Health Index Modelling in Condition Assessment of Gas Insulated Switchgear

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Abstract. Gas Insulated Switchgear (GIS) is essential in electrical distribution networks, especially in space-constrained areas, offering efficiency and reliability. However, GIS is prone to degradation from environmental conditions, mechanical stress, and improper operations, requiring periodic assessments to maintain reliability. Traditional Health Index (HI) methods evaluate GIS primarily based on physical conditions, neglecting factors like asset age, operation frequency, and environmental impacts that influence performance. This study enhances GIS condition assessment by integrating the Conditional Factor (CF) value into the HI model, providing a broader risk evaluation, particularly for tropical environments. A unique contribution is the inclusion of Frequent Lightning Incidence in the CF calculation, alongside maintenance history, pollution levels, subsystem conditions, and surge arrester readiness. These factors improve the comprehensiveness of the Overall Health Index (OHI), combining HI and CF. The OHI model aims to improve accuracy in evaluating GIS conditions, enabling better maintenance planning and reducing failure risks in tropical regions like Indonesia. This advanced model supports informed decision-making and extends the lifespan of GIS assets by addressing both visible and latent risk factors, ensuring network reliability in challenging environments.

Keywords: *Gas Insulated Switchgear (GIS), Health Index (HI), Conditional Factor (CF), Frequent Lightning Incidence, Overall Health Index (OHI).*

1 Introduction

Gas Insulated Switchgear (GIS) technology has become increasingly important in electrical distribution networks, particularly in areas with space limitations. GIS offers high reliability even when installed in confined spaces, yet remains susceptible to various external factors that can affect its performance, such as extreme environmental conditions, excessive mechanical or electrical stress, and non-standard operational practices. Although GIS is designed to operate efficiently with minimal maintenance, these external factors can accelerate GIS degradation and increase the need for unexpected maintenance [1-3]. Therefore, periodic condition assessment of GIS is crucial for maintaining the reliability and continuity of the electrical system.

The Health Index (HI) is a commonly used method for assessing the condition of GIS. HI provides a numerical representation of the physical and operational condition of GIS based on scores and weights, which has proven effective in evaluating visible physical conditions, such as component degradation or aging [4-6]. However, this method often fails to account for invisible factors that also influence GIS performance, such as equipment age, operational frequency, operational reliability, and adequacy of the disconnection rating. These factors are important as they significantly affect the performance and lifespan of GIS, and thus should be incorporated into the evaluation for a more accurate condition assessment.

A study by A.P. Purnomoadi et al. [6] also considered risk factors that increase the likelihood of GIS failure in tropical regions, including the condition of critical GIS subsystems, hazard levels at specific times, the number of faults per year, maintenance history, pollution levels, and surge arrester condition in substations. In this study, a simple scoring and weighting method was adopted and further developed to not only cover the physical condition of GIS but also include relevant risk indicators specific to tropical environments, similar to the research by A.P. Purnomoadi et al. [6]. However, the key difference in this study is the inclusion of lightning incidence frequency as an additional risk indicator. By considering all these risk indicators, the proposed assessment method is expected to provide a more comprehensive picture of the overall GIS condition.

The application of this method not only improves the accuracy of GIS condition assessments but also provides a stronger foundation for more objective and transparent maintenance and repair decision-making. Thus, this study aims to develop a GIS condition assessment method tailored to tropical regions, particularly Indonesia, to enhance the reliability of electrical distribution networks and reduce the risk of unexpected failures in critical equipment.

2 Field Diagnostics Testing and Information Requirements

2.1 Technical Data

Technical data is crucial information used to assess the condition of GIS equipment in the Health Index (HI) calculation. This data includes design parameters, technical specifications, and operational characteristics of each GIS component. Key data that must be included are equipment identifiers, such as the equipment name, technical label number, and serial number, as well as location and time information, including installation location, installation date, and manufacturing date. Additionally, model and manufacturer specifications, including the model and manufacturer of the equipment, should also be documented.

This technical data also encompasses operational information, such as the feeder name, GIS room description, and room function; voltage and current data, which include system rated voltage, equipment rated voltage, rated current, and rated short-circuit current; as well as the duration that the equipment can withstand a short circuit without incurring damage [1].

