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Maximize The Reliability of A Distribution System Based on Data Monitoring on Distribution Transformer Power Using The Fuzzy Decision Making Method Based on The Analytical Hierarchy Process (AHP)

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ABSTRACT

Distribution transformers are critical components in the electric power distribution system. Transformer failure can cause power outages and economic losses, so a systematic reliability evaluation method is needed. Previous studies generally evaluate reliability based on damage data parameters. The novelty of this study lies in the integration of four operating parameters (voltage, power factor, unbalance, and loading) simultaneously using the Fuzzy Decision Making method based on the Analytical Hierarchy Process. This study aims to analyze and determine the reliability ranking of three distribution transformer units based on monitoring data at Peak Load Time. The AHP weighting results show that power factor has the highest weight (0.47), followed by loading (0.27), unbalance (0.16), and voltage (0.10) with a Consistency Ratio of 0.012 (valid). The analysis results show that the East Transformer has the highest reliability index (73% - Good), the North Transformer (71% - Good), and the South Transformer (50.9% - Sufficient). The South Transformer requires priority repair due to high underload and unbalance conditions.

Keywords: *Reliability Index, Distribution Transformer, Fuzzy Decision Making, Analytical Hierarchy Process, Unbalance, Transformer Maintenance.*

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INTRODUCTION

The electrical power system constitutes a fundamental infrastructure designed to generate, transmit, and distribute electrical energy safely, reliably, and efficiently to consumers. Within the architecture of electrical power systems, the distribution network occupies a strategic position as the final link between transmission networks and end consumers. The success of distribution systems is determined by two main aspects, namely service continuity and reliability index that reflects the system stability level based on measurable parameters[1]. Distribution transformers represent crucial components in distribution networks that function to regulate voltage at various levels, from generators to end consumers[2][3].

Technical problems in distribution networks include voltage drop, load unbalance, and suboptimal power factor[4][5]. The load characteristics transmitted through transformers fluctuate with Peak Load Time (WBP) and Off-Peak Load Time (LWBP) patterns that can affect transformer performance[6]. Load increases during peak periods enlarge losses in the core and windings, resulting in working temperature rise and efficiency degradation[7][8]. Therefore, a systematic reliability evaluation method is required to detect non-optimal operating conditions at an early stage.

Conventional methods in analyzing system reliability generally rely only on direct measurements and manual calculations with limitations in accommodating the complexity of operational data. Xu et al.[9]implemented the Analytical Hierarchy Process (AHP) method integrated with fuzzy logic to support decision-making based on technical criteria. The fuzzy approach enables the determination of transformer reliability conditions with a high probability level based on testing and measurement parameter results[10][11]. Fuzzy logic has been widely applied in the electrical power field for power quality detection and classification as well as ensuring electrical energy system reliability[12].

The utilization of Fuzzy Decision Making based on AHP demonstrates advantages in constructing problem hierarchy structures and establishing priority weights for each criterion through pairwise comparison processes[13]. Afrane et al.[14] and Pérez-Briceño et al. [15] utilized the advantages of fuzzy in processing uncertain data to produce adaptive decision recommendations. The Fuzzy Decision Making model based on AHP is capable of determining the most efficient alternative by considering correlations among criteria and uncertainty in assessment[16].

Previous research generally evaluated transformer reliability based on single parameters or utilized historical failure data. The novelty of this research lies in the simultaneous integration of four operational parameters (average voltage, power factor, unbalance, and loading) using the Fuzzy Decision Making method based on AHP with actual monitoring data during Peak Load Time (WBP). This approach produces a transformer reliability index that is more accurate, proportional, and representative of field conditions. The objective of this research is to analyze and determine the reliability ranking of three distribution transformer units and generate data-based technical recommendations for system reliability improvement.

Previous research generally evaluated transformer reliability based on single parameters or utilized historical failure data. The novelty of this research lies in the simultaneous integration of four operational parameters (average voltage, power factor, unbalance, and loading) using the Fuzzy Decision Making method based on AHP with actual monitoring data during Peak Load Time (WBP). This approach produces a transformer reliability index that is more accurate, proportional, and representative of field conditions. The objective of this research is to analyze and determine the reliability ranking of three distribution transformer units and generate data-based technical recommendations for system reliability improvement.

