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Analysis of Mean Time Between Failures and Reliability of a 150 kV Circuit Breaker at Bantul Substation Using the Maximum Likelihood Estimation Method

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Abstract – *As technology advances in the modern era, the need and consumption of electrical energy in society has increased rapidly. With the need for electrical energy continuing to increase, various disturbances in the electrical system, including in substations, cannot be predicted when they will occur. The Power Breaker (PMT) is a vital equipment in the Bantul 150 kV substation power system that functions to break the electrical circuit under load to prevent interference and damage to equipment and ensure the smooth distribution of electrical energy to consumers. Based on the role of PMT, the estimation of PMT failure time has not been studied in depth. This study aims to analyze the Mean Time Between Failure and Reliability of the Bantul 150 kV Substation PMT. The method used in assessing PMT life is Maximum Likelihood Estimation. The data used are the results of observations of ten different PMTs in Bantul Substation. The results of the analysis show that the average value of the time period between failures (MTBF) varies between different PMTs. The highest MTBF value is PMT Wirobrajan 2 with a damage period of about 14.55 months, while the lowest MTBF is PMT Semanu 2 with a damage period of 5.48 months. The results of the analysis of failure probability, cumulative failure probability, reliability probability, and damage rate of 150 kV PMTs show significant variations between different PMTs. Reliability value produces the lowest value on PMT Transformer 3. While the highest Reliability value produces the highest value, namely on PMT Kopel. With the known MTBF and Reliability of 150 kV PMT at Bantul Substation, it can be used as a basis for maintenance and maintenance of PMT in its operation at Bantul Substation.*

Keywords – *Mean Time Between Failures; Reliability Analysis; 150 kV Circuit Breaker; Maximum Likelihood Estimation; Substation Maintenance.*

I. INTRODUCTION

THE advancement of technology and the increase in human activities across various sectors have driven the demand for electrical energy. However, the utilization of electrical energy carries risks as various disturbances can occur unexpectedly, from the generation process, transmission, substations, distribution substations, to consumer usage [1]. With the continued increase in electrical energy demand, disturbances in the power system cannot be predicted when they will occur. A reliable and safe power system is crucial to meet this energy demand [2].

One of the vital devices in electrical protection is the circuit breaker (CB), which plays a crucial role in protection management. Its function is similar to a switch that opens, conducts, and interrupts the flow of current under normal conditions. In cases of disturbances such as short circuits, CBs are designed to open, conduct, and interrupt the current flow within a certain period [3]. Despite its essential role, CBs are not immune to various issues that need to be examined and addressed.

One of the main issues is the decline in equipment performance, which results in damage and failure, leading to physical damage and functional failure [4]. The maintenance of CBs is a significant aspect of maintaining the reliability of the power system. Well-maintained CBs will function optimally in connecting and disconnecting the flow of electricity [5]. Important considerations in CB maintenance include CB failure data [6].

If CBs are not properly maintained, there will be long-term impacts, such as difficulty in determining the Mean Time Between Failure (MTBF) and CB Reliability. This can lead to cost inefficiencies, as replacing

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CBs that are still reliable may be done before the reliability level drops significantly [7]. Additionally, unexpected CB failures may occur in older, unmaintained CBs, causing disruptions in the power system [8].

This research focuses on disturbances occurring in substations, particularly concerning the role of CBs as vital protective devices in substation protection systems. CBs in substations are located in the Bus Auxiliary Yard between the Disconnect Switch (PMS) and the Current Transformer (CT) [9]. CBs interrupt the flow of electricity under load conditions using an arc-extinguishing medium such as SF_6 gas. The crucial role of CBs in substations emphasizes their importance in substation operations [10].

The Bantul Substation is one of the substations located in the Special Region of Yogyakarta and plays a significant role in distributing electricity to the public. To ensure smooth power distribution, the Bantul Substation must have a reliable protection system. This system is necessary so that when disturbances occur in substation equipment, they can be addressed promptly without disrupting consumer comfort in using electricity [11]. One of the protective devices used to safeguard equipment from disturbances is the CB. Power system protection is crucial for maintaining service continuity and safeguarding equipment from disturbances [12]. Substations, essential components of power systems, require protection systems to regulate voltage and address faults promptly [13]. Circuit breakers (CBs) are key protective devices used in various applications, including oil, air, SF6, and vacuum types [13]. Enhanced CB failure protection systems have been developed to ensure fault isolation when designated CBs fail to operate [14]. Protective relays, such as balanced relays for generators and inverse-time-element relays for lines, are vital for system reliability [15]. Disturbance recorders installed in substations enable utilities to monitor and evaluate protective relay equipment, improving fault analysis accuracy [16]. The implementation of effective protection systems is essential for detecting abnormal system behavior, limiting outages, and ensuring overall power system reliability [17, 18].

Therefore, this research aims to analyze the MTBF and Reliability of the 150 kV CB at the Bantul 150 kV Substation as a crucial step to deepen the understanding of CB roles and contribute to maintaining the reliability and safety of the power system at the 150 kV Bantul Substation. The author hopes that this research will provide valuable knowledge and expand the understanding of the importance of MTBF and Reliability in the long-term maintenance of CBs at the 150 kV Bantul Substation.

