

Analysis Of the Contact Resistance of the 150 kV Vacuum Circuit Breaker at the Cigereleng Bay Line Lagadar Substation

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Abstract – Power Circuit Breaker (PMT) is an electrical device used to connect or disconnect the flow of electricity at medium to high voltage. The purpose of this research is to evaluate the operational feasibility condition of the PMT Vacuum Circuit Breaker 150 kV installed on the Lagadar bay line. To what extent the device still meets the technical requirements according to the applicable standards, technical testing is conducted to determine the extent to which the PMT Vacuum Circuit Breaker 150 kV still meets the technical requirements according to the applicable standards. The methods used include Testing for contact resistance, insulation resistance, and contact bounce. This research was conducted by comparing the test results obtained with the standards. The contact resistance test yielded the following values phase R at 37 $\mu\Omega$, phase S at 34 $\mu\Omega$, and phase T at 40 $\mu\Omega$, all of which are below the maximum threshold of 50 $\mu\Omega$ according to IEC 60694 standards. Meanwhile, in the contact synchronization test, the closing times were: phase R 74.60 ms, phase S 71.15 ms, and phase T 72.05 ms, and the opening times were: phase R 24.65 ms, phase S 30.80 ms, and phase T 24.70 ms. The time differences between phases are still within the acceptable synchronization limits (below 10 ms).

Keywords: Power Breaker, Insulation Resistance, Contact Resistance, Contact Bounce, Vacuum Circuit Breaker, Substation, IEC Standards



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I. INTRODUCTION

One of the fundamental necessities in modern civilization is electric energy. Every year, the demand for electricity continues to increase. Along with population growth and industrial development, electric energy has become a vital element in meeting the energy needs of both the public and industries in the production processes of companies [6]. Therefore, PT. PLN (Persero), as the main company responsible for supplying and distributing electric energy in Indonesia, must be able to effectively meet the electricity demands of the general public [1]. Substation, or commonly referred to as GI, is

crucial components in the electrical power transmission network. responsible for regulating the flow of energy electricity and voltage adjustment from power plants to the required level. To fulfill its role this, the Substation is equipped with various tools, including primary and secondary equipment [3]. In performing its function, the substation is assisted by various types of equipment, both primary and secondary equipment [5]. Damage to any of the equipment in a substation can disrupt the transmission and distribution of electric power. Therefore, Circuit Breakers (CB) are crucial and must be regularly maintained through a series of tests to determine their operational feasibility, based on several test parameters carried out in accordance with established standards. One of the main functions of a high voltage circuit breaker is to break the current flow in transmission network, providing complete protection and control over The transmission infrastructure in an electric power system that employs high voltage overhead lines. In the transmission line, The function of a voltage circuit breaker is to stop or disconnect current flow [14]. Alternatively said, high-voltage overhead lines are a problem. In electrical energy systems, a single piece of electrical equipment is crucial [2]. After detecting a fault, the protective relay transmits a trip signal to the circuit breaker, the circuit breaker isolates disturbed areas from the electrical power system under abnormal situations[7].

The circuit breaker itself protects the substation in the power transmission system by acting as the main switch or safety device, functioning as a breaker or connector when current is flowing under load conditions in the transmission line [2]. After a protective relay serves Acting as a detector and signal transmitter for the tripping process, the protective relay enables the circuit breaker to isolate the faulted section from the power system during abnormal conditions [4]. Maintenance of the circuit breaker is necessary due to the importance of this equipment in interrupting and conducting electric power, as well as providing protection for other equipment. A failure in the If the circuit breaker malfunctions because of a

lack of preventive maintenance, damage to the power transmission system and equipment may result [6]. Circuit breaker (CB) damage significantly affects the performance of the electric power system, which may lead to losses. In addition, it can disrupt the overall power system operation. Therefore, it is necessary to conduct periodic performance testing of the CB to ensure it meets operational standards, enhances reliability, guarantees quality, and maintains the continuity of power transmission [3]. Circuit breaker reliability is a measure To ensure the dependability of the electrical power system, the correct and reliable operation of circuit breakers is critical. If regular and ongoing monitoring is done, it is possible to evaluate whether activating a circuit breaker is feasible [5].

