



Comprehensive Evaluation of Moisture and Dew Point Characteristics of SF₆ Gas in 150 kV GIS Circuit Breakers: Operational Insights from Krembangan Substation

Puji Slamet ^{a,1}, Reza Sarwo Widagdo ^{b,2}, Balok Hariadi ^{c,3}, Agnes Juita Marbun ⁵

^{1,2,4,5}Department of Electrical Engineering, Universitas 17 Agustus 1945 Surabaya, Indonesia

email coresponden author: rezaswidagdo@untag-sby.ac.id

Abstrak

Gas Sulfur Heksafluorida (SF₆) secara luas digunakan sebagai media isolasi dan pemadam busur api dalam Gardu Induk Berinsulasi Gas (GIS), terutama pada peralatan tegangan tinggi seperti Pemutus Tenaga (PMT). Kinerja dan keandalan gas SF₆ sangat dipengaruhi oleh dua parameter utama, yaitu kadar kelembapan (moisture content) dan titik embun (dew point). Peningkatan kelembapan dapat menurunkan kekuatan dielektrik gas, memicu kondensasi, dan meningkatkan risiko loncatan listrik yang dapat menyebabkan gangguan atau kegagalan peralatan. Penelitian ini bertujuan untuk melakukan evaluasi komprehensif terhadap nilai kelembapan dan titik embun SF₆ pada lima unit PMT GIS 150 kV di Gardu Induk Krembangan, serta menilai kesesuaiannya dengan standar internasional. Metode penelitian meliputi pengukuran langsung menggunakan gas analyzer portabel untuk memperoleh parameter moisture dan dew point pada kondisi operasi aktual. Data hasil pengujian kemudian dianalisis melalui pendekatan perhitungan standar, termasuk konversi titik embun terhadap tekanan operasi menggunakan persamaan termodinamika IEEE Std. 1125, serta penilaian kualitas gas berdasarkan batas kategori yang direkomendasikan dalam CIGRE Technical Brochure No. 234. Selain itu, nilai kelembapan dalam satuan ppmv dibandingkan dengan batas maksimum pabrikan untuk memastikan tingkat kekeringan gas. Hasil pengujian menunjukkan bahwa seluruh nilai kelembapan berada jauh di bawah batas pabrikan sebesar 500 ppmv dan termasuk dalam kategori aman menurut CIGRE. Nilai titik embun terukur berada dalam rentang -20°C hingga -30°C, dan setelah dikonversi ke kondisi standar, seluruh sampel tetap memenuhi batas kritis CIGRE yaitu tidak melebihi -5°C. Dengan demikian, kondisi gas SF₆ pada PMT GIS 150 kV Krembangan dinyatakan baik dan sesuai standar internasional.

Abstract

Sulfur Hexafluoride (SF₆) gas is widely used as an insulating and arc-quenching medium in Gas-Insulated Substations (GIS), particularly in high-voltage equipment such as Circuit Breakers (CB). The performance and reliability of SF₆ gas are strongly influenced by two key parameters: moisture content and dew point. Excessive moisture can reduce the dielectric strength of the gas, trigger condensation, and increase the risk of internal flashover that may lead to

Article history

Accepted : 14 October 2025

Approved: 12 November 2025

Kata kunci:

Gas SF₆, Gas Insulated Substation (GIS), Keandalan Peralatan, Kelembapan, Titik Embun

Keywords:

Dew Point, Gas Insulated Substation (GIS), Moisture Content, SF₆ Gas, Switchgear Reliability

equipment failure. This study aims to conduct a comprehensive evaluation of the moisture and dew point characteristics of SF₆ gas in five 150 kV GIS circuit breakers at the Krembangan Substation and assess their compliance with international standards. The methodology includes on-site measurements using a portable gas analyzer to obtain moisture and dew point values under actual operating conditions. The collected data were analyzed using standard calculation approaches, including dew-point conversion to operating pressure based on the thermodynamic equations recommended in IEEE Std. 1125, as well as gas-quality classification according to the limits specified in CIGRE Technical Brochure No. 234. In addition, the measured moisture values in ppmv were compared with the manufacturer's maximum allowable limit to determine the dryness level of the gas. The results show that all measured moisture values were significantly below the manufacturer's maximum limit of 500 ppmv and fall within the safe category defined by CIGRE. The measured dew-point values ranged from -20°C to -30°C, and after conversion to standard conditions, all samples remained below CIGRE's critical threshold of -5°C. Therefore, the SF₆ gas condition in the 150 kV GIS circuit breakers at Krembangan Substation is confirmed to be good and compliant with international reliability standards.