METHODS

This research uses a quantitative, simulation-based approach utilizing the Fuzzy Decision Making (FDM) method based on the Analytical Hierarchy Process (AHP) as the primary analytical framework. The research design is

descriptive-evaluative, aiming to assess and improve the reliability of the transformer distribution system through a comprehensive and systematic analysis of operational monitoring data.

The research subjects are three distribution transformer units: a 500 kVA north transformer, a 500 kVA east transformer, and a 1600 kVA south transformer located in the PT Petrokimia Gresik Official Housing Complex, East Java, Indonesia. The three transformers—the North Transformer, the East Transformer, and the South Transformer operate in a 3-phase distribution system with a Delta primary (6 kV) and Wye secondary (380V/220V) configuration. The selection of these three transformers was based on considerations of homogenous load characteristics (employee housing with commercial components such as supermarkets, cafes, and restaurants), identical capacities, and similar operational conditions within a single integrated distribution system. The research was conducted in the period from December 2025 to January 2026 with a focus on data collection in the period from 24-28 July 2025.

Data collection was carried out through direct measurement of electrical parameters in the outgoing panel (Low Voltage Main Distribution Panel) of each transformer using the spot measurement method at Peak Load Time (WBP) at 17.00 WIB. The selection of the measurement location in the outgoing panel was based on work safety considerations because it was on the low voltage side (380V). The measuring instruments used included a digital multimeter for measuring three-phase current (IR, IS, IT), for measuring line-to-line voltage (VRS, VST, VTR), and a power meter for measuring power factor, active power (kW), and apparent power (kVA). All instruments have been calibrated according to standards and have valid calibration certificates. Data collection was carried out with the assistance of authorized technicians from PT Petrokimia Gresik and following strict work safety (K3) procedures including the use of complete Personal Protective Equipment (PPE) and approved work permits.

The raw data obtained from the measurements are then processed through technical calculations to produce derived parameters that serve as criteria for assessing reliability. The average current is calculated using the formula:

$$I_{avarage} = \frac{I_R + I_S + I_T}{3}$$

Average voltage using the formula:

$$V_{avarage} = \frac{V_R + V_S + V_T}{3}$$

Transformer loading percentage using the formula:

$$I_{FL} = \frac{\text{S}}{\sqrt{3} \times V}$$

Where IFL is the full load current calculated from formula:

$$S = \sqrt{3} \times V \times I$$

Where S is the transformer power in kVA and V is the secondary voltage in kV, while the percentage of load unbalance is calculated using the formula:

$$uL = \frac{|a-1|+|b-1|+|c-1|}{3} \times 100\%$$

Where Imax represents the highest current among the three phases. The determination of criteria weights was performed using the Analytical Hierarchy Process (AHP) based on structured interviews and expert judgment. The experts involved included the Head of the Distribution Network Sub-Division of PT. Petrokimia Gresik, senior transformer maintenance technicians, and protection system engineers. The pairwise comparison among criteria was conducted using Saaty's 1–9 scale, in which a score of 1 denotes equal importance between two criteria, 3 indicates slight preference, 5 indicates stronger importance, 7 reflects very strong importance, and 9 represents absolute importance, while the values 2, 4, 6, and 8 serve as intermediate judgments. The resulting comparison matrix was normalized by dividing each element by the total of its respective column, and the priority weights were calculated as the average value of each row in the normalized matrix . Finally, the reliability of the expert assessments was evaluated through the Consistency Ratio to ensure that the judgments were logically consistent.

Table 1. Random Index Value

Matrix Size	RI Value
1 dan 2	0.00
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49
11	1.51
12	1.48
13	1.56
14	1.57
15	1.59

To validate the weighting results, a consistency level calculation is required, which involves finding the Consistency Index (CI) and Consistency Ratio (CR) values. This calculation is performed using:

$$\text{Consistency Ratio (CI)} = \frac{(\lambda\text{max}-\text{n})}{(n-1)}$$

$$\text{CR} = \frac{CI}{RI}$$

Description:
CI: Consistency Index
RI: Random Index
CR: Consistency Ratio
λmaks: Maximum Eigenvalue, which is the average value of the matrix multiplication by the priority weights.
n: Number of elements or criteria being compared (matrix order)

