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Analysis of Transformer Service Life Prediction at Traction Substation Cipete Raya MRT Jakarta Based on Temperature and Load Using Linear Regression Method.

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Abstract*. PT Mass Rapid Transit Jakarta operates a mass transportation system from Lebak Bulus Station to Bundaran HI. One of the traction substations is located in Cipete Raya, with a voltage rating of 20kV/1.2kV. A critical piece of equipment in this substation is the traction transformer, with a capacity of 4850 kVA/2x2500 kVA. The purpose of this study is to predict the service life of the Cipete Raya traction transformer based on temperature and load using the linear regression method. This study employs direct observation, analyzing load data from traction transformers 1 and 2 at Cipete Raya from January 2022 to June 2024, along with transformer temperature measurements. Secondary data include the technical specifications of the Cipete Raya traction transformer. The linear regression analysis for transformer 1 yields the equation y = 687.42 + 11.97x, indicating a 5.75% annual increase over the next 5 years, with a very strong correlation coefficient of R = 0.919. For transformer 2, the equation is y = 815.4543 + 6.488x, showing a 3% annual increase, with a strong correlation coefficient of R = 0.814. Based on the transformer aging calculations for June 2024, Transformer 1 has a per unit aging value (V) of 0.0014 and an estimated service life (n) of 407.689 years, while Transformer 2 has a V of 0.0012 and an estimated service life of 496.77 years. The aging model evaluation using MAPE shows that the prediction accuracy for transformers 1 and 2 is 6% and 3%, respectively, indicating excellent modeling performance.*

Keywords: *Traction Transformer, Traction Substation, Regression Linier, MRTJ*

1. INTRODUCTION

One of the critical pieces of equipment at a traction substation is the Traction Transformer. The Cipete Raya substation is equipped with two transformers that have been operational since 2017, with a capacity of 4850 kVA / 2x2500 kVA to supply the load for the electric rail trains running from Lebak Bulus to ASEAN, both upstream and downstream. The Mass Rapid Transit (MRT) Jakarta system employs various operational patterns. The peak hour operation pattern uses a headway of 5 minutes, while the non-peak hour operation pattern utilizes a headway of 10 minutes (MRT Jakarta, 2016). Additionally, the MRT Jakarta operational policy has undergone changes from 2022 to 2024 due to the government’s new normal COVID-19 regulations, which has impacted the load on the transformers. The transformers at the Cipete Raya traction substation are located indoors. Therefore, it is crucial to maintain the indoor air temperature and humidity. The aging of the transformers can be analyzed based on several internal and external factors. According to standards, transformers are typically designed to operate at ambient temperatures between 20°C and 22°C. However, in tropical climates, transformers can function effectively within ambient temperatures ranging from 30°C to

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40°C (Juwita & Liliana, 2023; Sahwidi, 2022). Load factors can influence the hotspot temperature of transformers. The lower the load, the lower the hotspot temperature will be. Conversely, higher loads result in higher hotspot temperatures (Juwita & Liliana, 2023; Maulana, 2021; Ramona Diningsih & Situmeang, 2022). If the transformer experiences a hotspot temperature exceeding 98°C, its aging will accelerate significantly, potentially reducing the expected lifespan of the transformer (Maruf & Primadiyono, 2021; Sahwidi, 2022). Based on the issues mentioned, efforts to ensure that traction transformers maintain reliability according to technical specifications are essential. This study aims to predict the service life of the transformers at the Cipete Raya MRT Jakarta traction substation based on temperature and load using linear regression methods.

2. THEORITICAL REVIEW

Transformer

A transformer is an electrical device that transfers and transforms electrical energy from one or more electrical circuits to another through a magnetic coupling, based on the principle of electromagnetic induction. A transformer consists of two parts: the primary side (input) and the secondary side (output), with each part consisting of coils of copper wire or windings (Djufri, 2021; Ramona Diningsih & Situmeang, 2022).

Traction Transformer

The Cipete Raya Traction Substation is owned by MRT Jakarta. It receives incoming power at 20 kV, which is then reduced to 1200 V AC and subsequently rectified to 1500 V DC to meet the load requirements of the trains (MRT Jakarta, 2016).