The maintenance of a circuit breaker (CB) involves testing several components within the CB, including insulation resistance testing and contact synchronization testing. Insulation resistance testing is one of the tests conducted on a CB. It is the process of measuring the resistance between the phase-energized parts of the CB and its body whether grounded or on the same phase as the input and output terminals. The resistance value must stay within the given range. The purpose of contact resistance testing is to ascertain how much current leaks between the powered components, specifically between the upper and lower terminals and the ground. Essentially, insulation resistance testing is intended to identify the resistance value in the CB caused by connection points that lead to power losses. These losses increase if the contact resistance value becomes higher. Circuit breaker reliability is a measure of the electrical power system's dependability, hence the viability of circuit breaker operation is crucial. Regular and continuous monitoring can help decide whether using a circuit breaker is feasible [11].

Determining each CB pole's working time and the CB's simultaneity during opening or closing operations are the goals of the synchronization test, which must not exceed the predetermined time limit. This study aims to collect data indicating whether the circuit breaker at the 150 kV Cigelereng Substation is still fit for use or needs to be replaced. Additionally, The purpose of this study is to give the author a better understanding of the measuring techniques and the capabilities of the instruments used to assess insulation resistance, contact resistance, and contact synchronization resistance [10]. The circuit breaker's (CB) performance must be tested, particularly to determine its feasibility during operation. This performance testing includes trip testing, synchronization testing, insulation resistance testing, and contact resistance testing. Through these tests, it is expected that functional failures can be avoided, which could otherwise lead to damage to the substation's CB and other parts [15]. The purpose of the contact resistance test on the PMT is to find the resistance value (R) within the range of milli-ohms to

micro-ohms. Additionally, the test can also determine the occurrence of power losses due to the connection points of the resistance values present in the PMT. To obtain the smallest value of R, a voltmeter with very low voltage sensitivity is required, and the resulting R value should not exceed the specified value, as this would increase the power losses [9]. Therefore, this study aims to contribute to the analysis of circuit breaker conditions based on direct measurements of insulation resistance, contact resistance, and contact simultaneity, in order to obtain a comprehensive overview of the equipment reliability in the 150 kV transmission system.

II. METHOD

The author studied and gathered the theoretical foundations required for this research, which were obtained from books, lecture materials, journals, and resources provided by mentors and staff at the Cigelereng Substation in West Bandung. These references were used to obtain theoretical data that serve as the basis for discussing the research problems.

The author conducted observations focused on monitoring and recording the maintenance activities of the 150 kV Circuit Breaker (CB), specifically on Contact Resistance, Insulation Resistance, and Synchronization Resistance at the 150 kV Cigelereng Substation in West Bandung.

Before conducting data collection, the author held discussions with the mentor and staff from the electrical maintenance department according to their respective areas of expertise. The discussions were carried out to review the research topic, scope of discussion, and available data at the 150 kV Cigelereng Substation in West Bandung, with a particular focus on the Power Circuit Breaker (CB).

The data required for conducting the research titled Performance Analysis of Circuit Breaker (CB) at the 150 kV Cigelereng Substation, West Bandung" are as follows:

1. Insulation Resistance Testing of the Circuit Breaker (CB)

The Equipment Maintenance Manual SE.032/PST/1984 and the VDE standard (catalogue 228/4) define the minimum insulation resistance at operating temperature using the rule: 1 kilovolt equals 1 megaohm (1 kV = 1 MΩ) (STANDARD), serve as the foundation for the insulation resistance limit for circuit breakers. Ohm's Law is used in the insulation resistance measurement to determine the insulation resistance after the leakage current has been determined, as shown in Equation (1).

$$I_{isPMT} = \frac{V_s}{R_{isPMT}} \quad (1)$$

Description: :

I_{isPMT} = Leakage current (A)

V_s = Voltage source (V)

R_{isPMT} = Resistansi (Ohm)