II. RESEARCH METHODS

This research adopts a descriptive quantitative method, where data is obtained through observation and then analyzed using numerical values and mathematical operations to determine the research results [19]. In this study, the author uses several stages, including the research object, research flow, and data processing.

The object used in this study is the failure data of ten 150 kV circuit breakers owned by PT. PLN (Persero) Bantul Substation, located in Bantul Regency, Special Region of Yogyakarta.

i. Research Flow

This research begins with data collection, which includes initial operation data and 150 kV CB failure data. The 150 kV circuit breakers at Bantul Substation include CB Kopel, CB Godean 1, CB Wates 2, CB Wirobrajan 1, CB Wirobrajan 2, CB Semanu 1, CB Semanu 2, CB Transformer 1, CB Transformer 2, and CB Transformer 3. The data collected spans from 2018 to 2023. From this failure data, the time to failure is identified based on each probability distribution to determine the MTBF and reliability. Figure 1 illustrates the research flow.

ii. Data Processing

Initially, the collected data is identified to determine the failure time distribution of the CBs. Determining this distribution is crucial for reliability analysis and MTBF calculation. First, the median value of failure is identified as shown in Equation 1 [20].

$$F_{ti} = \frac{i - 0.3}{n + 0.4} \tag{1}$$

With: i is the ith failure time data, and n is the number of failure data. Based on [21], the initial distribution identification for each probability distribution is performed.

The normal distribution is shown in Equations 2 and 3.

$$x_i = t_i \tag{2}$$

$$z_i = \Phi^{-1}[F_{ti}] \tag{3}$$

With: t_i is the time period, and z_i is obtained from the Standard Normal probabilities table. The lognormal distribution is shown in Equations 4 and 5.

$$x_i = \ln t_i \tag{4}$$

$$z_i = \Phi^{-1}[F_{ti}] \tag{5}$$

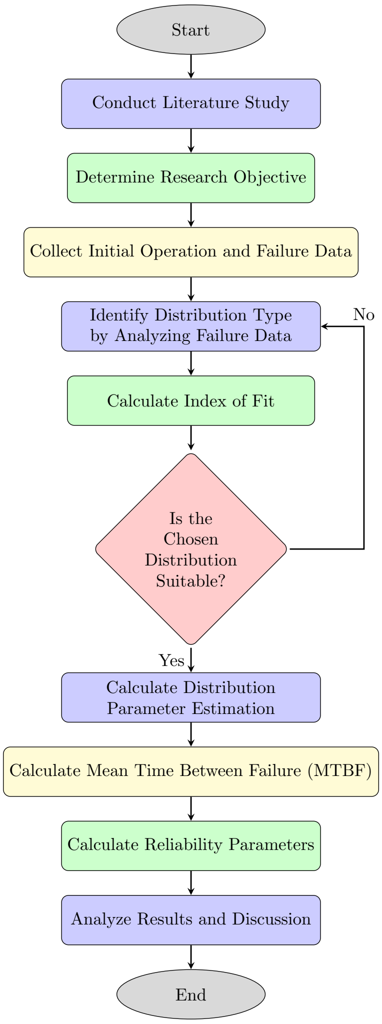

Figure 1: Research flow diagram

With: ln is the natural logarithm. The exponential distribution is shown in Equations 6 and 7.

$$x_i = t_i \tag{6}$$

$$y_i = \ln\left[\frac{1}{1-F(t_i)}\right] \tag{7}$$

The Weibull distribution is shown in Equations 8 and 9.

$$x_i = \ln t_i \tag{8}$$

$$y_i = \ln\left[\ln\left(\frac{1}{1-F_{ti}}\right)\right] \tag{9}$$

After identifying the failure time, the next step is to determine the index of fit (r) for each probability distribution. Based on [20], the calculation of the index of fit (r) is shown in Equation 10.

$$r = \frac{n\sum_{i=1}^{n} x_i y_i - (\sum_{i=1}^{n} x_i)(\sum_{i=1}^{n} y_i)}{\sqrt{(n\sum_{i=1}^{n} x_i^2 - (\sum_{i=1}^{n} x_i)^2)(n\sum_{i=1}^{n} y_i^2 - (\sum_{i=1}^{n} y_i)^2)}} \tag{10}$$

With: n is the number of failure data. The distribution with the highest index of fit value closest to 1 is selected, indicating the distribution that best fits the data.

The next step is to perform a Goodness of Fit Test based on the selected distribution. Equation 11 shows the calculation of the Bartlett test for the exponential distribution [22].

$$B = \frac{2r\left[\ln\left(\frac{1}{r}\right)\sum_{n}^{r} t_i - \left(\frac{1}{r}\right)\sum_{t=1}^{r} \ln t_i\right]}{1+\frac{(r+1)}{6r}} \tag{11}$$

With: r is the number of failures, t_i is the ith failure time data, and B is the test statistic value for the Bartlett test.