Then to find the weighted sum of the performance ratings for each alternative on a criterion, the normalization value is carried out using the Min-Max Normalization method to equalize the value scale for each criterion into the range 0-1 using the Simple Additive Weighting (SAW) method, which is a weighted summation method. This calculation is performed using.
Formula for Benefit Criteria:

$$r_{ij} = \frac{X_{ij} - X_{min}}{X_{max} - X_{min}}$$

Formula for Benefit Cost:

$$r_{ij} = \frac{X_{max} - X_{ij}}{X_{max} - X_{min}}$$

Description:

r_{ij} = Normalized value of alternative i on criterion j (scale 0-1)
X_{ij}= Actual value of alternative i on criterion j
X_{min} = Minimum value based on standard
X_{max} = Maximum value based on standard

Then, to calculate the reliability index, it is calculated using the Weighted Sum Model (WSM) method by multiplying the weight of the AHP results criteria by the normalized value of each parameter. This calculation is performed using:

$$V_i = (W_1 \times r_1) + (W_2 \times r_2) + (W_3 \times r_3) + (W_4 \times r_4)$$

Description:
V_i = Reliability index of the i-th alternative (scale 0-1)
W_j= Weight of the j-th criterion (AHP result)
r_{ij} = Normalized value of alternative i on criterion j
n = Number of criteria

RESULT AND DISCUSSION

Operational Parameter Monitoring Data

1. Per-Phase Current Measurement Data

Figure 1 shows per-phase current data taken from per-phase current monitoring data on the outgoing panels of the north, east, and south transformers. The measured time period is the peak load time at 5:00 PM. This is because in residential areas and supermarkets, the peak load time for the electrical system is from 5:00 PM to 9:00 PM, which is the opposite of the typical peak load time.

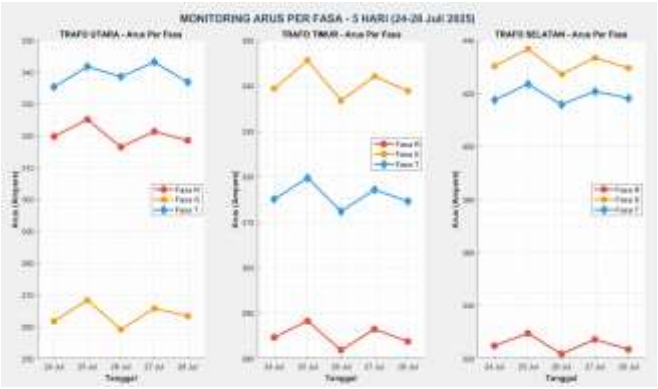


Figure 1. Current graph per phase on the north, east, and south transformers

2.Voltage Measurement Data for Each Phase

Figure 2 shows the current data for each phase taken from the per-phase voltage monitoring data on the outgoing panels of the north, east, and south transformers.

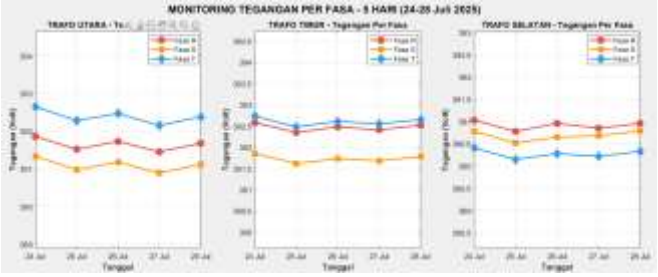


Figure 2. Voltage graph per phase on the north, east, and south transformers

3.Power Factor Measurement Data

Figure 3 shows the power factor data for each phase taken from the per-phase power factor monitoring data on the outgoing panels of the north, east, and south transformers.



Figure 3. Power Factor graph on the north, east, and south transformers

Results of Technical Parameter Calculations

In accordance with the formulation in the equation, here is an example of a technical parameter calculation conducted on July 24, 2025, at 5:00 PM.

a. Average Current

Average Current at the North Transformer, taken at 5:00 PM

$$Iavarage = \frac{IR+IS+IT}{3}$$

$$Iavarage = \frac{392.58+261.8+335.4}{3}$$

$$Iavarage = \frac{917}{3}$$

$$Iavarage = 305.6\ A$$

b. Average Voltage

Average Voltage at the North Transformer taken at 5:00 PM

$$Vavarage = \frac{VR+VS+VT}{3}$$

$$Vavarage = \frac{391.86+391.33+392.65}{3}$$

$$\text{Vavarage} = \frac{1.175{,}84}{3}$$

$$\text{Vavarage} = 391$$

c. Transformer Percentage Loading (% Loading)

Full Load Current on the North Transformer taken at 5:00 PM

$$I_{FL} = \frac{S}{\sqrt{3} \times V}$$

$$I_{FL} = \frac{500.000 \text{ VA}}{\sqrt{3} \times 380}$$

$$I_{FL} = \frac{500.000 \text{ VA}}{658{,}179}$$

$$I_{FL} = 759{,}671 \text{ A}$$

The result for the full load current value is 759.671 A.