Figure 1. Traction Transformator

Silicon Rectifier

The Silicon Rectifier (SR) is a component within the traction substation that functions as a rectifier, converting the voltage from the Rectifier Transformer from 1200 VAC to 1500 VDC. Inside the SR, there are rectifiers known as diodes; diodes are a type of uncontrolled rectifier. (Maulana, 2021; MRT Jakarta, 2016)

Overhead Contact System

The Overhead Contact System (OCS) is an electrical conductor system used to transmit and supply power from the Traction Substation (TSS) to the rolling stock via the pantograph. The OCS includes several components, such as the Feeding System, Catenary System, Supporting Facilities, and Protection System. (Sumarsono, 2020)

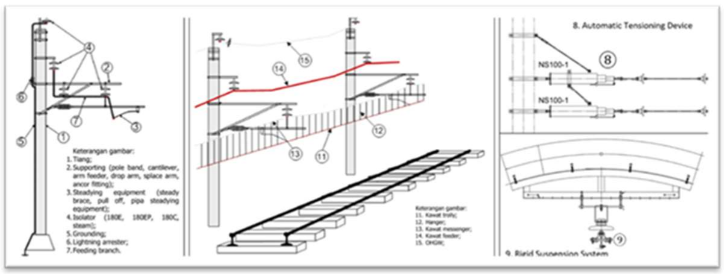


Figure 2. Overhead Contact System in MRTJ

Linear Regression Method

Linear regression is a method used to establish and express a functional relationship between variables through a mathematical equation. Equation 1 represents a simple linear regression model employed to predict transformer load. The analysis focuses on daily load variations, with the methodology based on predicting transformer load through linear regression analysis. The outcome is a trend equation that facilitates forecasting future loads. (Harlan, 2018; Listiyarini, 2018)

$$Yt = a + b.\ Xt$$

Description:

Yt = Load at time t

Xt = Time period t

a = Constant

b = Regression coefficient

The equations for determining a and b can be found using the following equations:

$$a = \frac{(\sum Y)(\sum X^2) - (\sum X)(\sum XY)}{(n)(\sum X^2) - (\sum X)^2}$$

$$b = \frac{(n)(\sum XY) - (\sum X)(\sum Y)}{(n)(\sum X^2) - (\sum X)^2}$$

Description:

$\sum Y$ = Totally of transformer load.

$\sum X$ = Number of data collection per month.

n = The number of X and Y variables

Correlation is a method used to determine the strength of the relationship between two or more different variables, described by the correlation coefficient. The correlation coefficient quantifies the degree of association between two or more variables. The magnitude of the correlation coefficient does not indicate a causal relationship between the variables but rather describes the linear relationship between them. (Hulu, S., & Sinaga, 2019; Nugroho, 2005)

Table 1. Correlation Closeness Level Table

Correlation Coefficient Interval	Degree of Correlation
0-0,20	Vey Low
0,21-0,40	Low
0,41-0,70	Medium
0,71-0,90	Strong
0,91-0,99	Very Strong
1	Perfect

$$R = \frac{n(\sum XY) - (\sum X)(\sum Y)}{\sqrt{\{n(\sum X^2) - (\sum X)^2\}\{n(\sum Y^2) - (\sum Y)^2\}}}$$

Description:

R = Correlation Coefficient

$\sum Y$ = Totally of transformer load.

$\sum X$ = Number of data collection per month.

n = The number of X and Y variables

Calculation of Transformer Life Reduction

According to the State Electricity Company (PLN) standards, transformers used in Indonesia operate at a maximum temperature of 40°C. This is due to Indonesia's average daily and annual temperature being around 30°C. The reduction in transformer lifespan is influenced by the operating temperature. (Igirisa et al., 2021; Maulana, 2021)

$$\emptyset_h = beban\ transformator\ (\%) x\ T_{max}$$

$$V = 2^{\frac{\emptyset H - 98}{6}}$$

Description:

V = Relative velocity (p.u)

$\emptyset$H = Hot temperature point (°C)

Tmax= Winding Temperature (98°C)

Equation 2.8 can be used to calculate the reduction in transformer lifespan as follows (Pandapotan & Warman, 2013; Shafira et al., 2022):

$$\text{Reduction of transformer lifespan (\%)} = \frac{s.u}{t} x\ 100$$

$$\text{Estimated service life -n} = \frac{Base\ life - n}{Reduction\ of\ transformer\ lifespan}$$