The Weibull distribution Goodness of Fit Test uses the Mann's test as shown in Equation 12 [22]. The following section explains the parameter estimation for commonly used distributions based on the MLE method [22].

The main parameters of the normal distribution are μ (mean) and σ (standard deviation). Parameters μ and σ can be calculated using Equations 12 and 13.

$$\mu = \frac{\sum_{i=1}^{n} t_i}{n} \tag{12}$$

$$\sigma = \sqrt{\frac{\sum_{t=1}^{n} (t_i - \mu)^2}{n}} \tag{13}$$

The parameters for the lognormal distribution are μ (mean of the logarithm of data) and s (standard deviation of the logarithm of data). Parameters μ and s can be calculated using Equations 14 and 15.

$$\mu = \frac{\sum_{i=1}^{n} \ln t_i}{n} \tag{14}$$

$$s = \sqrt{\frac{\sum_{t=1}^{n} (\ln t_i - \mu)^2}{n}} \tag{15}$$

The main parameter of the exponential distribution is λ (failure rate), as shown in Equation 16.

$$\lambda = \frac{n}{T} \tag{16}$$

With: $T = \sum_{i=1}^{r} t_i$ is the total failure time. The Weibull distribution has two main parameters: β (shape parameter) and η (scale parameter). The parameter β indicates the shape of the distribution curve, while η determines the scale or time range of failures. Equations 17, 18, and 19 show the calculation of parameters β and η.

$$\beta = m = \frac{\sum_{i=1}^{N} x_i y_i - (\sum_{i=1}^{N} x_i \sum_{i=1}^{N} y_i)/N}{\sum_{i=1}^{N} x_i^2 - [\sum_{i=1}^{N} x_i]^2/N} \tag{17}$$

$$c = \frac{\sum_{i=1}^{N} y_i}{N} - m\frac{\sum_{i=1}^{N} x_i}{N} \tag{18}$$

$$\eta = e^{-c/m} \tag{19}$$

With: m is the same as β, and e is the exponential constant.

After obtaining the distribution parameters, the next step is to determine the MTBF (Mean Time Between Failure). MTBF can be defined as the expected operational time of a device before it fails. A high MTBF value indicates that the device tends to be more reliable and requires fewer repairs during its operation period.

According to [22], MTBF is closely related to the failure time distribution. Below are the MTBF formulas for several probability distributions. For the normal distribution, MTBF is the mean (μ) of the distribution, as shown in Equation 20.

$$\text{MTBF} = \mu \tag{20}$$

For the lognormal distribution, MTBF is shown in Equation 21.

$$\text{MTBF} = e^{\mu+\sigma^2/2} \tag{21}$$

For the exponential distribution, MTBF is the inverse of the failure rate, as shown in Equation 22.

$$\text{MTBF} = \frac{1}{\lambda} \tag{22}$$

For the Weibull distribution, MTBF is obtained from the shape parameter (β) and scale parameter (η), as shown in Equation 23.

$$\text{MTBF} = \eta \cdot \Gamma(1+\frac{1}{\beta}) \tag{23}$$

With: Γ is the standard gamma function. After obtaining the MTBF value, the next step is to calculate the Reliability based on the selected distribution. The equipment reliability parameters include the probability density function (PDF) $f(t)$, representing the probability of failure at a specific time t; the cumulative distribution function (CDF) $F(t)$, representing the probability that a component will fail at time t or earlier; the reliability function $R(t)$, representing the probability that a component will survive until time t; and the hazard rate function $h(t)$, representing the failure rate at time t given that the component is still functioning up to that time. According to [23], the calculations for reliability parameters for each distribution are as follows:

The reliability parameters for the normal distribution are shown in Equations 24 to 27.

$$f(t) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(t-\mu)^2}{2\sigma^2}} \tag{24}$$

$$F(t) = \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{t} e^{-\frac{(t-\mu)^2}{2\sigma^2}}\, dt \tag{25}$$

$$R(t) = 1 - F(t) \tag{26}$$

$$h(t) = \frac{e^{-\frac{(t-\mu)^2}{2\sigma^2}}}{\int_t^\infty e^{-\frac{(t-\mu)^2}{2\sigma^2}}\, dt} \tag{27}$$

The reliability parameters for the lognormal distribution are shown in Equations 28 to 31.

$$f(t) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(\ln t-\mu)^2}{2\sigma^2}} \tag{28}$$

$$F(t) = \Phi\left(\frac{\ln t - \mu}{\sigma}\right) \tag{29}$$

$$R(t) = 1 - F(t) = 1 - \Phi\left(\frac{\ln t - \mu}{\sigma}\right) \tag{30}$$

$$h(t) = \frac{f(t)}{R(t)} \tag{31}$$

The reliability parameters for the exponential distribution are shown in Equations 32 to 35.

$$f(t) = \lambda e^{-\lambda t} \tag{32}$$

$$F(t) = 1 - e^{-\lambda t} \tag{33}$$

$$R(t) = e^{-\lambda t} \tag{34}$$

$$h(t) = \lambda \tag{35}$$

The reliability parameters for the Weibull distribution are shown in Equations 36 to 39.