2.2 Condition Parameters

The structure of Gas Insulated Switchgear (GIS), which is divided into several subsystems, is used in the assessment of GIS condition parameters because each subsystem plays a crucial role in the overall performance, reliability, and safety of the system. The condition assessment of each subsystem helps monitor and predict potential issues, enabling more proactive and timely maintenance. These primary components typically consist of five subsystems, as follows [9]:

1. Main Subsystem (Conductors, Joints, Main Contacts): As the primary path for electrical flow, these components must always be in optimal condition to prevent resistance that could cause excessive heating or electrical failure. The assessment of the main subsystem provides information about the quality of electrical flow and the potential for wear on the components.
2. Secondary Subsystem (Relays and Indicators): These components are responsible for protection and control. Failure in the secondary subsystem can result in the loss of protective functions and increase the risk of system failure. Therefore, checking this subsystem ensures that the system remains safe and operational.
3. Dielectric (Solid Spacer and SF_6 Gas): Dielectric components are critical for insulation. Given the role of SF_6 in preventing electrical leakage, the condition of the gas and spacers must be monitored regularly to avoid leakage risks and ensure safety under high voltage conditions.
4. Operating Mechanism: This mechanism enables the circuit breakers and switches to function quickly and reliably. Evaluating the operating components ensures that the mechanism operates when needed, especially during emergency electrical disconnections.
5. Structural and Support Components (Enclosure, Foundation, Measuring Instruments): These structural elements provide stability to the GIS. The physical condition of the enclosure and foundation must be maintained to protect the GIS components from external factors such as weather, vibrations, and potential physical damage.

Overall, monitoring the condition of each GIS subsystem allows for a comprehensive evaluation of the system's health, enabling early detection of failures and more efficient maintenance.

2.3 Operating Condition

In this study, Lightning Strike Frequency has been included as a factor in the performance analysis of GIS, considering the high lightning potential in Indonesia, particularly in tropical regions. Based on data from 2023, Indonesia recorded an average of 15,000 to 60,000 lightning strikes annually across various regions [10]. Due to Indonesia's tropical climate, which frequently experiences heavy rainfall and thunderstorms, the potential for damage from lightning strikes is high. Frequent lightning strikes can cause serious disruptions to the electrical system, including GIS, especially if surge protection devices, such as surge arresters, are not functioning properly. This factor helps predict the potential damage from lightning strikes and ensures that GIS is equipped with adequate protection systems to prevent further disruptions or more severe damage.

To analyze the performance of Gas Insulated Switchgear (GIS), several key operational condition factors, in addition to lightning strike frequency, include:

1. Condition of Critical Subsystems: Assessing the condition of essential GIS components such as dielectric materials, operating mechanisms, and primary components. If these components are not in good condition, the GIS performance may be compromised.
2. Hazard Levels at Specific Service Times: Measuring the potential risks or hazards that may occur in GIS at certain times, such as under extreme conditions or high operational load.
3. Number of Faults per Year: Indicating how many faults GIS experiences in a year. The higher the number of faults, the greater the likelihood that the GIS will require repairs or system upgrades.
4. Maintenance History: The maintenance records of GIS. Regular and effective maintenance ensures that GIS continues to perform optimally and extends the lifespan of the system.
5. Pollution Levels: Measuring the level of pollution or contamination around the GIS. Pollution can damage components and reduce the efficiency of the insulation system.
6. Surge Arrester Readiness: Assessing whether surge arresters are properly functioning to protect the GIS from voltage surges, such as those caused by lightning or other disruptions.
7. Lightning Strike Frequency: Measuring how often lightning strikes occur in the area surrounding the GIS. Frequent lightning occurrences can increase the risk of damage to the GIS.

By considering all these factors, GIS operators can maintain optimal system performance, reduce the risk of disruptions, and extend the equipment's lifespan.