2. Contact Resistance Testing

The use of a current of 100 amperes is because the division calculation will be easier and faster. There are specific points of concern such as the use of scales, in order to avoid obtaining the same result between the measured current and the scale limit, which can cause overload and the readings to not reflect the actual conditions. The conductor-PMT or other equipment connection is a contact resistance that satisfies Ohm's Law requirements. If the contact resistance is found to be 1 Ohm and the current flowing is 100 Amperes, then the power loss caused by the contact [8]. resistance can be formulated with the equation. (2):

$$V_s = I_{isPMT} \cdot R_{isPMT} \quad (2)$$

Description :

I_{isPMT} = Leakage current (A)

V_s = Voltage source (V)

R_{isPMT} = Resistansi (Ohm)

3. Contact Synchronization Testing

Contact synchronization can be calculated by comparing the difference between the highest and lowest time values. According to the established standard, the time difference should be ≤ 10 ms, as expressed in Equation (3):

$$\Delta t = t_{maks} - t_{min} \quad (3)$$

Description :

Δt = Time difference

t_{maks} = Maximum time

t_{min} = Minimum time

III. RESULTS AND DISCUSSION

This study involves three tests that support the performance evaluation of the Circuit Breaker (CB), namely :

Table 3. 1 Insulating Resistance Test Results of the Circuit Breaker on the Lagadar Line Bay at the 150 kV Cigelereng Substation

Monitoring Point	Voltage	Measurement Result (MΩ)		
		Phase R Line	Phase S Line	Phase T Line
Top - Bottom	150 kV / 150.000 V	1000.000	1000.000	1000.000
Phase - Ground	150 kV / 150.000 V	1000.000	1000.000	1000.000
Phase - Phase	150 kV / 150.000 V	1000.000	1000.000	1000.000

The table 3.1. shows the results of the insulation resistance measurement on a 150 kV circuit breaker for three testing conditions: between the top and bottom (Top–Bottom), between phase and ground (Phase–Ground), and between phases (Phase–Phase). The testing was conducted at a voltage of 150 kV, and the results obtained for the three phases (R, S, and T) were 1,000,000 MΩ. This number shows that there is no current leakage and that the insulating resistance is in excellent shape, so the circuit breaker is declared still suitable and safe for operation. In order to verify

that the insulation resistance value is still in excellent condition and safe for use, this table presents the findings of the circuit breaker's insulation resistance test. High values (in the thousands of MΩ) indicate very good insulation and no current leakage between parts of the system.

Table 3.2 Results of contact resistance testing of the bay line circuit breaker at the 150 kV Cigelereng substation.

Monitoring Point	Current	Phase R Line	Phase S Line	Phase T Line
Upper Pole–Lower Pole	100 A	37	34	40

The table 3.2. shows the measurement results of the contact resistance between the upper and lower poles (Upper Pole–Lower Pole) at a current of 100 A for the three phases. The obtained values are 37 $\mu\Omega$ for phase R, 34 $\mu\Omega$ for phase S, and 40 $\mu\Omega$ for phase T. According to the IEC 62271-100 standards, the contact resistance value for medium to high voltage circuit breakers should generally be below 50 $\mu\Omega$ per phase. Thus, the measurement results are still within the established standard limits and indicate that the circuit breaker contact condition is still good, not experiencing excessive wear, and capable of conducting current without causing significant power loss. The purpose of measuring contact resistance is to determine the magnitude of electrical resistance at the circuit breaker contact joint when current flows, in order to ensure conductivity quality and detect wear, corrosion, or mechanical damage that could disrupt the circuit breaker's performance

Table 3.3 Results of contact synchronization testing of the bay line circuit breaker at the 150 kV Cigelereng substation.

Monitoring Point	Phase R Line	Phase S Line	Phase T Line
Close	74.60	71.15	22.05
Open (Trip 1)	24.65	30.80	24.70
(Open Trip 2)	23.70	30.85	23.70

The table 3.3. shows the contact simultaneity time on the circuit breaker. When in the closed condition, the time difference between phases is very large and does not comply with the IEC 62271-100 standard, which sets a maximum limit of around 3 ms. Meanwhile, in the open condition (Trip 1 and Trip 2), the timing is more synchronized and still within reasonable limits. This indicates that there is a problem with the closing mechanism. Finding the amount of synchronization between the circuit breaker contacts throughout the opening and shutting operation is the aim of the measurements in this table, and to ensure whether the operating time still complies with the IEC 62271-100 standard as a reference for reliable and safe performance.