Therefore, the loading percentage on the north transformer is:

$$\frac{\text{I avarage}}{I_{FL}} \times 100\%$$

$$\frac{305.6}{759{,}671} \times 100\%$$

$$40{,}2\%$$

The results obtained for the percentage value of transformer loading were 40.2%.

d. Transformer load imbalance (%unbalance)

Load imbalance on the north transformer taken at 5:00 PM

$$IR = a \times \text{I avarage}, \; a = \frac{IR}{\text{I avarage}}$$

$$392.58 = a \times 305.6, \; a = \frac{392.58}{305.6}$$

$$a = 1{,}04$$

$$IS = b \times \text{I avarage}, \; b = \frac{IS}{\text{I avarage}}$$

$$261.8 = b \times 305.6, \; b = \frac{261.8}{305.6}$$

$$b = 0{,}85$$

$$IT = c \times \text{I avarage}, \; c = \frac{IT}{\text{I avarage}}$$

$$335.4 = c \times 305.6, \; c = \frac{335.4}{305.6}$$

$$c = 1{,}09$$

So from the results obtained for coefficients a, b, and c, the formula for the percentage of load imbalance on the north transformer can be determined:

$$uL=\frac{|a-1|+|b-1|+|c-1|}{3} \times 100\%$$

$$uL=\frac{|1,04-1|+|0,85-1|+|1,09-1|}{3} \times 100\%$$

$$uL=\frac{0,28}{3} \times 100\%$$

$$uL=9,33\ \%$$

The results obtained for the load imbalance value on the north transformer were 9.33%.

Technical Calculation Results

Table 2 shows the average results of the technical calculations used as input for AHP-based Fuzzy Decision Making (FDM). Data was collected from the outgoing panel on July 24-28, 2025, at 5:00 PM during the WBP.

Table 2. Calculation Results

DATA INPUT				
TRANSFORMERS	**AVERAGE VOLTAGE**	**AVARAGE POWER FACTOR**	**UNBALANCE%**	**LOADING %**
NORTH	392 V	0,99	4,19%	40,62 %
EAST	392 V	0,99	3,17%	41,37 %
SOUTH	391 V	0,97	8,87%	16,15%

Based on the results of the calculation of the average value during the observation period, the North and East transformers showed relatively stable operational performance with an average voltage value of 392 V, a power factor of 0.99, and a load percentage of 40.62% and 41.37%, respectively. This value indicates that both transformers are operating under optimal and efficient charging conditions. Meanwhile, the Southern transformer has a slightly lower voltage value of 391 V, a power factor of 0.97, and the highest current imbalance rate of 8.87% with a charging percentage of only 16.15%. This condition shows that the South transformer is in an underload condition, which has the potential to cause the utilization of transformer capacity to be less optimal than other transformers.

Weighting of Criteria and Preparation of Comparison Matrix

The weighting of the criteria in this study is based on *experience judgment*, which is an assessment that refers to experience and practical knowledge in the field of electricity distribution systems at PT Petrokimia Gresik. The determination of weights considers the influence of each parameter on the reliability and safety of transformer operation based on actual field conditions and applicable technical standards. *Power factor* is set as the most dominant criterion because it directly affects the efficiency of power consumption. *Loading* is the second priority because the load level determines the performance and

operating life of the transformer. *Unbalance* ranks third because load imbalance can cause overheating, while average voltage has the lowest level of importance because it is generally still within the standard limits of the distribution system.

The weighting process was conducted using the Analytical Hierarchy Process (AHP) method by applying Saaty's 1–9 comparison scale to evaluate the relative importance between criteria in a pairwise manner. A value of 1 indicates equal importance, while a value of 9 represents absolute importance, and the intermediate values reflect compromise judgments between these two levels.