Description:

t = time (hour)

umur dasar = 20,55 year

n = Initial Installation Year

Hotspot temperature refers to the hottest condition of a transformer component, occurring at the transformer's windings. The heat generated leads to the degradation of transformer components, which can accelerate the transformer's aging process. The reduction in a component's performance due to heat is known as aging. (Gultom et al., 2017; Pandapotan & Warman, 2013)

Table 2. Transformer Aging Value According to IEC 354

Temp. Belilitan (^{O}C)	80	86	92	98	104	110	116	122	128	134	140
Susut Umur (p.u)	0,125	0,25	0,5	1	2	4	8	16	32	64	128
Perkiraan Umur (Thn)	>20	>20	>20	20	10	5	2,5	1,25	0,6	0,51	0,16

MAPE (Mean absolute Percentage Error)

Mean Absolute Percentage Error (MAPE) is the average absolute difference between predicted values and actual values, expressed as a percentage of the actual values. The use of Mean Absolute Percentage Error (MAPE) in evaluating forecasting results allows for measuring the accuracy level between forecasted figures and actual figures. The Mean Absolute Percentage Error (MAPE) can be calculated using the following equation (Nabillah & Ranggadara, 2020; Ruspendi et al., 2022):

$$MAPE = \frac{1}{n}\Sigma_{i=1}^{n}\left|\frac{y-y'}{y}\right| x\ 100\%$$

Description:

MAPE : Mean Absolute Percentage Error

n : number of data points

y : Actual Value

y' : Predicted value

For MAPE, there is a range of values that can be used as a benchmark to assess the performance of a forecasting model, as shown in the following table:

Table 3. MAPE Value

MAPE Value	Remark
<10%	Forecasting Model is Excellent
10-20%	Forecasting Model is Good
20-50%	Forecasting Model is Sufficent
>50%	Model Peramalan Poor

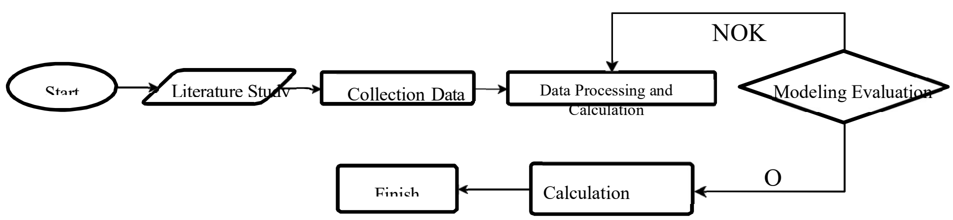
3. RESEARCH METHODS

This study employs a field research methodology, which includes direct surveys of the Traction Transformer Cipete Raya equipment.

Data Collection

1. Traction transformer loading data for Cipete Raya 1 and 2 from January 2022 to June 2024. The data was obtained from the SCADA Power MRTJ logger withdrawal.
2. Data on environmental temperature measurements, winding temperature, transformer oil temperature and N2 gas pressure that were monitored directly for 24 hours. The data was obtained from the measurement instrumentation found on the traction transformer.
3. Technical specification data of traction transformer 1 and 2 equipment Cipete Raya MRT Jakarta.

Research Flowchart



4. RESULT AND DISCUSSION

Transformer 1 Load Prediction

To determine the forecasted lifespan of the transformer, the linear regression trend equation y=687.42+11.97x must first be established. Based on this equation, the load prediction for the next 5 years is expected to increase by 5.75% annually. From the correlation coefficient calculation above, a value of R=0.919 was obtained, indicating that the correlation between X and Y is very strong according to the correlation strength table.

Table 4. Transformer 1 Load Prediction Results

Prediction of load Transformer			
Year	Month of -x	y = 11,97x + 687,42	Percentage
2022	12	831,06	33%
2023	24	974,7	39%
2024	36	1118,34	45%
2025	48	1261,98	50%
2026	60	1405,62	56%

Figure 3. Graphic of Transformer 1 Load Prediction

Transformer 2 Load Prediction

To determine the forecasted lifespan of the transformer, the linear regression trend equation y=815,4543+6,488x must first be established. Based on this equation, the load prediction for the next 5 years is expected to increase by 3% annually. From the correlation coefficient calculation above, a value of R=0,814 was obtained, indicating that the correlation between X and Y is very strong according to the correlation strength table.