To assess the performance feasibility of the circuit breaker, several testing steps were conducted, such as testing for contact resistance, insulation resistance,

and contact synchronization, which are explained in detail in the following sections:

The following is the calculation of leakage current for the bay line circuit breaker at the 150 kV Cigelereng Substation on March 4, 2024, based on the insulation resistance measurement results shown in Table 3.1.

- a. Leakage Current Calculation at the Measuring Point Between Upper and Lower Poles.
 - phase R Leakage Current = $\frac{150.000}{\frac{1000.000 \text{ M}\Omega}{150.000}} = 0.15 \text{ }\mu\Omega$
 - phase S Leakage Current = $\frac{150.000}{\frac{100000 \text{ M}\Omega}{150.000}} = 0.15 \text{ }\mu\Omega$
 - phase T Leakage Current = $\frac{150.000}{\frac{150.000}{150.000 \text{ M}\Omega}} = 0.15 \text{ }\mu\Omega$
- b. Leakage Current Calculation at the Measuring Point Between Phase and Ground
 - phase R Leakage Current = $\frac{150.000}{\frac{100.000 \text{ M}\Omega}{150.000}} = 0.15 \text{ }\mu\Omega$
 - phase S Leakage Current = $\frac{150.000}{\frac{1000.000 \text{ M}\Omega}{150.000}} = 0.15 \text{ }\mu\Omega$
 - phase T Leakage Current = $\frac{150.000}{\frac{1000.000 \text{ M}\Omega}{150.000}} = 0.15 \text{ }\mu\Omega$
- c. Leakage Current Calculation at the Measuring Point Between Phase and Phase
 - phase R Leakage Current = $\frac{150.000}{\frac{1000.000 \text{ M}\Omega}{150.000}} = 0.15 \text{ }\mu\Omega$
 - phase S Leakage Current = $\frac{150.000}{\frac{100.000 \text{ M}\Omega}{150.000}} = 0.15 \text{ }\mu\Omega$
 - phase T Leakage Current = $\frac{150.000}{\frac{1000.000 \text{ M}\Omega}{150.000}} = 0.15 \text{ }\mu\Omega$

Insulation resistance measurement was carried out using an insulation tester (Megger brand) with a test voltage of 150 kV. The insulating resistance measurement results are shown in Table 3.1. As shown in Table 3.1, the insulation resistance still meets the required standard, which states that the minimum insulation resistance for a 150 kV circuit breaker (CB) must be 1000 G Ω .

Once the measurement results are obtained, the leakage current for each terminal and phase can be calculated using the formula in Equation (1), with a test voltage of 150,000 V. The analysis shows that the resulting leakage current values do not exceed the standard limit of 1 kV/1 M Ω .

The test data indicate that each phase has the same insulation strength or resistance, which is influenced by the condition of each insulator. If the insulator is covered with dust or dirt, it can significantly affect its insulation capability.

The insulation resistance test results for the CB on March 4, 2024, show that the resistance values for phases R, S, and T are each 1000 G Ω , and all the calculated leakage current values are well below the permissible leakage current limit of 1 kV/1 M Ω , according to VDE Catalogue 228/4.

From the insulation resistance testing and leakage current calculations, it can be concluded that the insulation materials tested on the CB are continues to meet the criteria for safe and proper functioning based on the standard. If the measured results fall below the

standard after testing, it is recommended to replace the circuit breaker with a new one that has better insulation capability.

Power Loss Calculation on Circuit Breaker Contacts Power loss calculation on the bay line circuit breaker at the 150 kV Cigelereng Substation on March 4, 2024, is based on the contact resistance measurement results shown in Table 3.2.