Table 3. Weighting Scale

SCALE	COMPARISON
1	EQUALLY IMPORTANT
3	A LITTLE MORE IMPORTANT
5	MORE IMPORTANT
7	MORE IMPORTANT
9	ABSOLUTELY MORE IMPORTANT
2,4,6,8	THE VALUE BETWEEN TWO ADJACENT CONSIDERATIONS

The pairwise comparison matrix was developed by considering the relative importance of each criterion in assessing the reliability index of the distribution transformer. The evaluation applied the Saaty 1–9 scale while taking into account the actual operating conditions of the distribution system. Power factor was assigned the highest level of importance because it has a direct impact on the efficiency of electrical power utilization. Loading was ranked as the second most significant criterion, as maintaining the transformer within an optimal loading range is essential for efficient operation. Unbalance was placed third since load imbalance may lead to excessive heating in the transformer. Meanwhile, average voltage was considered the least critical criterion because, under normal conditions, the distribution system voltage is generally maintained within the prescribed standard limits.

$$A = \begin{bmatrix} 1 & 1/3 & 2 & 1/2 \\ 3 & 1 & 4 & 2 \\ 1/2 & 1/4 & 1 & 1/3 \\ 2 & 1/2 & 3 & 1 \end{bmatrix}$$

Table 4. Comparison Matrix

CRITERIA	UNBALANCE	PF	AVERAGE VOLTAGE	LOADING
UNBALANCE	1	1/3	2	1/2
PF	3	1	4	2
AVERAGE VOLTAGE	1/2	1/4	1	1/3
LOADING	2	1/2	3	1

The normalization process in the matrix below and table 5 is carried out by summing each column of the comparison matrix first. The number of unbalanced columns is 6,500, the power factor column is 2,083, the voltage column is 10,000, and the loading column is 3,833.

$$A = \begin{bmatrix} 1{,}000 & 0{,}333 & 2000 & 0{,}500 \\ 3{,}000 & 1{,}000 & 4000 & 2000 \\ 0{,}500 & 0{,}250 & 1000 & 0{,}333 \\ 2{,}000 & 0{,}500 & 3000 & 1000 \end{bmatrix}$$

Table 5. Normalization Calculation

CRITERIA	UNBALANCE	PF	AVERAGE VOLTAGE	LOADING
UNBALANCE	1,000	0,333	2,000	0,500
PF	3,000	1	4,000	2,000
AVERAGE VOLTAGE	0,500	1,000	1,000	0,333
LOADING	2,000	0,250	3,000	1,000
QUANTITY	6,500	2,083	10,000	3,833

Next, each element of the matrix is divided by the total value of its respective column, as presented in Table 6, to obtain the normalized matrix. The normalization results indicate that the sum of each column in the normalized matrix equals 1, confirming that the normalization process has been performed correctly.

$$A = \begin{bmatrix} 0{,}154 & 0{,}160 & 0{,}200 & 0{,}130 \\ 0{,}462 & 0{,}480 & 0{,}400 & 0{,}522 \\ 0{,}077 & 0{,}120 & 0{,}100 & 0{,}087 \\ 0{,}308 & 0{,}240 & 0{,}300 & 0{,}261 \end{bmatrix}$$

Table 6. Normalization Results

CRITERIA	UNBALANCE	PF	AVERAGE VOLTAGE	LOADING
UNBALANCE	0.154	0.160	0.200	0.130
PF	0.462	0,480	0,400	0,522
AVERAGE VOLTAGE	0,077	0,120	0,100	0,087
LOADING	0,308	0,240	0,300	0,261
QUANTITY	1	1	1	1

Subsequently, the values in each row are summed, and the result is divided by the number of criteria (n = 4) to obtain the priority weight of each criterion. The criterion with the highest value represents the

highest priority. The results are presented in Table 7.

Table 7. Priority Results

CRITERIA	UNBALANCE	PF	AVERAGE VOLTAGE	LOADING	Σ BARIS	PRIORITIES
UNBALANCE	0.154	0.160	0.200	0.130	0,644	0,161
PF	0.462	0,480	0,400	0,522	1,864	0,466
AVERAGE VOLTAGE	0,077	0,120	0,100	0,087	0,384	0,096
LOADING	0,308	0,240	0,300	0,261	1,181	0,277

After getting the priority value of each criterion, then calculating the consistency value can be seen in the following table:

