Insulation Resistance Testing on 275 kV Circuit Breakers at GITET Arun Based on PT PLN (Persero) Directive SKDIR 520

Azzumar, Rahmaniar, Siti Anisah

Abstract

The insulation resistance test on the 275 kV Circuit Breaker (CB) at GITET Arun is a crucial step in maintaining the electrical system's reliability and safety. This study aims to analyze the insulation resistance test results before and after maintenance, based on the SKDIR 520 PT PLN (Persero) standard. The method involves measuring insulation resistance using an Insulation Resistance Tester (Megger MIT 525) and evaluating the effectiveness of maintenance activities such as cleaning bushings and stubs. The test results indicate that after maintenance, the insulation resistance values increased by an average of 30% at the upper terminal, lower terminal, and upperlower terminal, thereby meeting the established operational standards. In conclusion, routine maintenance improves CB insulation resistance values and ensures the reliability of the power system

Keywords: Isolation resistance, Circuit Breiakeir, maintenance, SKDIiR 520 PT PLN (Persero).

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Introduction

An electrical power system comprises a series of components, including generators, transformers, transmission lines, distribution lines, and electrical loads, which collectively form an integrated electrical distribution network [1]. According to James, an electrical power system consists of power generation centers and substations (load centers) that are interconnected through transmission networks, thereby establishing a unified interconnection to ensure that electrical power flows efficiently according to system demand [2]. In electrical power distribution, an Extra High Voltage Substation (GITET) is required to regulate the voltage transmitted from generating units to various load centers. With advancements in modern technology, these substations are equipped with protective switching devices known as Circuit Breakers (CB). A CB is designed to automatically connect or disconnect electrical power flow in the event of a fault within the transmission system, thereby preventing equipment damage and maintaining operational safety. Furthermore, substations have continued to play a critical role in ensuring the continuity and reliability of electrical energy delivery within the power transmission network, serving as one of the essential infrastructures that support overall system stability [3].

In the modern era, electrical energy has become a primary necessity in both urban and rural areas, supporting domestic activities, commercial operations, and industrial growth. Circuit Breakers (CBs) represent a fundamental element within electrical distribution and transmission systems, as they provide controlled circuit interruption under load conditions and prevent damage to substation equipment during abnormal operating states [4]. A Circuit Breaker is defined as a mechanical switching apparatus capable of making, carrying, and breaking currents under normal conditions, and performing switching operations under specified abnormal conditions such as short-circuit faults, in accordance with its technical ratings. Circuit Breakers operate automatically to protect electrical circuits from excessive current caused by overloads or faulted conditions [5]. Power Circuit Breakers deployed in extra-high-voltage substations are specifically engineered to detect system anomalies, isolate fault locations, and prevent cascading failures within the power grid [6]. Fault currents not properly interrupted may result in severe thermal stress, electromechanical forces, dielectric breakdown, and potential system instability.

International standards such as IEC 62271-100 and IEEE Std C37.04 specify performance requirements, including rated short-circuit breaking capacity, dielectric withstand level, transient recovery voltage (TRV), mechanical endurance, and insulation coordination. These standards ensure reliability, consistency, and interoperability among high-voltage switchgear. Additionally, IEC 60376 and IEC 62271-1 define acceptable parameters for SF_6 gas, commonly used for arc-quenching due to its excellent dielectric strength.

Although significant research has been conducted on Circuit Breaker performance, existing studies primarily focus on short-circuit analysis, arc-quenching mechanisms, and operational reliability. However, fewer studies address insulation degradation trends monitored through periodic insulation resistance measurements in accordance with utility- standard directives such as SKDIR PT PLN (Persero) 520. This presents an important research gap, particularly related to predictive maintenance and lifecycle extension strategies.

Addressing this gap is crucial, as deteriorating insulation resistance may lead to leakage currents, reduction of dielectric withstand capability, and increased risk of equipment failure. Therefore, periodic testing and analysis of insulation resistance values serve as an effective condition-based maintenance indicator, ensuring system reliability and operational safety in high-voltage substations.

