Poisson's Approach to Useful Life Analysis of Transmission Lines

Sutisna[1], Edvin Priatna[2], Nur Widiyasono[3]
[1,2] Electrical Departement, University of Siliwangi. Tasikmalaya city, Indoensia
[3] Informatic Departement, University of Siliwangi. Tasikmalaya city, Indoensia
[1] email: sutisna@unsil.ac.id

[*submitted*: 14-09-2025 | *review*: 14-09-2025 | *published*: 31-10-2025]

ABSTRACT: *Reliability is defined as the probability of a device or system performing its functions adequately over a period of time under certain operating conditions. Component failure can impact the power supply to customers, and result in high costs associated with loss of power supply and or replacement of components. This article implements the Poisson model in estimating the reliability value of the electric power grid to obtain the useful life of each load bus. This useful life period as an indicator of the period of preventive maintenance. With the estimation of the reliability value using the Poisson Method is shown by obtaining maximum probability which is the best end of system performance. This method was tested on the IEEE 14 bus diagram system. As a sample of the maximum probability test results in bus_2, bus_3, and bus_5 occurred in 14th year, 9th year, and 11th year*

KEYWORDS:. *Reliability Value, Poisson Method, Useful Life*

I. INTRODUCTION

Electric power systems should be able to provide electricity supply to customers as cost-effectively as possible with adequate reliability guarantees. Reliability is defined as the probability of a device or system performing its functions adequately over a period of time under certain operating conditions [1]. Component failure can impact the power supply to the customer, and result in high costs associated with loss of power supply and or component replacement [2].

Maintenance optimization becomes important with the right level of reliability to keep the system in setup and meet customer demands [3]. The concept of preventive maintenance is to reduce the probability of failure by maintenance before failure. This is a good strategy in the case of the aging process of well-identified components [4]. A large portion of the total cost of an electric power system goes towards maintenance and capital depreciation. The main goal of this article is the implementation of the Poisson method so that useful life is obtained in relation to preventive maintenance time on the transmission network [5].

The most basic problem in the electric power system lies in the quality, continuity, and availability of electric power services to consumers[6]. The reliability index is a measure of reliability expressed in terms of probability, so in distribution system planning the reliability aspect is one of the important parts in decision making [7]. Analysis of the reliability of the electric power system will contribute to measuring the extent to which the system meets performance criteria, and will assist in making economic decisions.

Maintenance performed prior to component failure to keep the system in the operational period. Preventive maintenance includes the performance of regular inspections as well as repairs. Usually done periodically, or according to manufacturing standard guidelines [8], [9]. Very frequent maintenance in a system leads to quite high operational costs and can result in errors caused by maintenance. On the other hand, performing maintenance rarely leads to an increased risk of failure and early wear of equipment. In other words, system operators who develop maintenance strategies are faced with higher operational costs and the risk of failure in power systems.

Ravaghi Ardabili, Haghifam and Abedi [10] conducted research on maintaining electricity distribution networks with a reliability value approach. Moslemi et al [11] examined the maintenance schedule using the falure mode method, resulting in reliability scores. Paci, Bualoti and Çelo
[12] examined the reliability index of distribution systems using Fuzzy.

II. RESEARCH METHODS

This study adopts a structured methodological approach to analyze the reliability of the electric power system. The methods are designed to ensure that the results are scientifically valid, replicable, and directly aligned with the research objectives. The IEEE 14-bus test system is employed as the standard model to represent the complexity of an electrical network, enabling the evaluation of system performance under realistic operating conditions. Data used in the analysis are normalized to a 100 MVA base, while operational limits of voltage magnitude and phase angle are set to 0.95–1.05 p.u. and –45° to +45°, respectively.