Introduction

Substations are critical components of electrical power systems, functioning to regulate voltage levels and ensure the stability and reliability of transmission and distribution networks. One of the essential devices within a substation is the power circuit breaker, which must reliably interrupt current under both normal and fault conditions (Pratama & Arfianto, 2019). To achieve safe switching performance, high-voltage circuit breakers commonly employ insulating and arc-quenching media, among which Sulfur Hexafluoride (SF₆) is the most widely used (Widagdo et al., 2024). SF₆ possesses high dielectric strength, strong electronegativity, and excellent arc-extinguishing capabilities, making it highly suitable for Gas-Insulated Switchgear (GIS). Its dielectric strength 2.5 to 3 times higher than air and increasing with pressure is a key advantage for high-voltage equipment (Ekaputra et al., 2012). However, despite these desirable properties, the insulating performance of SF₆ is highly sensitive to moisture contamination. Elevated moisture levels reduce dielectric strength, increase the likelihood of partial discharge, and may lead to insulation failure. Therefore, moisture-content and dew-point evaluation, as referenced in international standards such as CIGRE Technical Brochure No. 234, is an essential aspect of SF₆ condition assessment (Setiono, 2017).

Previous studies, including Goeritno et al. (2018), have evaluated SF₆ performance using approaches such as Failure Modes and Effects Analysis (FMEA) to identify failure risks in

circuit breakers. Although such studies highlight general factors influencing SF₆ degradation, they often lack detailed quantitative analysis of moisture and dew-point parameters under real operating conditions. Other works, such as Nurjannah et al. (2021), emphasize the importance of meeting international standards but do not investigate compartment-level variations within GIS installations. Despite the existing literature, comprehensive evaluations of SF₆ gas quality that integrate empirical measurements, standardized dew-point conversions, and moisture assessments across multiple GIS compartments remain limited, particularly for 150 kV substations in Indonesia. Studies examining spatial variations of SF₆ conditions across several circuit-breaker bays are also relatively scarce.

This study addresses that gap by analyzing moisture content and dew point in five 150 kV GIS circuit-breaker compartments at the Krembangan Substation. The analysis uses standardized calculation methods based on IEEE Std. 1125 and CIGRE TB-234 to determine whether the gas meets international quality requirements. This compartment-based assessment provides a more detailed understanding of SF₆ condition variations within the GIS and supports the development of improved condition-based maintenance strategies. Furthermore, this study aims to provide a comprehensive evaluation of SF₆ gas conditions by integrating empirical measurements with standardized dew-point conversions, assessing gas quality using CIGRE TB-234 thresholds, identifying compartment-specific variations that are often overlooked in prior studies, and offering a refined diagnostic framework to support condition-based maintenance in high-voltage substations. These contributions are expected to enhance the reliability assessment of SF₆-insulated equipment and provide practical insights for improving operational safety and maintenance planning within GIS environments.

Method

The research methodology was refined to provide a clearer and more detailed explanation of how the data were obtained and how the analytical process was conducted. This study adopts a mixed-method approach that integrates qualitative understanding with quantitative measurement to assess the condition of SF₆ gas in high-voltage circuit breakers. The research began with an extensive literature review to establish a strong theoretical foundation, drawing from PLN technical standards, manufacturer manuals, and previous scholarly studies as comparative references. This was followed by direct field observation at the 150 kV GIS Krembangan Substation, where on-site inspections and informal interviews with operational personnel were carried out to ensure that the research design aligned with real operational

conditions. The core of the methodology involved systematic data collection on the Power Circuit Breaker (PMT) by measuring key indicators of SF₆ gas quality, including moisture content, dew point temperature, internal gas pressure, and compartment temperature. These parameters were measured using a calibrated SF₆ Analyzer, which applies established thermodynamic and gas-insulation diagnostic formulas to compute dew point values, moisture concentration in ppmv, and pressure-temperature corrections. The collected data were then evaluated by comparing measured values with allowable ranges specified in IEC standards and PLN maintenance guidelines, ensuring that the final assessment reflects both empirical findings and recognized international criteria.