$$f(t) = \frac{\beta}{\eta}\left(\frac{t}{\eta}\right)^{\beta-1} e^{-\left(\frac{t}{\eta}\right)^\beta} \tag{36}$$

$$F(t) = 1 - e^{-\left(\frac{t}{\eta}\right)^\beta} \tag{37}$$

$$R(t) = e^{-\left(\frac{t}{\eta}\right)^\beta} \tag{38}$$

$$h(t) = \frac{f(t)}{R(t)} = \frac{\beta}{\eta}\left(\frac{t}{\eta}\right)^{\beta-1} \tag{39}$$

III. RESULTS AND DISCUSSION

i. Initial Operation Data of 150 kV Circuit Breakers

The initial operation data of 150 kV circuit breakers (CBs) is essential for analyzing the failure time distribution of the CBs. Collecting the initial operation data provides basic information on the starting age of each device to be analyzed, which will later be compared with the time of failure. Table 1 shows the initial operation data of 150 kV CBs at Bantul Substation.

Understanding the initial operation time of the CBs is crucial for evaluating their reliability and operational lifespan.

Table 1: Initial Operation Data of 150 kV Circuit Breakers

No	CB	Initial Operation Date
1	Kopel	08/07/1999
2	Godean 1	19/03/2004
3	Wates 2	12/09/2002
4	Wirobrajan 1	03/09/1998
5	Wirobrajan 2	03/09/1998
6	Semanu 1	23/04/2003
7	Semanu 2	28/04/2006
8	Trafo 1	18/02/1997
9	Trafo 2	17/03/2014
10	Trafo 3	14/12/1995

ii. Failure Data of 150 kV Circuit Breakers

The data collected in this study includes information on the failure times of each 150 kV CB from January 1, 2018, to December 31, 2023. The failure data is based on the time intervals between failures in months. Table 2 shows the failure data of CB Kopel.

Table 2: Failure Data of CB Kopel

No	Failure Date	Time to Failure (months)
1	March 20, 2019	-
2	June 1, 2020	14.4
3	March 7, 2021	9.2
4	October 14, 2021	7.2
5	March 26, 2022	5.4
6	July 1, 2022	3.2
7	February 19, 2023	7.6
8	July 31, 2023	5.4
9	November 6, 2023	3.2

Table 3 shows the failure data of CB Godean 1. Table 4 shows the failure data of CB Wates 2. Table 5 shows the failure data of CB Wirobrajan 1. Table 6 shows the failure data of CB Wirobrajan 2. Table 7 shows the failure data of CB Semanu 1. Table 8 shows the failure data of CB Semanu 2. Table 9 shows the failure data of CB Trafo 1. Table 10 shows the failure data of CB Trafo 2. Table 11 shows the failure data of CB Trafo 3.

Table 3: Failure Data of CB Godean 1

No	Failure Date	Time to Failure (months)
1	April 29, 2019	-
2	January 6, 2020	8.3
3	November 26, 2020	10.7
4	October 11, 2021	9.5
5	November 23, 2022	12.4
6	September 19, 2023	11.9

Table 4: Failure Data of CB Wates 2

No	Failure Date	Time to Failure (months)
1	June 12, 2019	-
2	March 31, 2020	9.6
3	May 21, 2021	13.7
4	May 30, 2022	12.7
5	September 13, 2023	15.5

Table 5: Failure Data of CB Wirobrajan 1

No	Failure Date	Time to Failure (months)
1	June 2, 2018	-
2	February 28, 2019	9.3
3	April 4, 2020	13.2
4	February 23, 2021	10.7
5	January 19, 2022	10.9
6	November 1, 2022	9.4
7	November 22, 2023	12.7

Failures in circuit breakers (CBs) are critical events in power system operations as they can disrupt electricity supply and affect network reliability. Therefore, collecting data related to CB failure times is an essential step in understanding failure patterns, evaluating reliability, and planning effective maintenance strategies.

iii. Index of Fit for CBs

In calculating MTBF, the Index of Fit (r) serves as a metric to determine the probability distribution that best fits the failure data. To find the best distribution for the CB failure data, this study examines several distributions. The Index of Fit is calculated using four different distributions: normal, lognormal, exponential, and Weibull.

Example calculations based on the failure data of CB Godean 1 show the following Index of Fit (r) values:

1. $r_{\text{normal}} = 0.832$
2. $r_{\text{lognormal}} = 0.834$
3. $r_{\text{exponential}} = 0.760$
4. $r_{\text{Weibull}} = 0.852$

Based on these calculations, the Weibull distribution shows the best fit for the failure data of CB Godean 1. Therefore, the Weibull distribution is selected as the most appropriate probability model to represent the failure pattern of CB Godean 1.