The research methodology consists of several key stages, including the preparation of system data, load-flow analysis, calculation of edge reliability values, and application of the Poisson method for estimating the useful life of each load bus. Each step is designed to provide a clear representation of the system's operational reliability, while also identifying the period in which preventive maintenance should be optimally performed. The methodological framework ensures that the findings not only demonstrate technical accuracy but also provide practical implications for maintenance strategies in real power distribution networks

A. IEEE 14 BUS SYSTEM

This research uses a power system model released by IEEE. The power system model includes 14 buses, of which bus_1 is the source bus and bus_2 to bus_14 is the load bus. The IEEE 14 bus system is shown in figure 1. The system data is taken from Table 1. The data given in the following tables is on 100MVA base. The minimum and maximum limits of voltage magnitude and phase angle are considered to be 0.95 p.u. to 1.05 p.u. and -45◦ to +45◦ respectively.

Tbl. 1. Edge Reliability Value.

Bus		R, pu	X, pu	λ, f/yr	R_e
1	2	0,01938	0,05917	0,24	0,79
1	5	0,05403	0,22304	0,67	0,51
2	3	0,04699	0,19797	0,58	0,56
2	4	0,05811	0,17632	0,72	0,49
2	5	0,05695	0,17388	0,7	0,49
3	4	0,06701	0,17103	0,83	0,44
4	5	0,01335	0,04211	0,17	0,85
4	7	0	0,20912	0	1
4	9	0	0,55618	0	1
5	6	0	0,25202	0	1
6	11	0,09498	0,1989	0,02	0,98
6	12	0,12291	0,25581	0,03	0,97
6	13	0,06615	0,13027	0,01	0,99
7	8	0	0,17615	0	1
7	9	0	0,11001	0	1
9	10	0,03181	0,0845	0,01	0,99
9	14	0,12711	0,27038	0,03	0,97
10	11	0,08205	0,19207	0,02	0,98

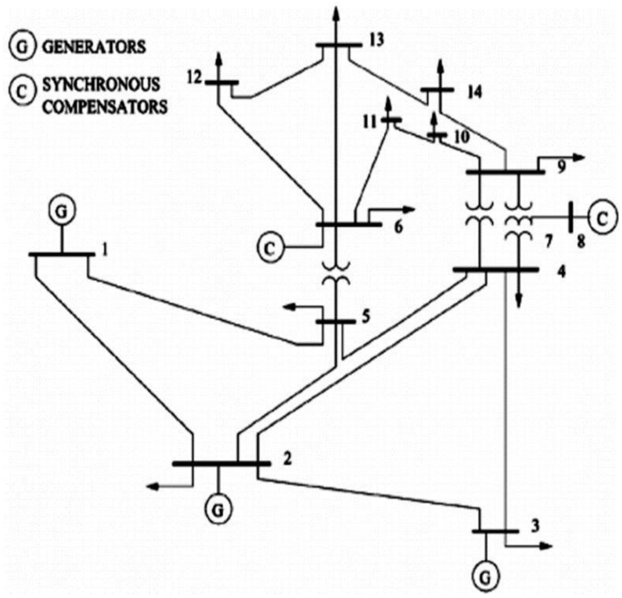

Fig. 1. IEEE 14 bus system

III. RESULTS AND DISCUSSION

By performing load-flow analysis on the system presented in Fig. 1, the network configuration with its corresponding power flow directions can be clearly identified. This analysis not only provides an overview of the active power transfer within the system but also illustrates the number of alternative paths available for each load bus, as depicted in Fig. 2. Such visualization is essential to understand the redundancy and connectivity of the network, which directly influence the overall reliability of the power system.

