol. 2, no. 1, pp. 16–22, 2021, https://doi.org/10.25273/electra.v2i1.10500.

[17] R. D. Laksono, I. T. Yuniahastusi, and A. P. P. Prakoso, "Skenario Peningkatan Keandalan Sistem Pembangkit Tenaga Listrik di Wilayah Bali Berdasarkan LOLP," *Jurnal Electra*, vol. 2, no. 1, pp. 39–45, 2021, https://doi.org/10.25273/electra.v2i1.10525.

[18] R. R. Dharmawan and U. T. Kartini, "Analisis Indeks Keandalan PLTGU Blok 1 PT. PJB UP Gresik Menggunakan Perhitungan Teorema Bayes dan Decomposisi LU," *Jurnal Teknik Elektro*, vol. 9, no. 3, pp. 658–665, 2020, https://jurnalmahasiswa.unesa.ac.id/index.php/16/article/view/35589.

[19] Syahrial, K. Sawitri, and P. Gemahapsari, "Studi Keandalan Ketersediaan Daya Pembangkit Listrik Pada Jaringan Daerah X," *Jurnal Elkomika*, vol. 5, no. 1, pp. 93–105, 2017, https://doi.org/10.26760/elkomika.v5i1.93.

[20] A. Tanjung, A. Jaya, S. Suryanto, and Apollo, "Evaluasi Keandalan PLTA Bakaru," *Sinergi*, vol. 19, no. 1, pp. 80–87, 2021, https://doi.org/10.31963/sinergi.v19i1.2762.

[21] Adriwiyono and B. P. Ichtiarto, "Analisa Kinerja Pembangkit Turbin Gas PT PJB Unit Pembangkit Muara Tawar Menggunakan Generating Availability Data System," *Operatoins Excellence*, vol. 10, no. 3, pp. 304–320, 2018, https://doi.org/10.22441/oe.v10.3.2018.010.

[22] A. Burhandono and N. Sinaga, "Menjaga Keandalan Sistem PLTS dengan Metode Failure Mode Effect Analysis (FMEA)," *Jurnal Teknik Industri*, vol. 12, no. 1, pp. 30–39, 2022, https://trijurnal.trisakti.ac.id/index.php/tekin/article/view/13958.

[23] F. Anwar, "Usulan Perhitungan dan Perbaikan Tingkat Keandalan Desalination Plant PLTGU Muara Tawar dengan Menggunakan Weibull Analisis dan FMEA sebagai Dasar Skala Prioritas Pengoperasian," *Jurnal PASTI*, vol. VIII, no. 2, pp. 171–190, 2014, https://www.neliti.com/publications/182877/usulan-perhitungan-dan-perbaikan-tingkat-keandalan-desalination-plant-pltgu-muar.

[24] Adrianti, "Evaluasi Keandalan Pembangkit Listrik Tenaga Surya yang Terhubung ke Grid," *Jurnal Nasional Teknik Elektro*, vol. 5, no. 2, pp. 230–236, 2016, https://doi.org/10.20449/jnte.v5i2.281.

[25] H. D. Armono, D. K. Nugroho, and Mukhtasor, "Monte Carlo Simulation for Reliability Hydraulic Stability of Rubble Mound Breakwater Armour at Sudimoro Power Plant, Pacitan," *IOP Conference Series: Earth and Environmental Science*, vol. 698, no. 1, 2021, https://doi.org/10.1088/1755-1315/698/1/012031.

[26] I. Pamungkas, H. T. Irawan, Arhami, and M. Dirhamsyah, "Simulasi Monte Carlo untuk Menentukan Keandalan pada Bagian Boiler di Pembangkit Listrik Berbasis Batubara," *Jurnal Optimalisasi*, vol. 4, no. 2, pp. 83–96, 2018, http://jurnal.utu.ac.id/joptimalisasi/article/view/1505.

[27] A. N. Abdalla *et al.*, "Metaheuristic Searching Genetic Algorithm Based Reliability Assessment of Hybrid Power Generation System," *Energy Exploration and Exploitation*, vol. 39, no. 1, pp. 488–501, 2021, https://doi.org/10.1177/0144598720959749.

[28] M. Cepin, *Assessment of Power System Reliability*. London: Springer, 2011, https://doi.org/10.1007/978-0-85729-688-7.

[29] R. Billinton and R. N. Allan, *Reliability Evaluation of Power Systems*, 2 ed. New York: Plenum Press, 1996, https://doi.org/10.1007/978-1-4899-1860-4.

[30] A. A. Chowdhury and D. O. Koval, *Power Distribution System Reliability*. New Jersey: John Wiley & Sons, Inc, 2009, https://doi.org/10.1002/9780470459355.

[31] Menteri ESDM RI, *Rencana Usaha Penyediaan Tenaga Listrik PT. PLN (Persero) 2019-2028*. Indonesia, 2019.

AUTHOR BIOGRAPHY

Ikrima Alfi lecturer in Department of Electrical Engineering, Universitas Teknologi Yogyakarta. S1 and S2 graduates from Gadjah Mada University. Field of research: Electrical Power Transmission and Distribution, Power Systems.

Rifqi Fauzan Kusmayana obtained a Bachelor of Engineering (S.T.) degree from the Department of Electrical Engineering, Universitas Teknologi Yogyakarta in 2020. Concentration of specialization in the field of electrical power.