3 GIS health index model

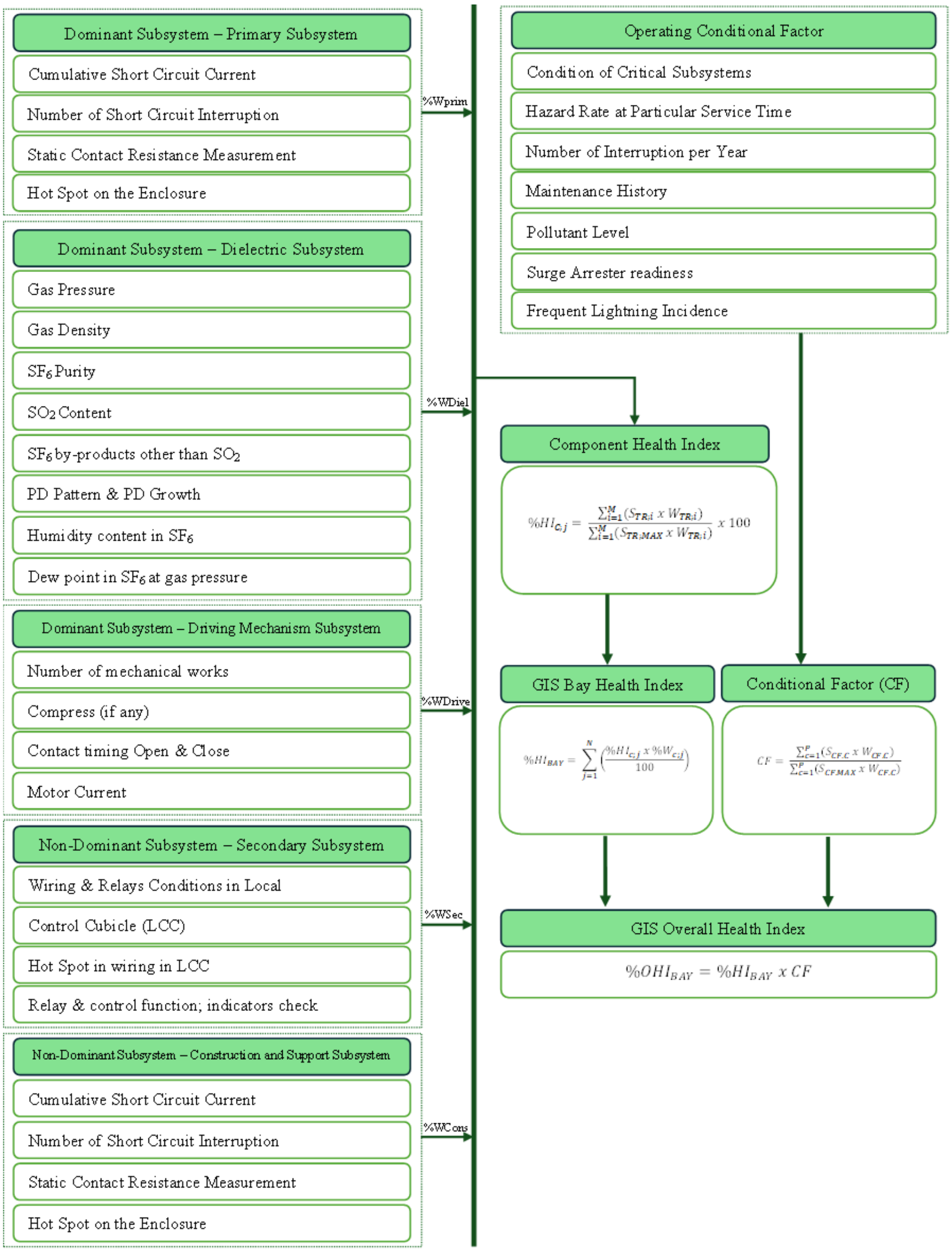

Figure 1 Proposed GIS Assessment Model

Figure 1 illustrates the proposed GIS assessment model in this study. In this model, the Overall Health Index (OHI) is calculated by multiplying the Health Index (HI) by the Conditional Factor (CF). The Health Index (HI) reflects the physical and operational condition of each key GIS component, while the Conditional Factor (CF) considers external factors that may affect component performance, such as operating environment, equipment age, and usage intensity. By combining HI and CF, this method provides a more comprehensive picture of the overall GIS condition, enabling more accurate evaluations that are relevant for maintenance planning and operational decision-making

To ensure an objective and accurate assessment, this method employs the Analytical Hierarchy Process (AHP). AHP helps determine the appropriate weighting for each evaluated component, considering both technical and operational factors.