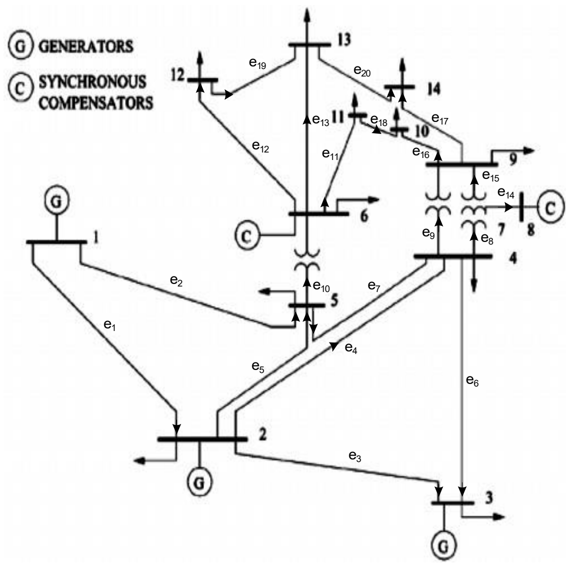

Fig. 2. Diagram of 14 buses with load-flow direction

Furthermore, the reliability value for each transmission line or edge in the system is calculated using equation (1). These values represent the probability of maintaining stable operation under normal conditions while accounting for potential component failures. To better illustrate the initial state of the system, Fig. 3 presents a bar chart summarizing the reliability values of each bus during the first year of observation. This initial reliability profile serves as the baseline reference for subsequent analysis using the Poisson method to estimate the useful life of each bus..

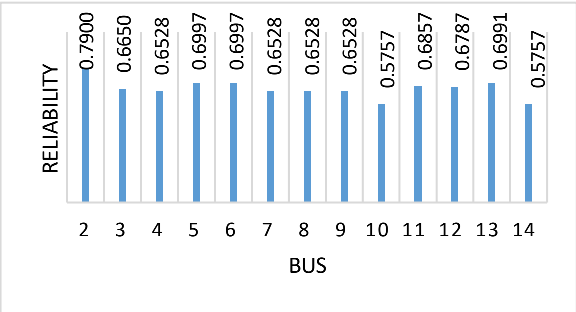

Fig. 3. Reliability value diagram 14 bus IEEE.

From this reliability value, an estimate of the reliability value is then carried out using the Poisson method using equation (3). The Poisson method is used to estimate the value of reliability when the probability is maximum. In bus_2, Maximum Probability (MP) occurred in ke_14. Bus_3 and bus_4, MP occurred in ke_9. Bus_5 and bus_6, MP occurred in ke_11. Bus_7, bus_8, and bus_9, MP occurred in ke_9. Bus_10, MP occurred in ke_5. Bus_11 and bus_12, MP occurred in ke_10. And buses _13 and bus_14, MP occurred in ke_11 and ke_5, respectively, as shown in Table 2.

Tbl. 2 Probability Of Reliability Value With Poisson Method.

Load Bus	IEEE Bus 14 Probability of Reliability Value (n^{th} time)					
	1	...	5	...	7	8
2	3,4129E-05	...	1,5869E-03	...	7,6157E-03	1,5077E-02
3	1,1310E-02	...	5,8613E-02	...	9,3909E-02	1,0742E-01
4	1,5768E-02	...	6,8419E-02	...	1,0031E-01	1,0976E-01
5	3,6269E-03	...	3,2017E-02	...	6,6952E-02	8,7494E-02
6	3,6269E-03	...	3,2017E-02	...	6,6952E-02	8,7494E-02
7	1,5768E-02	...	6,8419E-02	...	1,0031E-01	1,0976E-01
8	1,5768E-02	...	6,8419E-02	...	1,0031E-01	1,0976E-01
9	1,5768E-02	...	6,8419E-02	...	1,0031E-01	1,0976E-01
10	6,3624E-02	...	9,8255E-02	...	8,5937E-02	7,2630E-02
11	5,9485E-03	...	4,2132E-02	...	7,8917E-02	9,7606E-02
12	7,4778E-03	...	4,7574E-02	...	8,4454E-02	1,0169E-01
13	3,7086E-03	...	3,2425E-02	...	6,7480E-02	8,7973E-02
14	6,3624E-02	...	9,8255E-02	...	8,5937E-02	7,2630E-02
Load Bus	IEEE Bus 14 Probability of Reliability Value (n^{th} time)					
	9	10	11	...	**14**	**15**
2	2,7717E-02	4,7033E-02	7,3159E-02	...	1,4895E-01	1,4744E-01
3	1,1410E-01	1,1187E-01	1,0055E-01	...	3,9487E-02	2,2584E-02
4	1,1152E-01	1,0460E-01	8,9926E-02	...	3,0913E-02	1,6913E-02
5	1,0617E-01	1,1892E-01	1,2211E-01	...	7,1505E-02	4,6721E-02
6	1,0617E-01	1,1892E-01	1,2211E-01	...	7,1505E-02	4,6721E-02
7	1,1152E-01	1,0460E-01	8,9926E-02	...	3,0913E-02	1,6913E-02
8	1,1152E-01	1,0460E-01	8,9926E-02	...	3,0913E-02	1,6913E-02
9	1,1152E-01	1,0460E-01	8,9926E-02	...	3,0913E-02	1,6913E-02
10	5,6999E-02	4,1291E-02	2,7419E-02	...	4,3432E-03	1,8353E-03
11	1,1210E-01	1,1884E-01	1,1548E-01	...	5,7329E-02	3,5452E-02
12	1,1369E-01	1,1734E-01	1,1101E-01	...	5,0845E-02	3,0611E-02
13	1,0650E-01	1,1900E-01	1,2190E-01	...	7,0868E-02	4,6195E-02
14	5,6999E-02	4,1291E-02	2,7419E-02	...	4,3432E-03	1,8353E-03