Based on the IEEE C37.100:1992 Standard Definitions for Power Switchgear, a Circuit Breaker is classified as a mechanical switching device capable of closing, carrying, and interrupting load currents under normal conditions according to its rated capacity, as well as closing, carrying (within a specified time duration), and interrupting load currents under abnormal or fault conditions in accordance with its fault interruption rating [7]. A CB operates by opening its contacts during disturbances, particularly when short-circuit currents occur within the extra-high voltage transmission system at the substation. Failure of the CB to operate during a disturbance can result in severe damage to other equipment. Malfunctioning CBs can hinder service delivery to consumers and potentially damage high-value assets. Therefore, periodic preventive maintenance is essential to ensure that electrical equipment remains operational within optimal performance limits, enabling continuous and reliable service to consumers. One of the primary maintenance activities for Circuit Breakers is the performance of insulation resistance testing.

A Power Circuit Breaker (PMT) is a switching device or mechanical switch capable of interrupting, closing, and carrying load currents under normal operating conditions, as well as interrupting, closing, and carrying fault currents under abnormal system conditions, such as short-circuit events [8]. Maintenance of power circuit breakers is crucial due to their vital role in interrupting and conducting electrical power, as well as protecting other equipment within the system. Circuit Breakers serve as a primary protection device to prevent equipment failures caused by electrical disturbances. However, the effectiveness of this protection depends significantly on the type, technology, and sensitivity of the breaker in responding to changes in the electrical system [9]. Failures in the electrical transmission system and equipment damage may occur if the breaker fails to operate, often due to inadequate or improper maintenance procedures. Maintenance activities for Circuit Breakers are carried out by performing tests on several components within the device, including insulation resistance testing. According to Yusniati, Circuit Breakers play a critical role in maintaining system safety and protection within electrical power networks, particularly when responding to system disturbances. Circuit Breakers are primarily responsible for interrupting short-circuit currents, which have the potential to exceed nominal current levels flowing through conductors and insulators. Furthermore, Circuit Breakers are used to disconnect electrical loads in high-voltage systems, especially to isolate equipment requiring corrective maintenance from loads that must remain energized [10]. Testing procedures on Circuit Breakers aim to evaluate operational performance, typically consisting of insulation resistance testing, contact resistance measurement, and contact synchronization assessment.

The measurement of insulation resistance in Circuit Breakers aims to determine the magnitude of leakage current occurring between energized components and ground. Through insulation resistance testing, it is expected that the resistance value remains within the specified operational limits, thereby preventing unintended current flow between phase terminals caused by excessively low insulation resistance. The insulation resistance of electrical installation cables is one of the key parameters that indicate the quality of an electrical installation, considering that the primary function of insulation is to ensure safety and protection within the electrical system.
The general formula for insulation resistance testing is expressed as follows [11]

$$R_{Insulation} = \frac{V}{I}$$

Where:
$R_{insulation}$ = Insulation resistance (MΩ or GΩ)
V = Applied test voltage (Volt)
I = Measured leakage current (Ampere) Minimum Standard Value of Insulation Resistance Based on the system voltage [12]:

Table 1. Circuit Breaker Insulation Test Standards

Nominal Voltage of the Circuit Breaker (CB)	DC Test Voltage	Minimum Value
< 1 kV	500 V or 1000 V	≥ 1 MΩ
1 - 12 kV	2500 V	≥ 1000 MΩ
> 12 kV	5000 V or 10000 V	≥ 5000 MΩ

Temperature Correction Formula R_20°C = R_t × K_t

Where:
R_20°C = Insulation resistance at the reference temperature 20°C R_t = Measured insulation resistance at temperature t
K_t = Temperature correction factor Correction factor (for every 10°C increase) :
K_t = 0.5^((t-20)/10)
Practically, it can be stated that the insulation resistance decreases by approximately 50% for every 10°C increase in temperature.
Polarization Index (PI)
PI = R_10minute / R_1minute Assessment Criteria:
PI < 1 : Poor condition (hazardous) PI 1-2 : Fair condition
PI 2-4 : Good condition
PI > 4 : Very good condition