The weighting and scoring method works by assigning a weight to each component based on its importance in the overall system. With the help of AHP, the weight determination is carried out in a structured manner through an evaluation process that considers various technical and performance aspects of each component.

The application of this method not only enhances the accuracy of the HI and CF evaluations but also ensures that each component involved in the system's condition is assessed appropriately according to its function in the overall GIS operation.

3.1 Analitical Hierarchy Process (AHP)

In this study, the weighting and scoring method is applied to calculate the Health Index (HI), linking the weights and scores using the Analytical Hierarchy Process (AHP). AHP is a measurement approach commonly used to determine the weights of both qualitative and quantitative data, making it suitable for multi-criteria applications in decision-making processes [11]. Using AHP, the weights of various field test types and key components can be calculated, which are then integral elements in the HI calculation.

In this method, the weight values for each criterion are determined using AHP, which compares the criteria pairwise based on their relative importance[7-8]. Once the weights are determined, each alternative is evaluated against each criterion. The alternative with the highest total score is selected as the best option. Overall, the AHP method is used to determine the weights of the criteria, while the Weighted Sum Model (WSM) calculates the final score using the following formula [12]:

$$S_{(Ai)} = \sum W_j \; x \; S_{ij} \quad (1)$$

Where W_j represents the weight indicating the importance level of criterion j; S_{ij} represents the score indicating how well alternative A_i meets criterion j.

3.2 Health Index Calculation

To generate a comprehensive GIS condition assessment, the GIS Health Index (HI) model is developed with two types of scores: Dominant Score and Non-dominant Score. The Dominant Score reflects the degradation level of the three main GIS subsystems in tropical regions, while the Non-dominant Score indicates degradation in the secondary subsystems and construction components of the GIS. The evaluation of these subsystems aims to maintain the condition and performance of the GIS at optimal levels [6].

In the main subsystems, which include the main conductor subsystem, important parameters such as total short-circuit current and the number of short-circuit faults are monitored. These parameters track the condition of the main components and prevent excessive heating through the measurement of static contact resistance. Additionally, hot spots on the enclosure are monitored to detect potential issues that could impair performance.

In the dielectric subsystem, parameters such as gas pressure and density, SF_6 gas purity, SO_2 levels, and other byproducts of SF_6 are monitored to maintain effective insulation. Humidity measurements and dew point calculations at gas pressure are also conducted to ensure no insulation degradation occurs that could reduce GIS reliability. The drive subsystem includes parameters such as the number of mechanical operations, compressor pressure (if applicable), contact open/close times, and motor current, all of which ensure that the mechanism operates smoothly.

Meanwhile, the secondary subsystem evaluates the condition of cables and relays in the Local Control Cabinet (LCC), as well as hot spots in the cables and LCC. This inspection is crucial to ensure that backup power sources, such as batteries and control fuses, are functioning properly. Finally, the construction and supporting subsystem assesses the structural condition of the GIS by measuring parameters such as total short-circuit current, the number of faults, static contact resistance, and hot spots on the enclosure. These inspections play a key role in maintaining the GIS's structural stability and reliability.

Based on research [1], the weight of each component is calculated using the geometric mean and then normalized so that the total adds up to 100 percent. To determine the component Health Index percentage (%HIc), each component is scored based on its condition: 0 for poor condition, 3 for satisfactory condition, and 5 for normal condition. This Nilai $\%HI_C$ value is then used to calculate the percentage of the bay health index ($\%HI_{BAY}$) by combining $\%HI_C$ and the weights of each major component. Subsequently, the weighting and scoring method is used to calculate the condition factor score for each GIS bay, which is ultimately used to adjust the overall GIS Health Index percentage (%OHI).

The percentage $\%HI_C$for each major component in the GIS bay is calculated using Equation (2).

$$\%HI_{C;j} = \frac{\sum_{i=1}^{M}(S_{TR;i}\ x\ W_{TR;i})}{\sum_{i=1}^{M}(S_{TR;MAX}\ x\ W_{TR;i})}\ x\ 100 \quad (2)$$

Where $\%HI_{C;j}$ represents the Health Index percentage for component j; $S_{TR;i}$ is the lowest score from the i-th test result; $S_{TR;MAX}$ is the maximum score from the test result; $W_{TR;i}$ is the weight of the i-th testing method; and M is the total number of testing methods.