1. Analysis of Dew Point and Moisture Content

To evaluate the quality of SF₆ gas and determine whether it meets the required standards, a series of mathematical calculations are performed based on the measurement results obtained from field testing. These calculations aim to derive key parameters such as absolute pressure, normalized pressure at standard temperature, partial pressure of water vapor, and ultimately, the dew point temperature. After the data collection phase, the next step is data processing through mathematical calculations, which are conducted to evaluate the SF₆ gas condition. The first calculation involves determining the absolute pressure of the gas using the following equation (Da Silva et al., 2023):

$$P_{absg} = Inlet\ Press + P_{normal} \quad (1)$$

Where,

P_{absg} : Absolute pressure of SF₆ gas relative to ambient atmospheric pressure (bar)

$Inlet\ Press$: Measured gas pressure (bar)

P_{normal} : Normal atmospheric pressure (typically 1 bar)

Once the absolute pressure relative to atmospheric conditions is calculated, the next step is to normalize the pressure to a standard ambient temperature of 20°C using the following equation:

$$P_{Absolut\ 20^0} = \frac{P_{absg} \times 293}{273 + T_{SF_6}} \quad (2)$$

Where,

T_{SF_6} : Actual temperature of SF₆ gas (°C)

$P_{Absolut\ 20^0}$: Absolute pressure normalized to 20°C ambient temperature (bar)

After obtaining the normalized absolute pressure, the partial pressure of water vapor is calculated using the following formula (Vianna et al., 2017):

$$P_{\text{Partial}} = \frac{\text{Moisture Content (ppmv)}}{1 \text{ M}\Omega} \times P_{\text{Absolut } 20^{\circ}}$$

The resulting partial pressure of water vapor is then used to determine the dew point at 20°C. This is done by referencing the IEEE 1993 standard conversion table, which maps partial vapor pressure values to corresponding dew point temperatures at 20°C. *Table 1* presents the correlation between water vapor partial pressure and the dew point temperature based on IEEE 1993 standard data. Furthermore, to determine the standardized Moisture Content of SF₆ gas in accordance with CIGRE Technical Brochure No. 234, the following equation is used:

$$MC_{\text{Standardized}} = \frac{0.004}{P_{\text{absg}}} \times 10^3 \quad (4)$$

Where,

$MC_{\text{Standardized}}$: Standardized Moisture Content

P_{absg} : Absolute pressure of SF₆ relative to ambient atmospheric pressure (bar)

Table 1
Partial Pressure (mmHg) Values Against Dew Point Values

Water Vapor Partial Pressure (mmHg)		Dew Point (°C)	Water Vapor Partial Pressure (mmHg)		Dew Point (°C)
0,009	0,01	-59	0,861	0,862	-19
0,010	0,011	-58	0,947	0,948	-18
0,012	0,013	-57	1,041	1,042	-17
0,013	0,014	-56	1,142	1,143	-16
0,015	0,016	-55	1,252	1,253	-15
0,017	0,018	-54	1,373	1,374	-14
0,02	0,021	-53	1,503	1,504	-13
0,023	0,024	-52	1,644	1,645	-12
0,026	0,027	-51	1,798	1,799	-11
0,029	0,03	-50	1,964	1,965	-10
0,033	0,034	-49	2,144	2,145	-9
0,037	0,038	-48	2,34	2,341	-8
0,042	0,043	-47	2,55	2,551	-7
0,048	0,049	-46	2,778	2,779	-6
0,054	0,055	-45	3,025	3,026	-5
0,06	0,061	-44	3,291	3,292	-4
0,068	0,069	-43	3,578	3,579	-3
0,076	0,077	-42	3,887	3,888	-2
0,086	0,087	-41	4,22	4,221	-1
0,096	0,097	-40	4,58	4,581	0
0,108	0,109	-39	4,92	4,921	1
0,121	0,122	-38	5,29	5,291	2
0,135	0,136	-37	5,68	5,681	3
0,151	0,152	-36	6,1	6,101	4
0,169	0,17	-35	6,54	6,541	5