Table 8. Consistency Results

CRITERIA	UNBALANCE	PF	AVERAGE VOLTAGE	LOADING	Σ BARIS
UNBALANCE	0.154	0.160	0.200	0.130	0,644
PF	0.462	0,480	0,400	0,522	1,864
AVERAGE VOLTAGE	0,077	0,120	0,100	0,087	0,384
LOADING	0,308	0,240	0,300	0,261	1,181

So to find the λmax, namely the number of each row divided by each priority and the result will be summed, The summation results will be divided by many criteria (n=4) can be seen in the following formula:

$$CX = \frac{\sum \text{line}}{\text{Priorities}}$$

$$C1 = \frac{0,644}{0,161} = 4,019$$

$$C2 = \frac{1,864}{0,466} = 4,049$$

$$C3 = \frac{0,386}{0,096} = 4,021$$

$$C4 = \frac{1,181}{0,277} = 4,043$$

Total = 16,132

So from the results above, it is obtained to find the λmax, namely:

$$\lambda\text{max} = \frac{\text{Total}}{n}$$

$$\lambda\text{max} = \frac{16,132}{4} = 4,033$$

Then the formula to find the consistency ratio (CI) is as follows:

$$\text{Consistency Ratio (CI)} = \frac{(\lambda max\text{-}n)}{(n\text{-}1)}$$
$$\text{Consistency Ratio (CI)} = \frac{(4{,}033\text{-}4)}{(4\text{-}1)}$$
$$\text{Consistency Ratio (CI)} = \frac{0{,}033}{3}$$
$$\text{Consistency Ratio (CI)} = 0{,}011$$

For n = 4, the Random Consistency is 0.90

$$CR = CI / RC$$
$$CR = 0{,}011/ 0{,}90$$
$$CR = 0{,}012$$

Since CR is ≤0.1, the consistency ratio of the calculation is acceptable.

Priority Weight Results

Based on the calculation of AHP, the priority weights are obtained as follows:

Table 9. Priority Weight Results

CRITERIA	WEIGHT	PERSEENTASE
PF	0,47	47%
LOADING	0,27	27%
UNBALANCE	0,16	16%
TEGANGAN	0,10	10%
TOTAL	1,00	100%

Based on the results of weighting criteria using the AHP method in table 9, it was found that the power factor had the highest priority weight of 0.47 (47%), which shows that the power factor is the most dominant criterion in transformer performance assessment. Furthermore, the loading criterion has a weight of 0.27 (27%), which indicates the importance of the loading level in supporting the efficiency and utilization of transformer capacity. The unbalance criterion obtained a weight of 0.16 (16%), which plays a role in maintaining power quality and preventing operational interruptions. Meanwhile, the stress criterion had the lowest weight of 0.10 (10%), indicating that the voltage variation was relatively small and still within the tolerance limit, so its effect on decision-making was lower than the other criteria.

Classification of Types of Criteria

Each criterion is categorized into two types: benefit and cost. A benefit criterion indicates that higher values reflect more favorable conditions, whereas a cost criterion indicates that lower values represent better performance.

Table 10. Classification of Types of Criteria

CRITERIA	JENIS	REASON
UNBALANCE	COST	THE LOWER IT IS CLOSER TO 0%, THE BETTER THE LOAD BALANCE BETWEEN PHASES
PF	BENEFIT	THE HIGHER IT IS CLOSER TO 1.00, THE BETTER THE POWER EFFICIENCY WILL BE
AVERAGE VOLTAGE	BENEFIT	IN THE STANDARD RANGE OF SPLN (361-399V), STABLE AND HIGH VALUES INDICATE GOOD VOLTAGE QUALITY
LOADING	BENEFIT	HIGHER VALUES CLOSE TO THE OPTIMAL RANGE (50-80%) INDICATE BETTER UTILIZATION OF TRANSFORMER CAPACITY

Determination of Max and Min Values Based on Standards

The determination of the maximum value and minimum value for each criterion is determined based on the applicable reference standard.