The estimation of the reliability value using equation (1) with a fixed failure rate is obtained the estimated reliability value for the next 15 years as shown in the table 3. The reliability value corresponding to the maximum probability of each bus is marked with a value in the table with a color box. Bus_2, the maximum probability occurs in 14^{th} year, corresponding to a reliability value of 0.0369 Pu. Bus_3, the maximum probability occurs in 9^{th} year, corresponding to a reliability value of 0.0254 pu, and the same for subsequent buses as shown in table 3.

Tbl. 3 Reliability Value Of Each Bus Diagram 14 Bus Ieee

Load Bus	IEEE Bu s 14 Diagra m Reliabilit y Value (n^{th} time)						
	1	**2**	**...**	**5**	**6**	**7**	**8**
2	0.7900	0.6241	...	0.3077	0.2431	0.1920	0.1517
3	0.6650	0.4422	...	0.1300	0.0865	0.0575	0.0382
4	0.6528	0.4261	...	0.1185	0.0774	0.0505	0.0330
5	0.6997	0.4896	...	0.1677	0.1173	0.0821	0.0575
6	0.6997	0.4896	...	0.1677	0.1173	0.0821	0.0575
7	0.6528	0.4261	...	0.1185	0.0774	0.0505	0.0330
8	0.6528	0.4261	...	0.1185	0.0774	0.0505	0.0330
9	0.6528	0.4261	...	0.1185	0.0774	0.0505	0.0330
10	0.5757	0.3314	...	0.0632	0.0364	0.0210	0.0121
11	0.6857	0.4702	...	0.1516	0.1039	0.0713	0.0489
12	0.6787	0.4606	...	0.1440	0.0977	0.0663	0.0450
13	0.6991	0.4887	...	0.1670	0.1167	0.0816	0.0571
14	0.5757	0.3314	...	0.0632	0.0364	0.0210	0.0121
Load Bus	IEEE Bus 14 Diagram Reliability Value (n^{th} time)						
	9	**10**	**11**	**12**	**13**	**14**	**15**
2	0.1199	0.0947	0.0748	0.0591	0.0467	0.0369	0.0291
3	0.0254	0.0169	0.0112	0,0075	0,0050	0,0033	0,0022
4	0.0215	0.0141	0.0092	0,0060	0,0039	0,0026	0,0017
5	0.0402	0.0281	0,0197	0,0138	0,0096	0,0067	0,0047
6	0.0402	0.0281	0,0197	0,0138	0,0096	0,0067	0,0047
7	0.0215	0.0141	0.0092	0,0060	0,0039	0,0026	0,0017
8	0.0215	0.0141	0.0092	0,0060	0,0039	0,0026	0,0017
9	0.0215	0.0141	0.0092	0,0060	0,0039	0,0026	0,0017
10	0,0069	0,0040	0,0023	0,0013	0,0008	0,0004	0,0003
11	0.0335	0.0230	0,0158	0,0108	0,0074	0,0051	0,0035
12	0.0306	0,0207	0,0141	0,0096	0,0065	0,0044	0,0030
13	0.0399	0.0279	0,0195	0,0136	0,0095	0,0067	0,0047
14	0,0069	0,0040	0,0023	0,0013	0,0008	0,0004	0,0003

As with the bathtub hazard curve, for bus_2 where the maximum probability occurs in 14^{th} year this indicates that the useful life period or operating period normal (*useful life*) dari bus_2 is for 14 years from the first year (existing reliability value) to the 14^{th} year when the maximum probability of reliability value occurs. Similarly, for bus_3, bus_4, and the next bus, the useful life corresponds to when the maximum probability of the reliability value of each bus. The year when maximum probability occurs is the year that the network for the bus has lost its best performance.