Water Vapor Partial Pressure (mmHg)		Dew Point (°C)
0,009	0,01	-59
0,010	0,011	-58
0,012	0,013	-57
0,013	0,014	-56
0,015	0,016	-55
0,017	0,018	-54
0,02	0,021	-53
0,023	0,024	-52
0,026	0,027	-51
0,029	0,03	-50
0,033	0,034	-49
0,037	0,038	-48
0,188	0,189	-34
0,209	0,21	-33
0,233	0,234	-32
0,259	0,26	-31
0,288	0,289	-30
0,319	0,32	-29
0,354	0,355	-28
0,392	0,393	-27
0,434	0,435	-26
0,48	0,481	-25
0,53	0,531	-24
0,585	0,586	-23
0,646	0,647	-22
0,712	0,713	-21
0,783	0,784	-20

Water Vapor Partial Pressure (mmHg)		Dew Point (°C)
0,861	0,862	-19
0,947	0,948	-18
1,041	1,042	-17
1,142	1,143	-16
1,252	1,253	-15
1,373	1,374	-14
1,503	1,504	-13
1,644	1,645	-12
1,798	1,799	-11
1,964	1,965	-10
2,144	2,145	-9
2,34	2,341	-8
7,01	7,011	6
7,51	7,511	7
8,04	8,041	8
8,61	8,611	9
9,21	9,211	10
9,85	9,851	11
10,52	10,521	12
11,24	11,241	13
11,99	11,991	14
12,79	12,791	15
13,64	13,641	16
14,54	14,541	17
15,49	15,491	18
16,49	16,491	19
17,55	17,551	20

This formula allows the conversion of moisture content to a standardized value at reference conditions, enabling comparison with international quality limits for SF₆ gas used in high-voltage switchgear. By evaluating the result against the CIGRE 234 threshold values, it can be determined whether the gas remains within acceptable moisture limits or requires replacement to maintain insulation performance and system reliability.

Results and Discussion

In high-voltage power systems, the presence of a Circuit Breaker (CB) is essential to ensure the reliability and safety of system operations. A CB functions to interrupt electrical currents during both normal operation and fault conditions, thereby preventing equipment damage and maintaining system stability (Widagdo et al., 2024). One common type of circuit breaker used

in 150 kV substations is the GIS type, which utilizes gas media for insulation and arc-quenching purposes. A specific example of such a CB is detailed in Table 2.

Table 2
Circuit Breaker Specification

Brand	CEGALSTHOM
Type	BHG 114
Configuration	<i>Three Pole</i>
Rated Voltage	170 kV
Rated Current	2000 A
Gas Insulation Type	SF ₆
Gas Pressure	5,5 Bar
Frequency	50 Hz

Table 2 presents the technical specifications of a power circuit breaker manufactured by CEGALSTHOM, model BHG 114. This circuit breaker is configured as a Three Pole type, meaning it can simultaneously interrupt all three phases of a high-voltage AC system. It is designed to operate at a rated voltage of 170 kV, making it suitable for use in a 150 kV system with adequate safety margins to withstand transient over-voltages. The breaker is capable of handling a nominal current of 2000 A, which aligns with the demands of high-load power transmission systems. The insulating and arc-quenching medium used in this circuit breaker is SF₆ gas, well known for its high dielectric strength and excellent arc interruption performance. However, due to SF₆ being a potent greenhouse gas, its handling requires strict environmental and safety protocols. The gas pressure maintained at 5.5 Bar ensures optimal operating conditions for effective insulation and current interruption.

Table 3
SF₆ Gas Test Result

Circuit Breaker (150 kV)	Phase	Test Result		Pressure (bar)	Temperature (°C)
		Moisture Content (ppmv)	Dew Point (°C)		
Bay Transformer 1	R	70	-45,1	6,89	31
	S	60	-46,4	7,13	31
	T	63	-46	6,93	31
Bay Transformer 2	R	448	-28,3	7,12	31
	S	307	-32	6,69	31
	T	220	-35,1	7,1	31
Bay Transformer 3	R, S, T	171	-47,8	6,74	31
Bay Sawahan 1	R	78	-44,2	7,09	31
	S	74	-44,7	7,13	31
	T	69	-45,3	7,04	31
Bay Sawahan 2	R	144	-38,9	7,08	31