Table 6: Failure Data of CB Wirobrajan 2

No	Failure Date	Time to Failure (months)
1	July 30, 2018	-
2	November 15, 2019	15.5
3	January 6, 2021	13.7
4	April 3, 2022	14.9
5	June 6, 2023	14.1

Table 7: Failure Data of CB Semanu 1

No	Failure Date	Time to Failure (months)
1	January 19, 2019	-
2	June 31, 2019	5.4
3	January 28, 2020	6.9
4	July 25, 2020	6.1
5	March 19, 2021	7.8
6	August 28, 2021	5.3
7	February 13, 2022	6.5
8	October 10, 2022	7.9
9	May 4, 2023	6.8
10	December 7, 2023	7.1

iv. Goodness of Fit Test for CBs

The application of distributions based on failure data is evaluated using the Goodness of Fit Test. After conducting the distribution fit test, the Weibull distribution proved to be the most suitable for representing the observed data. This selection is based on the Index of Fit (r) value, indicating that the Weibull distribution fits the data better than the other distributions. This analysis aims to test whether the observed data follows a specific probability distribution pattern. Two hypotheses are proposed: H_0, which states that the data follows the selected distribution, and H_1, which states that the data does not follow the distribution. The comparison between these hypotheses determines the data's fit with the analyzed distribution.

The test is conducted using Mann's Test because the CB Godean 1 failure data follows a Weibull distribution, yielding the highest Index of Fit. With a 95% confidence interval ($\alpha = 0.05$):

1. H_0: The failure data of CB Godean 1 follows a Weibull distribution.
2. H_1: The failure data of CB Godean 1 does not follow a Weibull distribution.

After calculations, the computed value for the Weibull distribution (M) is 1.481, and the critical value from the F-distribution table is 6.388. Thus:

$$M_{\text{calculated}} < M_{\text{table}} \quad \Rightarrow \quad 1.481 < 6.388$$

Based on the hypothesis testing results, the null hypothesis (H_0) is not rejected, and the alternative hypothesis (H_1) is rejected, indicating that the failure data for CB Godean 1 passes the Goodness of Fit Test and follows a Weibull distribution.

Table 8: Failure Data of CB Semanu 2

No	Failure Date	Time to Failure (months)
1	August 1, 2018	-
2	December 10, 2018	4.3
3	May 22, 2019	5.4
4	October 19, 2019	4.9
5	April 7, 2020	5.6
6	September 4, 2020	6.1
7	December 28, 2020	4.2
8	May 19, 2021	4.7
9	November 13, 2021	5.8
10	April 9, 2022	5.2
11	November 18, 2022	6.7
12	April 6, 2023	5.4

Table 9: Failure Data of CB Trafo 1

No	Failure Date	Time to Failure (months)
1	December 23, 2018	-
2	June 11, 2019	5.6
3	February 27, 2020	8.5
4	October 21, 2020	7.8
5	May 12, 2021	6.7
6	April 15, 2022	9.1
7	December 24, 2022	8.3
8	September 15, 2023	9.3

v. Weibull Distribution Parameters for CBs

After the distribution fit test, the Weibull distribution is confirmed as the most suitable for representing the failure data of CB Godean 1. The next step is to determine the parameters of this Weibull distribution. The Weibull distribution is commonly used in reliability analysis due to its flexibility in accommodating various failure distribution shapes. The main parameters to be calculated for the Weibull distribution are the shape parameter (β) and scale parameter (η). These parameters provide essential information about the characteristics of the failure data.

According to [22], the β and η parameters based on the Weibull distribution for CB Godean 1 yield a shape parameter (β) of 5.36 and a scale parameter (η) of 11.44.

Table 10: Failure Data of CB Trafo 2

No	Failure Date	Time to Failure (months)
1	March 24, 2019	-
2	September 30, 2019	6.2
3	May 12, 2020	7.3
4	December 31, 2020	7.7
5	March 16, 2021	6.5
6	November 4, 2021	7.7
7	July 7, 2022	8.1
8	March 29, 2023	8.7
9	October 26, 2023	6.9

Table 11: Failure Data of CB Trafo 3

No	Failure Date	Time to Failure (months)
1	September 10, 2018	-
2	July 23, 2019	10.4
3	June 24, 2020	12.9
4	June 9, 2021	11.5
5	June 27, 2022	12.6
6	August 21, 2023	13.8

vi. Mean Time Between Failure (MTBF) for CBs

The Mean Time Between Failure (MTBF) indicates how long equipment can operate before experiencing failure. MTBF calculation is performed after the distribution parameters are determined. The parameters used in the MTBF calculation depend on the selected distribution. For the Weibull distribution, the parameters used are the shape parameter (β) and scale parameter (η).
The MTBF calculation for CB Godean 1 is 10.55 months. This MTBF value indicates that the average time before failure occurs for CB Godean 1 is approximately 10.55 months. Thus, this result can be used to develop a more effective maintenance schedule, enhancing reliability and operational efficiency.

vii. Reliability of 150 kV Circuit Breakers

Based on [22], the reliability calculations for CB Godean 1 yield the following parameter values.