Table 11. Determination of Max and Min Values Based on Standards

CRITERIA	JENIS	MIN	MAX	STANDARD
UNBALANCE	COST	0%	5%	IEC 60038/ANSI-C84.1-1995,
PF	BENEFIT	0,85	1	IEEE STD 141-1993
AVERAGE VOLTAGE	BENEFIT	361 V	399 V	SPLN 1:1995
LOADING	BENEFIT	0%	80%	IEEE C57.91-2011

The determination of assessment criteria in this study is based on technical standards that are commonly used in electric power distribution systems. The unbalance criterion is categorized as *the cost* criterion, because the smaller value of the current imbalance indicates the better condition of the system. The range of unbalance values is set between 0% to 5% with reference to IEC 60038 and ANSI C84.1-1995 standards. Meanwhile, the criteria of power factor, average voltage, and loading are categorized as *benefit* criteria, because higher values indicate more optimal transformer performance. The power factor has a value range of 0.85 to 1.00 according to IEEE Std 141-1993, while the average voltage is in the range of 361 V to 399 V based on SPLN 1:1995. For the loading criteria, the minimum limit is set at 0% and the maximum limit is 80% with reference to IEEE C57.91-2011, which represents the safe and optimal transformer loading conditions. The use of a minimum value of 0% in the loading criteria is carried out to facilitate the data normalization process, so that all loading values can be expressed on a uniform and proportional scale without changing the technical characteristics of the criteria. This approach allows the

decision-making process using the *AHP-based Fuzzy Decision Making* method to be more systematic and consistent.

Reliability Index Calculation

The reliability index was calculated using the *Weighted Sum Model* (WSM) method by multiplying the weight of the AHP result criteria by the normalization value of each parameter.

$$V_i=(W_1\times r_1)+(W_2\times r_2)+(W_3\times r_3)+(W_4\times r_4)$$

Description:
V_i = Alternative reliability index i-i (scale 0-1)
Wi_j = Weight of the j criterion (AHP result)
r_{ij} = Alternative normalization value i at criterion j
n = Number of criteria (4)

In accordance with the formulation of the equation, it can be calculated for the calculation of the reliability index, which is as follows:

1. Calculation of the reliability index on the north transformer

Table 12. Calculation of the reliability index on the north transformer

CRITERIA	WEIGHT	NORMALIZATION
PF	0,47	0,933
LOADING	0,27	0,502
UNBALANCE	0,16	0,162
TEGANGAN	0,10	0,816
TOTAL	1,00	-

$$V_{Utara}=(W_1\times r_1)+(W_2\times r_2)+(W_3\times r_3)+(W_4\times r_4)$$
$$V_{Utara}=(0,47\times 0,933)+(0,27\times 0,502)+(0,16\times 0,162)+(0,10\times 0,816)$$
$$V_{Utara}=0,438+0,137+0,135+0,025$$
$$V_{Utara} = 0,73$$

So the reliability index for the northern transformer is obtained with the result = 0.73×100% = 73%

2. Calculation of reliability index on eastern transformer

Table 13. Calculation of reliability index on eastern transformer

KRITERIA	BOBOT	NORMALISASI
PF	0,47	0,933
LOADING	0,27	0,517
UNBALANCE	0,16	0,366
TEGANGAN	0,10	0,816
TOTAL	1,00	-

$$V_{Timur}=(W_1\times r_1)+(W_2\times r_2)+(W_3\times r_3)+(W_4\times r_4)$$
$$V_{Timur}=(0,47\times 0,933)+(0,27\times 0,517)+(0,16\times 0,366)+(0,10\times 0,816)$$
$$V_{Timur}=0,438+0,139+0,058+0,082$$
$$V_{Timur} = 0,71$$

So the reliability index for the eastern transformer is obtained with the result = 0.71 × 100% = 71%

3. Calculation of reliability index on South transformer

Table 14. Calculation of reliability index on South transformer

KRITERIA	BOBOT	NORMALISASI
PF	0,47	0,800
LOADING	0,27	0,201
UNBALANCE	0,16	0
TEGANGAN	0,10	0,789
TOTAL	1,00	-

$$V_{Selatan}=(W_1\times r_1)+(W_2\times r_2)+(W_3\times r_3)+(W_4\times r_4)$$
$$V_{Selatan}=(0,47\times 0,800)+(0,27\times 0,201)+(0,16\times 0)+(0,10\times 0,789)$$
$$V_{Selatan}=0,376+0,054+0,000+0,079$$
$$V_{Selatan} = 0,509$$

Then the reliability index on the southern transformer was obtained with a result = 0.509 × 100% = 50.9%

Reliability Index Results

Table 15. Reliability Index Results

RANGE	CATEGORY	ACTIONS
80% - 100%	EXCELLENT	ROUTINE MAINTENANCE
60% - 79%	GOOD	PERIODIC MONITORING
40% - 59%	ENOUGH	MINOR EVALUATION AND IMPROVEMENT
20% - 39%	BAD	IMMEDIATE REPAIR
0% - 19%	VERY BAD	EMERGENCY MEASURES