Dielectric Absorption Ratio (DAR) Formula DAR = R_60second / R_30second

Insulation resistance is the resistance that exists between two insulated conductors (cables) or between a conductor and the neutral (N) point [13]. Maintenance activities are generally categorized into two types of work: maintenance and repair. Maintenance includes activities such as repairing, preserving, cleaning, adjusting, measuring, and inspecting. Preventive maintenance refers to actions taken to prevent equipment damage, whereas repair refers to corrective actions taken to fix existing faults or failures [14]

The testing is carried out periodically (every two years) to evaluate the insulation quality of the Circuit Breaker (CB) and ensure that the device remains in proper operating condition. Insulation resistance testing on the 275 kV Circuit Breaker at GITET Arun is conducted with reference to PT PLN (Persero) Directive Number 520, which regulates standard maintenance procedures and the minimum allowable insulation resistance values for high-voltage equipment. This procedure aims to ensure the compliance of equipment performance with the reliability standards of the national electrical power system. Insulation resistance testing is highly useful as a method to prevent leakage currents and potential electrical failures.

In reference to the issues previously discussed, the researcher is encouraged to carry out a study with the following title: "Insulation Resistance Testing on 275 kV Circuit Breakers at GITET Arun Based on PT PLN (Persero) Directive SKDIR 520."

Literature Review

Insulation resistance refers to the electrical resistance present between two insulated conductors (cables) or between a conductor and ground (earth) [15]. The purpose of insulation resistance is to limit the flow of undesired current between windings and the grounded core. In general, the higher the insulation resistance value and the associated polarization index, the better the insulation condition. Insulation resistance measurement on a Power Circuit Breaker (CB) is a testing process carried out using an insulation resistance tester to obtain the resistance value between energized components (phase terminals) and the grounded metal enclosure (case), as well as between the upper and lower terminals of the same phase.

Based on the International Electrotechnical Vocabulary (IEV) 441-14-20, a Circuit Breaker (CB) is characterized as a mechanically operated switching apparatus engineered to establish, conduct, and interrupt electrical currents under standard operating conditions. In addition, it is designed to close, sustain for a designated period, and safely interrupt currents during abnormal system events such as short circuits. Circuit Breakers constitute one of the principal elements of high-voltage switchgear and represent a critical protective barrier within electric power systems. When faults occur in a power network, the system experiences a combination of thermal overload, electrodynamic forces, dielectric stress, and transient instability. If these disturbances are not isolated promptly, they can escalate and cause widespread equipment damage or system-wide outages [16]. Effective fault interruption by Circuit Breakers ensures continuity of service, minimizes equipment deterioration, and upholds the operational security of the grid.

The performance requirements of high-voltage Circuit Breakers are governed by several international standards. IEC 62271-100 and IEEE C37.04 define minimum criteria such as short-circuit breaking capacity, making current capability, dielectric withstand performance, mechanical endurance, and transient recovery voltage (TRV). Adherence to these specifications guarantees consistent performance during fault interruption and ensures compatibility with the system's insulation coordination design. Circuit Breakers can be grouped according to several categories, including rated system voltage, type of actuation mechanism (hydraulic, pneumatic, spring-charged), insulation medium (vacuum, SF_6, or oil), and arc-quenching principles. For high-voltage applications, SF_6 gas Circuit Breakers are commonly applied due to the gas's exceptional dielectric strength and arc-extinguishing properties. These characteristics allow compact equipment design and improved fault-clearing performance, as defined under IEC 60376 and IEC 62271-1 [17].

Additionally, IEEE Std C37.100 standardizes terminology and operational characteristics for protective switchgear, while IEC 60056 outlines test methodologies, including dielectric testing, mechanical endurance evaluations, and short-circuit performance assessments. Compliance with these standards is essential to ensure reliability, safety, and longevity of switching equipment in both transmission and distribution environments.