$\%HI_{BAY}$ is calculated using Equation (3):

$$\%HI_{BAY} = \sum_{j=1}^{N}\left(\frac{\%HI_{C;j}\ x\ \%W_{C;j}}{100}\right) \quad (3)$$

Where $\%HI_{BAY}$ represents the Health Index percentage for the bay; $\%HI_{c;j}$ is the Health Index percentage for component j; $\%W_{c;j}$ is the weight percentage of the main component j; and N is the maximum number of main components.

3.3 Operating Conditional Factor Calculation

The concept of the Conditional Factor (CF) was first introduced to assess the condition of power distribution systems and has since become a key element in high-voltage asset evaluation. This is important because Health Index (HI) calculations based solely on testing data, field inspections, or maintenance records often do not provide a sufficiently accurate picture. The HI method generally only considers visible signs of physical aging, such as those obtained from technical testing results and maintenance inspections.

However, the risk of GIS failure is not only influenced by the physical condition of assets but also by risk factors that are often not directly visible. In this study, seven primary risk indicators were identified as factors that amplify the potential for GIS failure in a tropical climate. These indicators include the condition of critical GIS subsystems, the level of hazard during specific periods, the frequency of annual disruptions, maintenance history, environmental pollution levels, surge arrester readiness at substations, and lightning strike frequency. These indicators highlight the importance of considering operational condition factors in GIS health assessments for more accurate results, especially in tropical environments.

These hidden risk factors are introduced in the form of the CF, which is used to adjust the Overall Health Index (%OHI) for the GIS bay, making the assessment more comprehensive. The CF is calculated based on operational condition data from various relevant criteria. Each criterion is converted into a score reflecting its impact on operational condition. This score, together with the weight for each criterion, is used to calculate the CF value. Based on the research by Panmala, N. in 2022, the formula to calculate the CF is given by Equation (4):

$$CF = \frac{\sum_{c=1}^{P}(S_{CF.C}\ x\ W_{CF.C})}{\sum_{c=1}^{P}(S_{CF.MAX}\ x\ W_{CF.C})} \tag{4}$$

Where CF is the condition factor; $S_{CF.C}$ is the score of the operational criterion c; $S_{CF.MAX}$ is the maximum score for each criterion; $W_{CF.C}$ is the weight for the operational criterion c; and P is the total number of operational criteria.

3.4 Overall Health Index Calculation

Based on the research conducted by Panmala, N. in 2022, the overall bay Health Index percentage ($\%OHI_{BAY}$) is calculated by multiplying the $\%HI_{BAY}$obtained with the Conditional Factor (CF), as shown in Equation (5):

$$\%OHI_{BAY} = \%HI_{BAY}\ x\ CF \tag{5}$$

Where $\%OHI_{BAY}$is the overall bay Health Index percentage; CF is the condition factor; and $\%OHI_{BAY}$is the bay Health Index percentage.

The resulting $\%OHI_{BAY}$percentage is categorized into three zones that indicate the condition of the GIS bay: good, moderate, and poor. Table 1 shows the range of $\%OHI_{BAY}$for condition classification.

Table 1 Range of $\%OHI_{BAY}$ for Condition Classification

$\%OHI$	Condition	Description
90% - 100 %	Good	The system is in good condition and does not need immediate action
60% - 89%	Moderate	The system is in moderate condition and needs particular attention
<60%	Poor	The system is approaching its end of life

3.5 conditions and parameter scoring

In this study scoring process adopted from study [6] where these values were adjusted to a numerical scale. The scoring values can be seen from table 2 below.