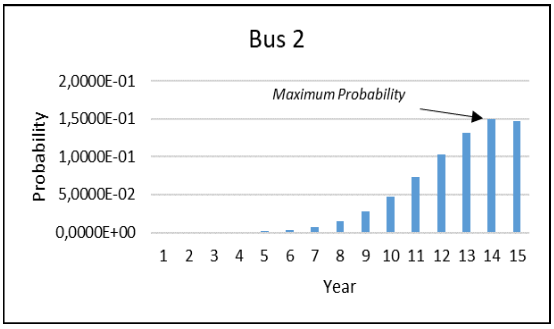

Fig. 4. The maximum probability of bus_2 occurs in 14th year.

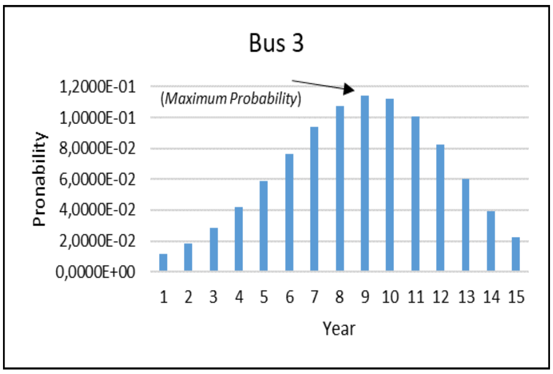

Fig. 5. The maximum probability of bus_3 occurs in 9th year.

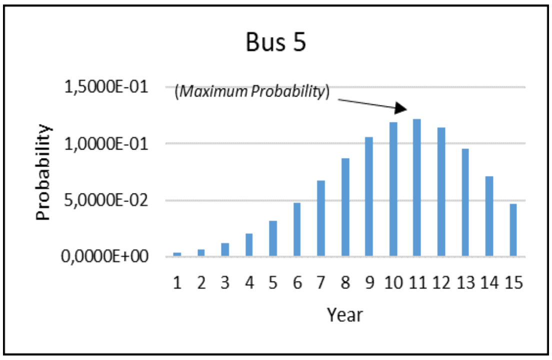

Fig. 6. The maximum probability of bus_5 occurs in 11th year.

Figures 4, 5, and 6 are examples of reliability value probability histograms for bus_2, bus_3, and bus_5, showing the year of occurrence of the maximum probability reliability value of the bus.

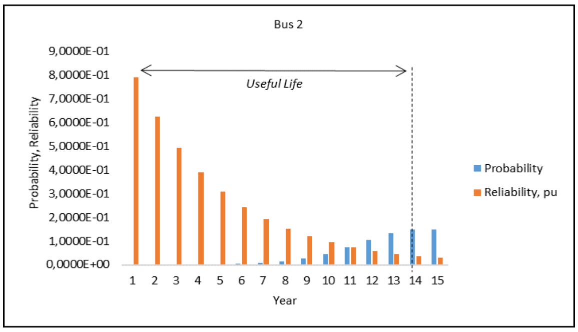

Fig. 7. Useful life and conformity of reliability values on bus_2.

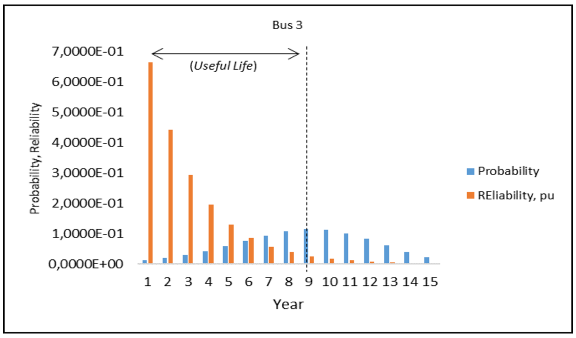

Fig. 8. Useful life and conformity of reliability values on bus_3.