$$f(t) = 1.12 \times 10^{-5}$$

This $f(t)$ value indicates that the probability of failure at $t = 1$ is 0.001

$$F(t) = 2.10 \times 10^{-6}$$

This $F(t)$ value indicates that the expected probability of failure for CB Godean 1 at $t = 1$ is 0.0002

$$R(t) = 9.99 \times 10^{-1}$$

This $R(t)$ value indicates that the probability of CB Godean 1 functioning without failure at $t = 1$ is 99.9

$$h(t) = 1.12 \times 10^{-5}$$

The function $h(t)$ measures the failure rate at $t = 1$, given that CB Godean 1 has survived up to that time.

viii. Summary of MTBF and Reliability Parameters

This study analyzed the MTBF and reliability parameters for ten 150 kV CBs at Bantul Substation. Each CB was analyzed using the appropriate probability distribution to calculate MTBF and its reliability parameters. The following tables summarize the analysis results, including the probability of failure $f(t)$, cumulative distribution function $F(t)$, reliability function $R(t)$, failure rate $h(t)$, and MTBF in months. These results provide insights into the performance of each CB and guide maintenance strategies to ensure the reliability of the power system at Bantul Substation.

Table 12: PDF and CDF Parameters for 150 kV CBs at Bantul Substation

No	CB	$f(t)$	$F(t)$
1	Kopel	1.24×10^{-1}	1.34×10^{-1}
2	Godean 1	1.12×10^{-5}	2.10×10^{-6}
3	Wates 2	3.12×10^{-5}	6.96×10^{-6}
4	Wirobrajan 1	9.63×10^{-3}	4.00×10^{-3}
5	Wirobrajan 2	6.40×10^{-2}	6.60×10^{-2}
6	Semanu 1	1.98×10^{-3}	5.31×10^{-4}
7	Semanu 2	5.83×10^{-3}	1.00×10^{-3}
8	Trafo 1	3.04×10^{-4}	6.89×10^{-5}
9	Trafo 2	9.52×10^{-5}	1.83×10^{-5}
10	Trafo 3	2.09×10^{-8}	2.71×10^{-9}

ix. Analysis of MTBF and Reliability of 150 kV CB

For CB Godean 1, the distribution used to calculate MTBF and reliability is the Weibull distribution. The Probability Density Function (PDF) $f(t)$ graph of this distribution indicates that CB Godean 1 has a high probability of failure at the beginning of its operation, which then decreases over time. This indicates that CB Godean 1 is more prone to failure during the early months of operation up to the MTBF. The highest probability of failure occurs in the initial months and then decreases over time past the MTBF. The Mean Time Between Failure (MTBF) shows the average operating

Table 13: Reliability and Hazard Rate Parameters for 150 kV CBs at Bantul Substation

No	CB	$R(t)$	$h(t)$
1	Kopel	8.65×10^{-1}	1.43×10^{-1}
2	Godean 1	9.99×10^{-1}	1.12×10^{-5}
3	Wates 2	9.99×10^{-1}	3.12×10^{-5}
4	Wirobrajan 1	9.99×10^{-1}	9.68×10^{-3}
5	Wirobrajan 2	9.33×10^{-1}	6.80×10^{-2}
6	Semanu 1	9.99×10^{-1}	1.98×10^{-3}
7	Semanu 2	9.98×10^{-1}	5.84×10^{-3}
8	Trafo 1	9.99×10^{-1}	3.05×10^{-4}
9	Trafo 2	9.99×10^{-1}	9.52×10^{-5}
10	Trafo 3	9.99×10^{-1}	2.09×10^{-8}

Table 14: MTBF and Selected Distribution for 150 kV CBs at Bantul Substation

No	CB	MTBF (months)	Selected Distribution
1	Kopel	6.95	Exponential
2	Godean 1	10.55	Weibull
3	Wates 2	12.87	Weibull
4	Wirobrajan 1	12.40	Weibull
5	Wirobrajan 2	14.55	Exponential
6	Semanu 1	6.83	Weibull
7	Semanu 2	5.48	Weibull
8	Trafo 1	7.97	Weibull
9	Trafo 2	7.56	Weibull
10	Trafo 3	12.20	Weibull

time of the CB without failure, which is 10.55 months. The PDF graph is illustrated in Figure 2 below.

Another reliability parameter is the Cumulative Distribution Function (CDF) $F(t)$ derived from the Weibull distribution. The $F(t)$ graph shows that CB Godean 1 has a high cumulative probability of failure over time. This is indicated by the shape of the $F(t)$ curve, which rises quickly initially and then approaches 1 over time. The CDF graph for CB Godean 1 is illustrated in Figure 3 below.

Another reliability parameter is the Reliability Function $R(t)$. The $R(t)$ graph of the Weibull distribution shows that CB Godean 1 has a high reliability probability at the beginning of operation, which then decreases over time. The MTBF indicates the average operating time before failure occurs. Figure 4 illustrates the reliability function for CB Godean 1.

Another reliability parameter is the Hazard Rate $h(t)$ derived from the Weibull distribution. The hazard rate graph for the Weibull distribution is not flat due to the flexibility of this distribution, which is determined by the shape parameter (β) and the scale parameter (η). The β value for CB Godean 1 is 5.36. If β is greater than 1, the hazard rate increases over time. The $h(t)$ value for CB Godean 1 is illustrated in Figure 5.