Table 2 Condition and parameters scoring

Cumulative short circuit current scoring	
≤30% of limit	10
30% < limit≤70%	8
70% < limit≤100%	5
> Limit	1
Number of short circuit interruptions	
≤30% of limit	10
30% < limit≤70%	8
70% < limit≤100%	5
> Limit	1
Static contact resistance measurement	
ΔRst-contact≤5%	10
5% < Δ Rst-contact≤10%	8
10% < Δ Rst-contact≤20%	5
Δ Rst-contact > 20%	1
Hotspot on the enclosure	
No hot spot	10
With hotspot	1
Gas pressure	
Up to 0.5%	10
>0.5% up to 4%	8
>4% up to 7%	5
>7%	1
SF6 Purity	
Gpur≥98.7%	10
97.8%≤Gpur < 98.7%	8
97%≤Gpur < 97.8%	5
<97%	1

SO2 content	
GSO2≤1 ppmV	10
1 < GSO2≤4.6 ppmV	8
4.6 < GSO2≤10 ppmV	5
>10 ppmV	1

4 Result

The proposed method is applied to calculate the health index of the Cangkring GIS 150 KV in Cirebon west Java, which has just commenced operation in 2024. The health index calculation results for each component are presented in Table 3. These individual component health index values are then used to determine the bay health index as shown in table 4. The overall bay health index is subsequently obtained by multiplying the bay health index by the tropical conditional factors as shown in table 5. As the final result of $\%OHI_{BAY}$ in table 6 we can see that all six bay in Cangkring GIS 150 kV have moderate health index where the two transformator Bay 1 and 2 has lower value than other.

Table 3 Component Health Index

		SCORE					
Primary subsystem	Wi	BUSBAR 1 & KOPEL 150	BUSBAR 2 & KUBIKEL	SUNYARAGI 1	SUNYARAGI 2	TRAFO 1	TRAFO 2
Cumulative short circuit current	25	10	10	10	10	10	10
Number of short circuit interruption times	25	10	10	10	10	10	10
Static contact resistance measurement	20	10	10	10	10	10	10
Hot spot on the enclosure	30	10	10	10	10	10	10
%HI primary subsystem		100%	100%	100%	100%	100%	100%
dielectric subsystem							
Gas Pressure	15	10	10	10	10	10	10
Gas Density	10	10	10	10	10	10	10
SF6 Purity	10	10	10	10	10	10	10
SO2 content	20	10	10	10	10	10	10
PD Pattern & PD Growth	15	10	10	10	10	10	10
Humidity content in SF6	20	10	10	10	10	10	10
Dew point in SF6 at gas pressure	10	10	10	10	10	10	10
%HI dielectric subsystem		100%	100%	100%	100%	100%	100%
driving mechanism subsystem							
Number of mechanical works	20	10	10	10	10	10	10
Number of compress. replenish (ifany)	20	10	10	10	10	10	10
Contact timing Open & Close	20	10	10	10	10	10	10
Contact travel record	15	10	10	10	10	10	10
Motor Current	25	10	10	10	10	10	10
%HI driving mechanism subsystem		100%	100%	100%	100%	100%	100%
secondary subsystem							
Corrosion of wiring and aux relays	25	10	10	10	10	10	10
Deposited dust in wiring and aux relays	15	10	10	10	10	10	10
Hot Spot in wiring in LCC	30	10	10	10	10	10	10
Relay & control function; Indicators check	30	10	10	10	10	10	10
%HI secondary susbsystem		100%	100%	100%	100%	100%	100%
construction & supprot subsystem							
Corrosion level	30	10	10	10	10	10	10
Deposited Pollutants	15	8	8	8	8	8	8
Foundation integrity	25	10	10	10	10	10	10
Accuracy of gauges	30	10	10	10	10	10	10
%HI construstion & support susbsystem		97%	97%	97%	97%	97%	97%

In the table 3 above as we can see the result of component health index of each component. The result of the component health index result almost 100% of each health index. Almost of them have a good condition. After obtaining the Health Index (HI) results for each component, the HI for each bay was calculated. The calculation results of the Health Index for each bay are presented in Table 4 below. Based on these results, the Health Index values of each bay show similar figures, approaching 100%.