Circuit Breaker (150 kV)	Phase	Test Result		Pressure (bar)	Temperature (°C)
		Moisture Content (ppmv)	Dew Point (°C)		
	S	122	-40,3	7,03	31
	T	108	-41,5	7,08	31

The operating frequency of 50 Hz confirms compatibility with standard power systems in Indonesia and many other regions. Overall, the specifications of the CEGALSTHOM BHG 114 circuit breaker indicate that it is a robust and reliable component, well-suited for use in high-voltage substations. Its design supports safe and efficient operation in modern power transmission networks. Sulfur hexafluoride (SF₆) gas is widely used as an insulating and arc-quenching medium in high-voltage equipment such as circuit breakers in Gas Insulated Switchgear (GIS) systems. To ensure system reliability and safety, the quality of SF₆ gas must be periodically tested by evaluating parameters such as Moisture Content (MC), Dew Point (DP), gas pressure, and operating temperature (Zhang et al., 2025). Table 3 presents the results of SF₆ gas testing conducted on several 150 kV circuit breakers installed in transformer bays and Sawahan bays.

Based on the test results, the Moisture Content values across all test points remain within the safe threshold of below 500 ppmv. The highest MC value was recorded at Transformer Bay 2 phase S with 307 ppmv, which, although still acceptable, requires close monitoring as it approaches the upper limit. On the other hand, the lowest MC value was observed at Transformer Bay 2 phase R with 28 ppmv, indicating excellent gas dryness and optimal insulation condition. Regarding the Dew Point, all measurements show sufficiently low (negative) values, ranging from -28.3°C to -47.8°C. The best DP result was recorded at Transformer Bay 3 (R, S, T) with -47.8°C, while the highest DP was -32°C, again at Transformer Bay 2 phase S, suggesting higher moisture content at that point.

Gas pressure readings range from 6.69 Bar to 7.13 Bar, which fall within the recommended operational range for high-voltage equipment. Transformer Bay 1 phase S recorded the highest pressure, while Transformer Bay 2 phase S showed the lowest. The temperature across all test points was consistent at 31°C, indicating a stable thermal condition without signs of overheating that could affect gas performance. In conclusion, the overall SF₆ gas quality in the tested 150 kV circuit breakers is in good and acceptable condition. However, particular attention should be given to Transformer Bay 2 phase S, which shows relatively high MC and DP values compared to other locations. Continued monitoring and preventive maintenance are

recommended to prevent degradation in insulation performance and to ensure long-term operational reliability of the system.

After completing the data acquisition process, the next step involves performing technical calculations based on the test parameters of SF₆ gas in each phase of the Circuit Breaker (CB) at Bay Transformer 1. These calculations aim to evaluate the absolute pressure, water vapor partial pressure, dew point, and standardized moisture content (MC) values in accordance with recognized standards such as IEEE 1125 and CIGRE 234. These steps serve as the basis for assessing the insulation performance of SF₆ gas and identifying the potential degradation caused by moisture presence in the high-voltage breaker system.

Circuit Breaker – Phase R

Absolute Pressure Gauge Calculation

$$P_{absg} = Inlet\ Press + P_{normal} = 6.89 + 1.01 = 7.90\ bar$$

$$P_{absg} = 790\ kPa$$

This pressure indicates that the SF₆ gas in the CB is within a good operational range. Correction with atmospheric pressure is necessary to obtain the true absolute pressure within the enclosed system. This value is fundamental for further thermal and humidity-related calculations.

Absolute Pressure at 20°C, with SF₆ gas temperature at 31°C:

$$P_{Absolut\ 20^{\circ}} = \frac{P_{absg} \times 293}{273 + T_{SF_6}} = \frac{790k \times 293}{273 + 31} = 761\ kPa$$

This correction allows normalization of gas pressure at standard room temperature (20°C), enabling comparison with reference values from international standards. The result is used in the next stage of moisture vapor partial pressure calculation.