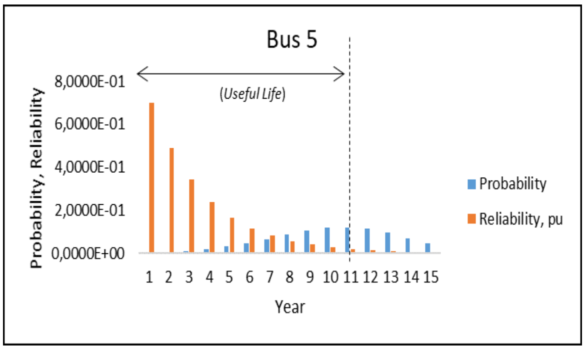

Fig. 9. Useful life and conformity of reliability values on bus_5.

Figures 7, 8, and 9 show a histogram of decreasing reliability scores with increasing years, and how reliability scores fit with when the maximum probability of reliability values occurs.

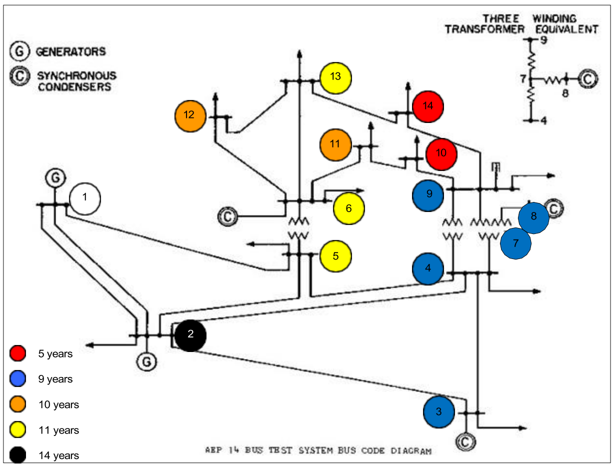

Fig. 10. Indicator of the normal period of operation (useful life) of each bus.

Fig. 10 shows the useful life of each bus from the IEEE Bus 14 bus diagram system with color indicators on all load terminal buses. Visualization with appropriate color assignment obtained grouping buses with the same normal operating period. Bus_2, the normal operating period is 14 years. Bus_3, bus_4, bus_7, bus_8, and bus_9 its normal operating period of 9 years. Bus_5, bus_6, and bus_13 its normal operating period of 11 years. Bus_10 and bus_14 its normal operating period for 5 years. And bus_11 and bus_12, the period of its normal operation is for 10 years.

IV. CONCLUSION

With the estimation of reliability values using the Poisson Method obtained the period of normal operation of the IEEE 14 bus diagram system. This is shown by obtaining maximum probability which is the best end of system performance. The maximum probabilities of bus_2, bus_3, and bus_5 occur in 14^{th} year, 9^{th} year, and 11^{th} year with reliability values of 0.0369 pu, 0.0254 pu, and 0.0197 pu, respectively. With time, the reliability value of each bus in the system decreases to the maximum probability time reliability value. This time interval is the period of normal operation (useful life) of the system. When the probability is maximum, this reliability value is also the beginning of the wearout period. This indicator must be carried out system failure prevention maintenance (Preventive Maintenance).

ACKNOWLEDGEMENTS

The authors gratefully acknowledge Universitas Siliwangi and the Department of Electrical Engineering for their support and facilities in completing this research..

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AUTHORS BIOGRAPHY AND CONTRIBUTIONS

Sutisna received a Master of Electrical Engineering from the Institut Teknologi Bandung in 2007. He now works as a lecturer at the Department of Electrical Engineering at Siliwangi University in Tasikmalaya- Indonesia. He is currently a Ph.D. candidate at Udayana University- Indonesia. His research interests include Analysis of Electric Power Systems, Electrical Power Transmission, Electrical Distribution Systems, and Digital Systems. His research areas include Power Systems, Optimization and Reliability.