Research Methodology

This study was initiated with data collection conducted on November 12, 2024, followed by a series of data processing, verification, and analytical assessment extending through March 2025. The research activities were carried out within the operational work area of PT PLN (Persero) UPT

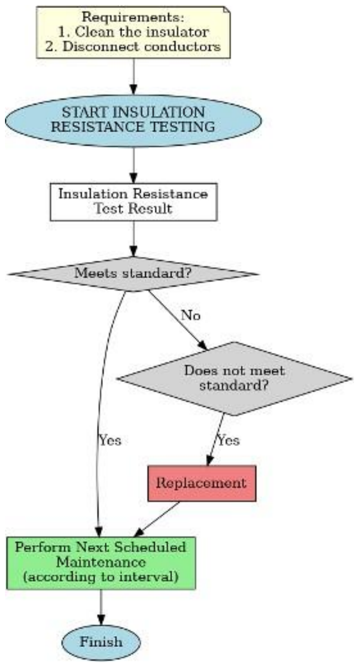

Figure 1. Flowchart of Insulation Resistance Testing Procedure

Banda Aceh, specifically at the GITET Arun Extra High Voltage Substation, which served as the designated testing location. The overall workflow of the research methodology is illustrated as follows:

The testing procedure consists of ensuring readiness of both the measuring instrument and the object being tested. The preparation of the measuring instrument follows the operational guidelines of each testing device. Meanwhile, the preparation of the test object involves isolating the equipment (e.g., Circuit Breaker) from any electrical voltage in accordance with the Work Procedure for High/Extra-High Voltage Electrical Installations (K3 Document/Blue Book), followed by disconnecting the upper and lower terminal clamps [18]. The preparation steps for the object of measurement are as follows:

1. Install local grounding on the upper and lower terminals to discharge any remaining residual voltage.

2. Clean the porcelain bushing surfaces using a cleaning solution and a soft cloth to prevent insulator damage and ensure accurate measurement results.
3. Perform insulation resistance measurement on the Circuit Breaker in open position between:
   a. Upper terminals (Ra, Sa, Ta) to casing (body)/ground
   b. Lower terminals (Rb, Sb, Tb) to casing (body)/ground
   c. Upper-to-lower phase terminals (Ra–Rb, Sa–Sb, Ta–Tb)
4. Record the insulation resistance measurement results along with surrounding ambient temperature.
5. The measurement results represent new reference data and will be used for evaluation and comparison with previous test results. A sample inspection sheet is attached ("Insulation Resistance Measurement Report for Power Circuit Breaker").
6. Reconnect the upper and lower terminal connections to their original positions.
7. Remove local grounding while performing final inspection to prepare for subsequent work stages.[18]

Figure 2. Cleaning process of the bushing

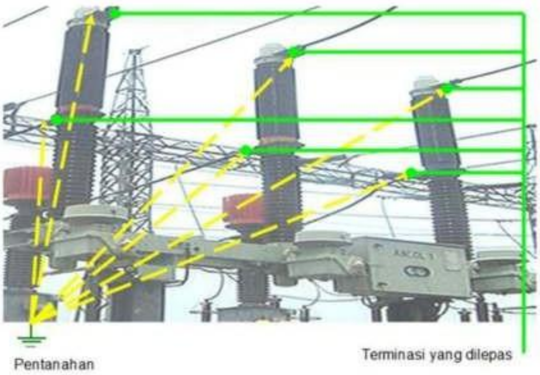

Figure 3. Local grounding installation and disconnection of upper and lower terminals

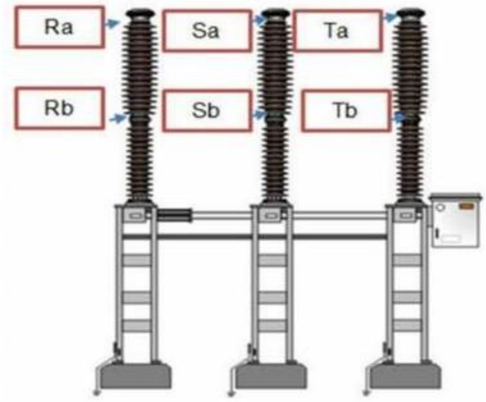

Figure 4. Circuit Breaker insulation resistance measurement terminals

The connections measured between the upper terminals (Ra, Sa, Ta) to the casing (body)/ground, the lower terminals (Rb, Sb, Tb) to the casing (body)/ground, and the upper- to-lower phase terminals (Ra–Rb, Sa–Sb, Ta–Tb) of the Circuit Breaker or other related equipment represent insulation resistance, which must comply with standard ohmic criteria. Generally, the requirement is approximately 1000 ohms with an applied test voltage of around 1000 volts. Therefore, if the insulation resistance value exceeds this threshold, it can be considered in good condition.[15]