Table 4 HI Bay

	%W	BUSBAR 1 & KOPEL 150	BUSBAR 2 & KUBIKEL	SUNYARAGI 1	SUNYARAGI 2	TRAFO 1	TRAFO 2
%HI primary subsystem	25	100%	100%	100%	100%	100%	100%
%HI dielectric subsystem	25	100%	100%	100%	100%	100%	100%
%HI driving mechanism subsystem	20	100%	100%	100%	100%	100%	100%
%HI secondary subsystem	15	100%	100%	100%	100%	100%	100%
%HI construstion & support subsystem	15	97%	97%	97%	97%	97%	97%
% HI BAY		85,15%	85,15%	85,15%	85,15%	85,15%	85,15%

Table 5 Conditional Factor calculation

	SCORE						
	Wcf	**BUSBAR 1 & KOPEL 150**	**BUSBAR 2 & KUBIKEL**	**SUNYARAGI 1**	**SUNYARAGI 2**	**TRAFO 1**	**TRAFO 2**
condition of critical subsystem	20	10	10	10	10	10	10
Hazard rate at particular	10	10	10	10	10	10	10
Number of interuption per year	15	10	10	10	10	10	10
maintenance history	15	10	10	10	10	10	10
pollutant level	5	10	10	10	10	8	8
surge arrester readiness	15	10	10	10	10	10	10
frequent Lightning Incidence	20	8	8	8	8	8	8
CF		0,96	0,96	0,96	0,96	0,95	0,95

Subsequently, the Conditional Factor for each GIS bay was calculated using seven condition factors. The calculation results are presented in Table 5. The Conditional Factor values were determined based on the weighting of these seven condition factors, which may influence the occurrence of faults.

Table 6 %OHI Bay

	BUSBAR 1 & KOPEL 150	BUSBAR 2 & KUBIKEL	SUNYARAGI 1	SUNYARAGI 2	TRAFO 1	TRAFO 2
%OHI BAY	81,74 %	81,74 %	81,74 %	81,74 %	80,89%	80,89%

Finally, the Overall Health Index (OHI) was obtained as presented in Table 6, calculated by multiplying the Conditional Factor with the Health Index of each GIS bay. The results show that the OHI values are nearly identical, with the lowest values found in Transformer Bay 1 and Transformer Bay 2, both at 80.89%.

5 Conclusions

Gas Insulated Switchgear (GIS) technology has become a crucial component in the power distribution system in Indonesia, particularly in densely populated urban areas. GIS offers high reliability and space efficiency, which are essential for the electrical systems in Indonesia. However, GIS remains vulnerable to external factors typical of tropical regions, such as extreme weather, high pollution levels, and frequent lightning strikes. These factors accelerate degradation and increase the need for unexpected maintenance.

This study develops a GIS condition assessment model based on the Health Index (HI) and Conditional Factor (CF), designed to accommodate the tropical characteristics of Indonesia. The calculation results using the proposed method on the Cangkring GIS 150 Kv facilitate the assessment of each bay's condition within the Cangkring GIS. The overall results show that all six bays have moderate health index values, with transformer bays 1 and 2 exhibiting the lowest values that is 80,89%.

The approach includes seven risk indicators relevant to tropical conditions, such as lightning strike frequency and environmental pollution levels, which are crucial for GIS in Indonesia. With this assessment model, GIS operators in Indonesia can perform more timely and proactive maintenance, minimizing the risk of unexpected failures and enhancing the reliability of the power distribution network in Indonesia.

5 Nomenclature

This section lists all the symbols, abbreviations, and notations used in this document.

W_j	=	represents the weight indicating the importance level of criterion j
S_{ij}	=	represents the score indicating how well alternative A_i meets criterion j
$\%HI_{C;j}$	=	represents the Health Index percentage for component j;
$S_{TR;i}$	=	the lowest score from the i-th test result;
$S_{TR;MAX}$	=	the maximum score from the test result;
$W_{TR;i}$	=	the weight of the i-th testing method;
M	=	the total number of testing methods.
$\%HI_{BAY}$	=	represents the Health Index percentage for the bay;
$\%W_{c;j}$	=	the weight percentage of the main component j;
N	=	the maximum number of main components
CF	=	the condition factor;
$S_{CF.C}$	=	the score of the operational criterion c;
$S_{CF.MAX}$	=	the maximum score for each criterion;
$W_{CF.C}$	=	the weight for the operational criterion c;
P	=	the total number of operational criteria.
$\%OHI_{BAY}$	=	the overall bay Health Index percentage;
CF	=	the condition factor

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Acknowledgement

The authors would like to thank PT PLN (Persero) for the support and assistance provided during this research. The support was very helpful in the smooth running and implementation of this research.