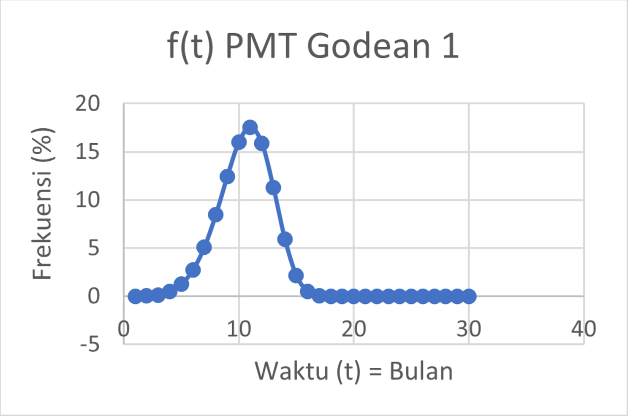

Figure 2: Probability Density Function of CB Godean 1

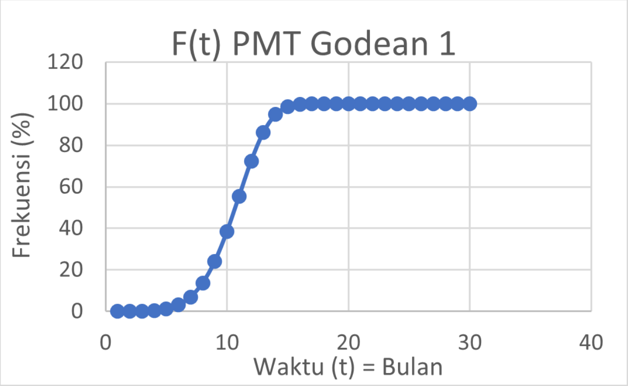

Figure 3: Cumulative Distribution Function of CB Godean 1

Besides the Weibull distribution, other distributions are also present in the failure data, such as the exponential distribution. An example of CB failure data that follows an exponential distribution is CB Wirobrajan 2.

For CB Wirobrajan 2, the distribution used to calculate MTBF and reliability is the exponential distribution. The $f(t)$ graph shows that CB Wirobrajan 2 has a high probability of failure at the beginning of operation and decreases exponentially over time. Although the failure data indicates increasingly shorter intervals, the exponential distribution provides the best model to represent the overall failure pattern, as shown by the index of fit calculation. The average operating time before failure is approximately 14.55 months, which means that, in the long term, one failure is expected to occur every 14.55 months. The PDF graph is illustrated in Figure 6 below.

Another reliability parameter is the Cumulative Distribution Function (CDF) $F(t)$ derived from the exponential distribution. CB Wirobrajan 2 has a cumulative probability of failure that increases over time. Initially, the cumulative probability of failure is low but increases sharply after a few months. The average oper-