TESTING	MEASUREMENT RESULT	RECOMMENDATION
Insulation Resistance	≤ 1 kV = 1 MΩ	• Cleaning of insulator • Perform retesting • Repair / replacement (overhaul)

Figure 5. Recommended values in insulation resistance testing

Results

Insulation resistance test results for CB6 AB 1 prior to maintenance are illustrated below:

PT. PLN (PERSERO) UIP3B	FORMULIR HASIL PEMELIHARAAN TAHUNAN PEMUTUS TENAGA (PMT)		SISTEM MANAJEMEN TERINTEGRASI
NOMOR DOKUMEN : FR-TRS-BOT-114	TANGGAL : 15 July 2022	REVISI : 2	HALAMAN : 1 DARI 1

Unit Tragi	: UPT BANDA ACEH	Merk	: SIEMENS AB1 : SIEMENS AB1 : SIEMENS AB1	Tegangan Operasi	: 275
Lokasi GI	: GITET ARUN	Serial Number	: R : 18/35150148 / A : S : 18/35150148 / A : T : 18/35150148 / A	Posisi Kondisi Cuaca	: ---- : CERAH
Bay	: GITET ARUN BAY PENGAPIT DIAMETER#1	Tanggal Pemeliharaan	: 12 November 2024 14:39:00	Tanggal Input Device	: 12 November 2024 14:39:38
Alat Uji	:	Tanggal Kirim Server	: 12 November 2024 14:51:17	Periode HAR	: 2 TAHUNAN
Suhu Pengujian (C)	: 32				
Media Isolasi	: ☒ SF6 ☐ Udara Hembus ☐ Minyak ☐ Vacuum				
Penggerak	: ☒ Pegas ☐ Pneumatik ☐ Hidrolik ☐ SF6 Dynamik				

B. PENGUKURAN / PENGUJIAN TAHANAN ISOLASI

1	PMT KONDISI OFF	Acuan	R (G	S (G	T (G	Tindaka	R (G	S (G	T (G	Kesimpula
	Terminal Atas - Ground Ra - gnd, Sa - gnd, Ta - gn	1M Ohm/kV SKDIR 0520-	98	82	72		112	132	92	
	Terminal bawah - Ground Rd - gnd, Sb - gnd, Tb - gnd	1M Ohm/kV SKDIR 0520-	169	222	142		173	226	163	
	Terminal Atas - Terminal Bawah Ra - Rb, Sa - Sb, Ta - Tb	1M Ohm/kV SKDIR 0520-	74	42	45		82	52	56	
11	PMT KONDISI ON	Acuan	R (G	S (G	T (G	Tindaka	R (G	S (G	T (G	Kesimpula
	Terminal fasa - ground : (Ra/Rb) - gnd, (Sa/Sb) - gnd, (Ta/Tb)	1M Ohm/kV SKDIR 0520-				-				-

Figure 6. Annual maintenance result form for Power Circuit Breakers

Based on the insulation resistance test results above, the data were directly obtained from the Insulation Resistance Tester (Megger MIT 525) in 2024. The initial measurement indicated that the condition was within acceptable limits; however, maintenance was still necessary to further improve the insulation resistance value. Routine maintenance can be performed to enhance the insulation quality of the 275 kV Circuit Breaker, such as cleaning the bushing and stubs using a suitable cleaning agent and soft cloth. After maintenance was carried out, a subsequent insulation resistance test was conducted, and the results showed a noticeable increase in the insulation resistance value below:

PT. PLN (PERSERO) UPT B SUMATERA

FORMULIR HASIL PEMELIHARAAN TAHUNAN PEMUTUS TENAGA (PMT)