Table 4
Test Result and Calculation of Moisture Content and Dew Point

PMT (150 kV)	Phase	Moisture Content (ppmv)		Dew Point (°C)			Pressure (bar)	Temp. (°C)
		Test Result	CIGRE Standard	Test Result	Calculation Result 20°C	CIGRE Standard		
Bay Transfor mer 1	R	70	<506,33	-45,1	-27	<-5	6,89	31
	S	60	<491,40	-46,4	-28	<-5	7,13	31
	T	63	<503,78	-46	-28	<-5	6,93	31
Bay Transfor mer 2	R	448	<492	-28,3	-6	<-5	7,12	31
	S	307	<519,48	-32	-11	<-5	6,69	31
	T	220	<493,21	-35,1	-15	<-5	7,1	31
Bay Transfor mer 3	R, S, T	171	<516,12	-47,8	-18	<-5	6,74	31

Bay Sawahan 1	R	78	<493,82	-44,2	-26	<-5	7,09	31
	S	74	<491,4	-44,7	-26	<-5	7,13	31
	T	69	<496,89	-45,3	-26	<-5	7,04	31
Bay Sawahan 2	R	144	<494,43	-38,9	-19	<-5	7,08	31
	S	122	<497,51	-40,3	-21	<-5	7,03	31
	T	108	<494,43	-41,5	-22	<-5	7,09	31

Water Vapor Partial Pressure, with Measured Moisture Content 70 ppmv

$$P_{\text{Partial}} = \frac{\text{Moisture Content (ppmv)}}{1 \text{ M}\Omega} \times P_{\text{Absolut } 20^{\circ}}$$

$$P_{\text{Partial}} = \frac{70}{1 \text{ M}\Omega} \times 761 = 53.3 \text{ Pa} = 0,399 \text{ mmHg}$$

Partial vapor pressure quantifies the moisture content in SF₆. According to IEEE 1125 Table 1, this corresponds to a dew point of -27°C, indicating a relatively good insulation condition, though nearing the threshold that requires monitoring.

Standardized Moisture Content (CIGRE 234)

$$MC_{\text{Standardized}} = \frac{0.004}{P_{\text{absg}}} \times 10^6 = \frac{0.004}{7.90} \times 10^6 = 506.33 \text{ ppmv}$$

This standardization enables accurate comparison against CIGRE limits. The value suggests that moisture content is approaching the upper threshold, indicating the need for regular monitoring and preventive maintenance. Table 4 presents the results of testing and calculating the moisture content (ppmv) and dew point (°C) of SF₆ gas in several 150 kV GIS circuit breaker bays, including Bay Transformer 1, Bay Transformer 2, Bay Transformer 3, Bay Sawahan 1, and Bay Sawahan 2.