1. Power Loss on Phase R

$$P_R = I^2 \cdot R = 100^2 \times 37 \cdot 10^{-6} = 0.37 \text{ W}$$

2. Power Loss on Phase S

$$P_S = I^2 \cdot R = 100^2 \times 34 \cdot 10^{-6} = 0.34 \text{ W}$$

3. Power Loss on Phase T

$$P_T = I^2 \cdot R = 100^2 \times 40 \cdot 10^{-6} = 0.4 \text{ W}$$

The contact resistance measurement was conducted using a Megger brand Micro Ohm Meter with an input current of 100 A. The contact resistance measurement results are presented in Table 5.2. According to the contact resistance measurements shown in Table 5.2, none exceeded the established standard, which is not to exceed 50 $\mu\Omega$. After obtaining the contact resistance test results, we can measure the power loss generated in each phase using the formula in equation 4.2. With the current used during the test being 100 A, the power loss calculation for the upper-lower terminal of phase R yielded a result of 0.37 Watts, for phase S a result of 0.43 Watts, and for phase T a result of 0.4 Watts. The contact resistance measurement results did not exceed the standard, which is below 50 $\mu\Omega$. Several causes for this include the age of the circuit breaker, the measuring instrument, terminal sanitation during the test, contact disconnection, environmental temperature, or technician negligence [7]. From the results of the Resistance at the Contact Point testing Pertaining to the 150 kV circuit breaker on the lagadar line bay at the 150 kV Cigelereng Substation on phases R, S, and T, it meets the standard with a value of $R \leq 50 \text{ }\mu\Omega$. The value obtained from the power loss calculation with an average value of 0.37 watts indicates that the contact circuit breaker installed on the lagadar line bay Is maintained in good working order and Fit for operation. Contact Synchronization Calculation.

The calculation of time differences in the bay line circuit breaker at the Cigelereng Substation on March 4, 2024, is based on the contact synchronization test results shown in Table 3.3.

1. $\Delta_t \text{ close} = t_{maks} - t_{mins} = 74.6 \text{ ms} - 71.1 \text{ ms} = 3.5 \text{ ms}$
2. $\Delta_t \text{ open Trip 1} = t_{maks} - t_{mins} = 30.80 \text{ ms} - 24.65 \text{ ms} = 6.15 \text{ ms}$
3. $\Delta_t \text{ open Trip 2} = t_{maks} - t_{mins} = 30.85 \text{ ms} - 23.70 \text{ ms} = 7.15 \text{ ms}$

Based on the results of the Contact Synchronization Test conducted on March 4, 2024, the calculated delta time (Δt) or time difference was 3.5 ms when the

circuit breaker (CB) was in the closed position, and 6.1 ms in the open position. Since these values meet the standard requirements, the CB is capable of tripping properly and performing reliably during fault conditions. If the delta time exceeds 10 ms, the synchronization performance of the CB is considered less reliable. According to the calculation results of the synchronization time difference, the 150 kV circuit breaker achieved a value that complies with the specified standard requirement, having a Δt value within 10 ms, based on the standard from ABB.

IV. CONCLUSION

For the insulation resistance test, a leakage current value of 0.15 mA was obtained on March 4, 2024. This value is still below the minimum standard. The insulation resistance at operating temperature is estimated using the standard guideline of 1 M Ω per 1 kV of operating voltage according to VDE Standard, Catalogue 228/4. For the contact resistance test, the following values were obtained on March 4, 2024 Phase R: 37 $\mu\Omega$, Phase S: 34 $\mu\Omega$, Phase T: 40 $\mu\Omega$. These values are below the maximum allowable contact resistance standard of $R \leq 50 \mu\Omega$ or 120% of FAT values, with a test current of 100 A, according to IEC 60694 ed.2.2:2002-01. For the contact synchronization test, the delta time values obtained on March 4, 2024 were 3.5 ms when closing (Δt close), 7.15 ms when opening (Δt open). These values are below the time difference limit of $\Delta t \leq 10$ ms, based on the reference from ABB manufacturer. Therefore, the performance of the Feeder 52 ST8 6.3 kV Circuit Breaker at the substation is capable of tripping and operating normally, and its reliability is still considered feasible for continued operation.

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