Table 4. Transformer 2 Load Prediction Results

Prediksi Beban			
Tahun	Bulan ke- x	y = 6,488x + 815,454	Persentase
2022	12	893,31	36%
2023	24	971,166	39%
2024	36	1049,022	42%
2025	48	1126,878	45%
2026	60	1204,734	48%

Figure 4. Graphic of Transformer 2 Load Prediction

Prediction of Transformer 1 Aging

The aging of the Cipete Raya traction transformers can be determined, in part, by analyzing the load parameters. Based on the transformer load predictions for the years 2022–2026, it is possible to estimate the lifespan of Cipete Raya traction transformers 1 and 2. From the calculations, for the 30th month (June 2024), the values obtained were y=1046.52, $\emptyset_h = 41{,}16°C$, V= 0.0014 p.u., and n= 407,689 years. As a result, the expected reduction in the lifespan of the traction transformers over the next 5 years was calculated. The Mean Absolute Percentage Error (MAPE) was found to be 6%, indicating the need for further evaluation of the transformer lifespan prediction model to assess its performance.

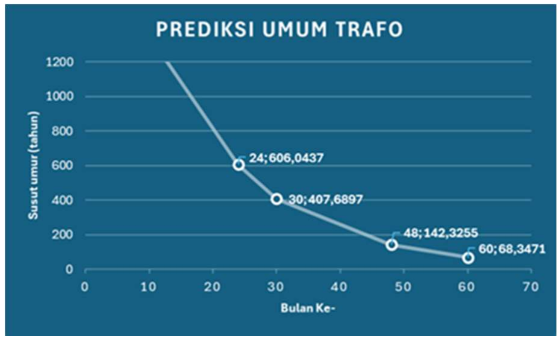


Figure 5. Graphic of Predicted Aging of Traction Transformer 1

Prediction of Transformer 2 Aging

The aging of the Cipete Raya traction transformers can be determined, in part, by analyzing the load parameters. Based on the transformer load predictions for the years 2022–2026, it is possible to estimate the lifespan of Cipete Raya traction transformers 2 and 2. From the calculations, for the 30th month (June 2024), the values obtained were y=1010,094 $\emptyset_h = 39{,}5°C$, V= 0.0012 p.u., and n= 497,77 years. As a result, the expected reduction in the lifespan of the traction transformers over the next 5 years was calculated. The Mean Absolute Percentage Error (MAPE) was found to be 4%, indicating the need for further evaluation of the transformer lifespan prediction model to assess its performance.

Figure 5. Graphic of Predicted Aging of Traction Transformer 2

5. CONCLUSION

Based on the discussion conducted under the title "Analysis of Predicted Lifespan of Transformers at Cipete Raya MRT Jakarta Traction Substation Based on

Temperature and Load Using Linear Regression Method," the following conclusions were drawn:

1. Based on the calculation of transformer aging, the predicted lifespan of Cipete Raya MRT Jakarta traction transformers 1 and 2 was determined using the linear regression method. Transformer 1 showed an increasing trend from 2022 to 2026, with an average annual increase of 5.75%. As a result, the estimated lifespan for Transformer 1 by the 30th month (June 2024) is 407.689 years. Similarly, Transformer 2 experienced a load increase of 3%, leading to an estimated lifespan of 496.77 years by the 30th month (June 2024).
2. The predictive load analysis for Cipete Raya MRT Jakarta traction transformers 1 and 2 was evaluated using the Mean Absolute Percentage Error (MAPE) method. The MAPE value for Transformer 1 was found to be an average of 6%, while Transformer 2 had a MAPE value of 4%. MAPE value of less than 10% indicates that the prediction method is highly accurate.

6. SUGGESTION

Based on the discussin conducted under the title "Analysis of Predicted Lifespan of Transformers at Cipete Raya MRT Jakarta Traction Substation Based on Temperature and Load Using Linear Regression Method," the following suggestions can be made for further research:

1. This study can serve as a reference and recommendation for other researchers or companies for further analysis related to the reliability of the Cipete Raya MRT Jakarta traction transformers.
2. It is recommended that transformer load data be collected for more than 3 years to facilitate data processing using the linear regression method.
3. It is also recommended to increase the quantity of instrumentation data for the Cipete Raya traction transformers to ensure more accurate and valid analysis results.

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