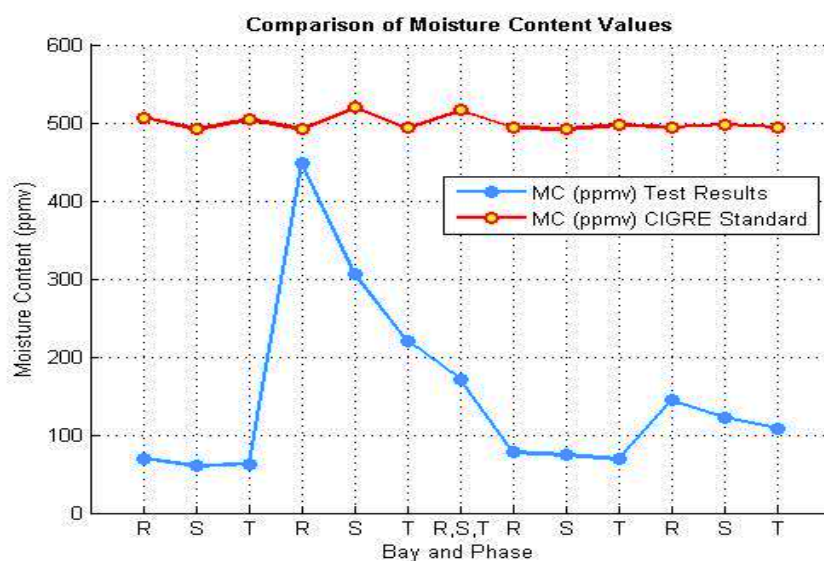


Figure 1. Comparison of Moisture Content Test Results with CIGRE Standard

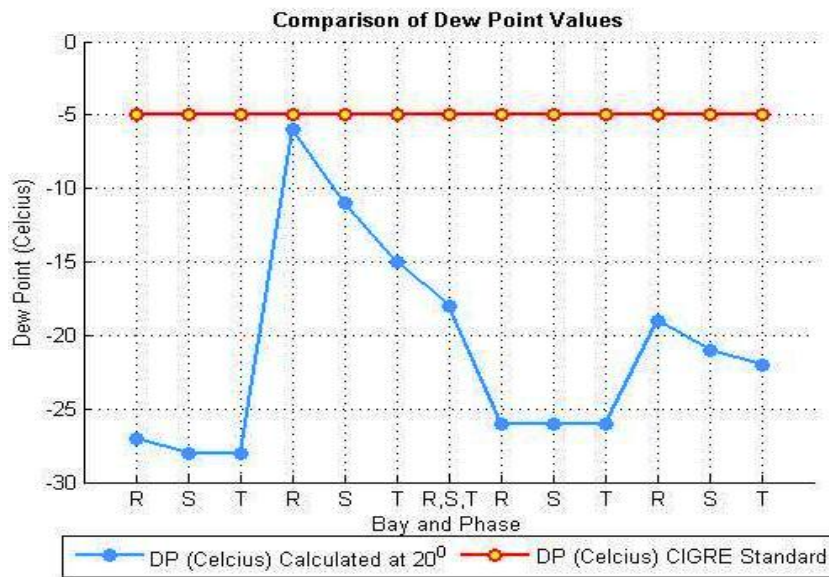


Figure 2. Comparison of Dew Point Values (°C) Calculated at 20°C with CIGRE Standard

The measured moisture content is compared with the CIGRE standard values, where all test results remain within acceptable limits (CIGRE standard values). The dew point is also analyzed, both in actual test results and in recalculated values at 20°C reference temperature. The results show that the moisture content across all phases remains below the CIGRE limits, ranging between 44 ppmv and 307 ppmv. Notably, the highest moisture level is found in phase S of Bay Transformer 2 (307 ppmv), yet it still complies with the standard. Dew point calculations reflect values ranging from -47.8°C to -28°C in actual tests, and from -26°C to -6°C after standard temperature correction. The pressure measurements of SF₆ gas remain consistent between 6.69 bar and 7.13 bar, and the testing temperature was uniformly maintained at 31°C during all measurements. These results indicate that the condition of SF₆ gas in all monitored bays remains within the operational safety margin set by international standards, ensuring the reliability and insulation integrity of the high-voltage equipment.

Figures 1 and 2 present a comparative analysis of moisture content and dew point values in SF₆ gas across various GIS circuit breaker bays and phases, benchmarked against CIGRE standards. In Figure 1, the blue line represents the actual test results of moisture content (in ppmv), while the red line with yellow markers indicates the CIGRE standard threshold for each phase. All recorded values remain below the standard limit, confirming that the SF₆ gas insulation is in safe and acceptable condition. The highest moisture content appears in phase S of Bay Transformer 2 at approximately 307 ppmv, which still falls under the CIGRE limit of 520 ppmv. Other locations, including Bay Sawahan 1 and 2, exhibit lower moisture values,

typically below 150 ppmv. These results align with the data in Table 4, indicating compliance with international moisture standards and supporting the system's dielectric integrity.

Figure 2 displays the dew point temperatures of SF₆ gas, recalculated at a reference of 20°C. The blue line reflects measured values, while the red line with yellow markers shows the CIGRE dew point limit of -5°C. All observed values are below this threshold, confirming that the SF₆ gas remains dry. The highest dew point, approximately -6°C, occurs in phase R of Bay Transformer 3, still within acceptable limits. The lowest values, around -27°C to -28°C, are noted in Bay Transformer 1 and Bay Sawahan 1. Overall, the data confirms effective moisture control and the high reliability of GIS insulation performance at the 150 kV substation.

Conclusion

The analysis of SF₆ gas quality in the 150 kV Krembangan GIS shows that both moisture content (ppmv) and dew point values across all bays generally remain well below the maximum thresholds defined by CIGRE standards and manufacturer limits. As illustrated in the graphs, the standardized CIGRE limits for moisture content (≈500 ppmv) and dew point (-5°C) lie far above the measured values, confirming that the insulation performance of the SF₆ gas is still within a safe operating range.