The results of the reliability index calculation in table 15 are interpreted using an assessment scale with a range of 0-100%. This scale is compiled to provide an overview of the reliability conditions of the distribution transformer and the actions required based on the index values obtained. The category division consists of five levels, namely Very Good, Good, Sufficient, Bad, and Very Bad. The Excellent category with a range of 80-100% indicates that the transformer is in optimal condition and only requires regular maintenance to maintain its performance. The Good category with a range of 60-79% indicates that the transformer is in operation-appropriate condition but needs to be monitored periodically to monitor the development of its condition. The Sufficient category with a range of 40% - 59% indicates that the transformer requires special attention and needs to be evaluated and minor improvements to the problematic parameters. The Poor category with a range of 20% - 39% indicates that the transformer needs immediate repair because some parameters are already outside the set standards. The Very Poor category with a range of 0% - 19% indicates that the transformer is in critical condition and requires emergency measures to prevent further disruption or damage.

Table 16. The results of the reliability index

RANGKING	TRANSORMATOR	RELIABILITY INDEX	CATEGORY	ACTIONS
1	WEST	73 %	GOOD	PERIODIC MONITORING
2	NORTH	71 %	GOOD	PERIODIC MONITORING
3	SOUTH	50,9%	ENOUGH	EVALUATION OF MINOR IMPROVEMENTS

Based on the results of the calculation using the Fuzzy Decision Making method with *the weighting of the Analytical Hierarchy Process*, the reliability index ranking for the three distribution transformers was obtained.

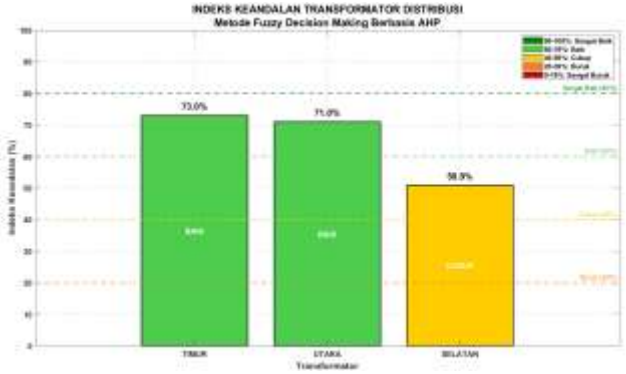


Figure 4 Reliability Index Ranking

East Transformer ranks first with a reliability index of 73% which is included in the Good category so it only requires periodic monitoring to maintain its performance. North Transformer ranks second with a reliability index of 71% which is also included in the Good category with periodic monitoring actions. The South transformer ranks last with the lowest reliability index of 50.9% which is included in the Sufficient category so that it requires minor evaluation and improvement, especially in the unbalanced parameters that exceed the standard of 5% and the loading is still low.

CONCLUSION

Based on the research conducted on the analysis of the distribution transformer reliability index using the Fuzzy Decision Making method combined with Analytical Hierarchy Process (AHP) weighting, the following conclusions can be drawn:

1. Power monitoring data of distribution transformers can be effectively utilized to evaluate operational conditions and reliability levels within the electric power distribution system. The parameters of loading, voltage, current, and power factor have been shown to comprehensively represent the actual condition of the transformer.
2. The Analytical Hierarchy Process (AHP) method was successfully applied to determine the relative importance of each reliability criterion in an objective and consistent manner. The resulting weights indicate that the most influential criteria contribute significantly to the overall reliability assessment of the distribution system.
3. The Fuzzy Decision Making approach is capable of accommodating uncertainty and variations in dynamic transformer monitoring data, thereby providing a more flexible evaluation of reliability compared to conventional methods that rely on fixed (crisp) thresholds.
4. The integration of AHP and Fuzzy Logic methods forms an effective decision-support model for enhancing the reliability of the electric power distribution system, particularly at the distribution transformer level.
5. The developed AHP–Fuzzy-based decision-making model is able to produce reliability condition recommendations that can serve as a reference for prioritizing monitoring, maintenance, and transformer load management.

Overall, the implementation of the AHP–Fuzzy method based on power monitoring data offers a systematic, adaptive, and practical approach to improving the reliability of electric power distribution systems.

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