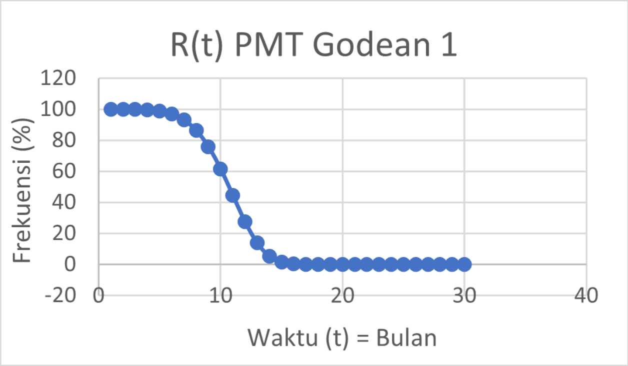

Figure 4: Reliability Function of CB Godean 1

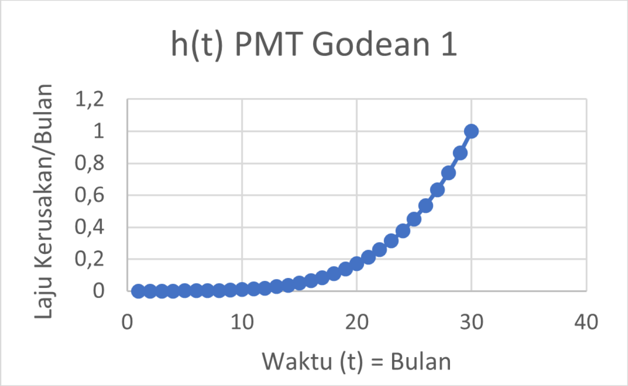

Figure 5: Hazard Rate of CB Godean 1

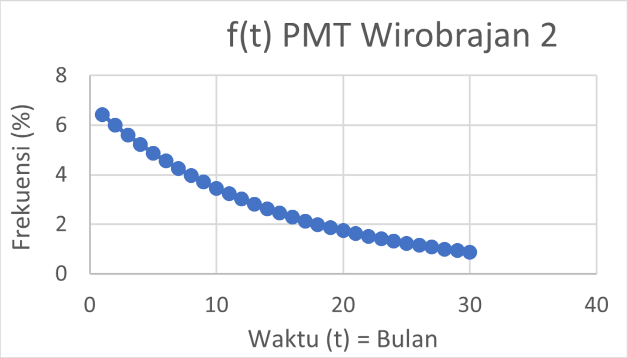

Figure 6: Probability Density Function of CB Wirobrajan 2

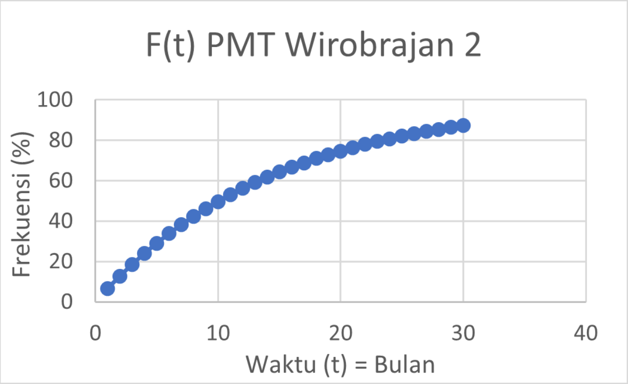

Figure 7: Cumulative Distribution Function of CB Wirobrajan 2

ating time before failure is approximately 14.55 months. The CDF graph for CB Wirobrajan 2 is illustrated in Figure 7 below.

Another reliability parameter is the Reliability Function $R(t)$. The exponential $R(t)$ graph shows that CB Wirobrajan 2 has a high reliability probability at the beginning of operation, which decreases over time. Figure 8 illustrates the reliability function for CB Wirobrajan 2.

Another reliability parameter is the Hazard Rate $h(t)$ derived from the exponential distribution. The hazard rate graph for the exponential distribution of CB Wirobrajan 2 is flat because this distribution has a characteristic constant failure rate over time. This means that the likelihood of failure at any given time does not depend on the previous operation time. In reliability analysis, the exponential distribution is used because of its ”memoryless” property, meaning that the probability of failure remains the same at any point in time, resulting in a flat hazard rate graph. CB Wirobrajan 2’s hazard rate is illustrated in Figure 9.

IV. CONCLUSION

From the analysis conducted, the following conclusions can be drawn. The MTBF analysis of 150 kV CBs at Bantul Substation shows a varied average failure period among the CBs. The highest MTBF is for CB Wirobrajan 2, with an average failure interval of approximately 14.55 months. The lowest MTBF is for CB Semanu 2, with an average failure interval of 5.48 months. These results provide insights into the frequency of CB failures and facilitate more effective maintenance planning to enhance system reliability.

The analysis results for the probability of failure, cumulative failure probability, reliability probability, and failure rate of 150 kV CBs indicate significant variations among different CBs. The lowest probability of failure $f(t)$ is for CB Trafo 3, nearing zero, while the highest $f(t)$ is for CB Kopel (1.24×10^{-1} failures/month). The lowest cumulative failure probability $F(t)$ is for CB Trafo 3, nearing zero, while the highest $F(t)$ is for CB Kopel (13.4% in the first month). The lowest hazard rate $h(t)$ is for CB Trafo 3, nearing zero, while the highest $h(t)$ is for CB Kopel (0.143 failure rate/month). These results indicate significant differences in the reliability performance of CBs at Bantul Substation.

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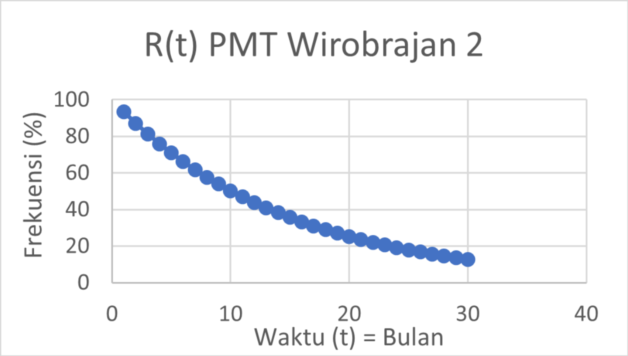

Figure 8: Reliability Function of CB Wirobrajan 2

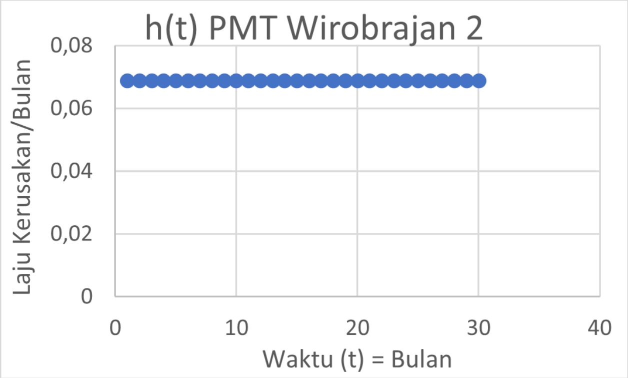

Figure 9: Hazard Rate of CB Wirobrajan 2

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