A notable finding appears in Bay Transformer 2, where a significant spike in moisture content is observed, reaching over 400 ppmv in phase R, followed by a gradual decline in phases S and T. This localized anomaly clearly visible on the plotted graph suggests potential moisture contamination within this compartment. The corresponding dew point pattern, which rises toward the threshold but remains within acceptable limits, further supports this indication of degraded gas quality in that specific bay.

Beyond confirming compliance with standards, this study contributes by providing a phase-level and bay-level diagnostic comparison, enabling the identification of compartment-specific issues that may not be visible through general assessment alone. The integration of dew point standardization at 20°C and visual comparison against CIGRE limits strengthens the diagnostic reliability of the findings. Given the clear deviation trend shown in Bay Transformer 2, the study emphasizes the need for targeted inspection and preventive maintenance to avoid potential dielectric breakdown. Overall, this research offers a practical evaluation framework that enhances condition-based monitoring and supports operational reliability for GIS systems using SF₆ insulation.

Reference

- Da Silva, C. L., Reis, O., Assuncao, F. D. O., Oliveira Castioni, J. C., Martins, R., Xavier, C. E., ... & Oliveira, L. E. L. (2023). *An online non-invasive condition assessment method of outdoor high-voltage SF6 circuit breaker*. *Machines*, 11(3), 323.
- Ekaputra, H., Negara, I. M. Y., & Satriyadi, I. G. N. (2012). *Analisis Kinerja Insulasi SF6 Pada Gas Insulated Switchgear (GIS) P3B Waru Berdasarkan Interpretasi Pengukuran Acoustic Insulation Analyzer (AIA) Menggunakan Metode Stokastik*. *Jurnal Teknik POMITS*, Vol. 1 (1), 1-6.
- Goeritno, A., Rasiman, S., & Komara, Z. (2018). *Kinerja Pemutus Tenaga Tegangan Tinggi Bermedia Gas SF6 Berdasarkan Sejumlah Parameter Diri*. *Jurnal EECCIS (Electrics, Electronics, Communications, Controls, Informatics, Systems)*, 12(2), 104-111.
- Nurjannah, D. S., Santoso, D. B., & Bangsa, I. A. (2021). *Analisa Pengujian Gas SF6 Pada Pemutus Tenaga (PMT) 66 kV Bay Reaktor 4R2 di GITET Bandung Selatan*. *Power Elektronik: Jurnal Orang Elektro*, Vol.10 (2), 57-59.
- Pratama, I. A., & Arfianto, T. (2018). *Analisis Kualitas Gas SF6 Pada Sealing End Terhadap Moisture Content dan Dew Point di GIS Kiaracandong PT. PLN (Persero) Transmisi Jawa Bagian Tengah*. *Rang Teknik Journal*, Vol. 2 (1), 49-56.
- Setiono, I. (2017). *Gas SF6 (Sulfur Hexa Fluorida) Sebagai Pemadam Busur Api pada Pemutus Tenaga (PMT) di Saluran Transmisi Tegangan Tinggi*. *METANA*, 13(1), 1-6.
- Vianna, E. A., Abaide, A. R., Canha, L. N., & Miranda, V. (2017). *Substations SF6 circuit breakers: Reliability evaluation based on equipment condition*. *Electric Power Systems Research*, 142, 36-46.
- Widagdo, R. S., Slamet, P., & Saputra, F. E. (2024). *Performance Analysis of SF6 Circuit Breakers: Case Study of Rungkut 150 kV Main Substation*. *Wahana: Tridarma Perguruan Tinggi*, 76(1), 17-27.
- Widagdo, R. S., Andriawan, A. H., Tauladan, I. S., & Maulana, A. I. (2024). *Analysis of Leakage Current Calculation Through Thermal Failure Voltage on 150/20 kV Transformers in GIS Simpang, Surabaya*. *Jurnal ELEMENTER*, 10(2).
- Yulistiawan, Hasan, B., Hasbullah. (2012). *Analisis Penggunaan Gas SF6 Pada Pemutus Tenaga (PMT) di Gardu Induk Cigereleng Bandung*. *Jurnal ELECTRANS*, Vol. 11 (2), 81-93.
- Zhang, B., Cao, M., Wang, Z., Zhou, R., Deng, J., Li, X., ... & Wang, P. (2025). *Dielectric recovery characteristics of SF6 circuit breaker under repeated lightning strikes*. *Electric Power Systems Research*, 241, 111348.