SISTEM MANAJEMEN TERINTEGRASI

NOMOR DOKUMEN : FR-TRS-DOT-114 | TANGGAL : 13 July 2022 | REVISI : 2 | HALAMAN : 1 DARI 1

Unit Tragi : UPT BANDA ACEH
Merk : SIEMENS AB1 : SIEMENS AB1 : SIEMENS AB1
Tegangan Operasi : 275
Lokasi GI : GITET ARUN
Serial Number : R : 18/35150148 / A : S : 18/35150148 / A : T : 18/35150148 / A
Posisi : ---
Kondisi Cuaca : CERAH
Bay : GITET ARUN BAY PENGAPIT DIAMETER#1
Tanggal Pemeliharaan : 12 November 2024 14:39:00
Tanggal Input Device : 12 November 2024 14:39:38
Alat Uji :
Tanggal Kirim Server : 12 November 2024 14:51:17
Periode HAR : 2 TAHUNAN
Suhu Pengujian (C) : 32
Media Isolasi : ☒ SF6 ☐ Udara Hembus ☐ Minyak ☐ Vacuum
Penggerak : ☒ Pegas ☐ Pneumatik ☐ Hidrolik ☐ SF6 Dynamik

B. PENGUKURAN / PENGUJIAN TAHANAN ISOLASI

1	PMT KONDISI OFF	Acuan	R (G Ohm)	S (G Ohm)	T (G Ohm)	Tindakan	R (G Ohm)	S (G Ohm)	T (G Ohm)	Kesimpulan
	Terminal Atas - Ground Ra - gnd, Sa - gnd, Ta - gn	1M Ohm/kV SKDIR 0520-2.K/DIR/2014	153	187	122		153	187	122	
	Terminal bawah - Ground Rd - gnd, Sb - gnd, Tb - gnd	1M Ohm/kV SKDIR 0520-2.K/DIR/2014	247	302	218		247	307	218	
	Terminal Atas - Terminal Bawah Ra - Rb, Sa - Sb, Ta - Tb	1M Ohm/kV SKDIR 0520-2.K/DIR/2014	98	67	72		98	67	72	
11	PMT KONDISI ON	Acuan	R (G Ohm)	S (G Ohm)	T (G Ohm)	Tindakan	R (G Ohm)	S (G Ohm)	T (G Ohm)	Kesimpulan
	Terminal fasa - ground : (Ra/Rb) - gnd, (Sa/Sb) - gnd, (Ta/Tb) - gnd	1M Ohm/kV SKDIR 0520-2.K/DIR/2014				-				-

Figure 7. Annual maintenance form for Power Circuit Breakers

From the test results obtained after maintenance activities, the insulation resistance of the Circuit Breaker increased by an average of 30% at the upper terminals, lower terminals, and upper–lower terminal connections. These values comply with the operational standards specified in PT PLN (Persero) Directive SKDIR 520. Therefore, the CB6 AB 1 unit at GITET Arun is declared ready for operation.

Conclusion

a. The insulation resistance test results on CB6 AB 1 at GITET Arun are in accordance with the standards set by PT PLN (Persero) Directive SKDIR 520, indicating a good condition since the measured insulation resistance exceeds 1000 ohms with an applied test voltage of approximately 1000 volts.
b. After conducting a series of tests, the results indicate that CB6 AB 1 does not exhibit any signs of deterioration and is still capable of operating under normal conditions.
c. The purpose of performing maintenance on high-voltage electrical equipment is to ensure the stability of power distribution, maintain system reliability, and extend equipment lifespan by minimizing potential failures.

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Analisis Pengujian Pemutus Tenaga (PMT) 150 KV Bay Penghantar Tanjung Pura di Gardu Induk Pangkalan Brandan untuk menyalurkan energi listrik secara terus – menerus kepada setiap pelanggannya [1]. Di terga nggunya sistem proteksi pada gardu induk . Oleh karena itu , diharuskan adanya perawatan pemeliharaan pada sistem penyaluran transmisi . Pemeliharaan yang dilakukan adalah Pemeliharaan Pemutus Tenaga (PMT) 150 kV Bay Penghantar Tanjung Pura di Gardu Induk Pangkalan Brandan ”. Gardu Induk Pangkalan Brandan terletak di Kabupaten Langkat , Sumatera Utara . Pada 60 MVA tegangan kerja 150 / 20 kV dan memiliki 4 Bay Penghantar 150 kV yaitu Bay. 5, 851–863.

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