FEASIBILITY ANALYSIS OF CIRCUIT BREAKER (PMT) ON BAY LINE AN BAY TRANSFORMER AT KOTA BARU SUBSTATION

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ABSTRACT

Electric transmission lines play a crucial role in delivering stable and efficient power to consumers. A key component in transmission systems is the Circuit Breaker (PMT), which protects major equipment from faults like overcurrent or short circuits. This study evaluates the operational feasibility of PMTs at Bay Line and Bay Trafo in Kota Baru Substation. Evaluation is based on insulation resistance, contact resistance, and contact simultaneity tests, using maintenance data from ULTG Pontianak. Results show insulation resistance above the 150 MΩ standard, averaging 165 MΩ (Bay Line) and 170 MΩ (Bay Trafo), indicating good insulation. Contact resistance meets IEC 60694 standards (≤50 µΩ), with a maximum of 42 µΩ recorded. Contact simultaneity, analyzed with a Megger Egil Circuit Breaker Analyzer, shows a maximum phase time difference of 8 ms, within the SPLN 52-1 1984 limit (≤10 ms). Findings confirm that PMTs remain operational and effectively protect the system. However, regular maintenance is essential, especially as the equipment exceeds 10 years of use. This study contributes to power reliability and future data-driven maintenance protocols.

Keywords: *Circuit Breaker, Insulation Resistance, Contact Resistance, Contact Simultaneity, Line Bay.*

INTRODUCTION

PMT operates by opening the contact to prevent excessive current caused by disturbances from entering and damaging other equipment. If the PMT fails to operate during a disturbance or experiences a delay in operation, it can significantly impact other key equipment. Damage to equipment in a substation can disrupt the transmission and distribution of electrical power. Therefore, the PMT must be regularly maintained through a series of tests to assess its operational feasibility, based on several test parameters according to established standards [1].

In relation to this, this study will evaluate the routine maintenance of the PMT conducted on the Bay Line and Bay Transformer (Bay Trafo) at the Kota Baru Substation, specifically at Bay Line Kota Baru - Parit Baru, Bay Line Kota Baru - Cendana, Bay Transformer 1, and Bay Transformer 2. The focus of this evaluation is to analyze the results of insulation resistance tests, contact resistance tests, and simultaneity tests. Based on this, the researcher has chosen the title: "Feasibility Analysis of Circuit Breakers (PMT) on Bay Line and Bay Transformer at Kota Baru Substation [2].

METHOD

Conducting Insulation Resistance Measurements

The measurement of insulation resistance in a circuit breaker (PMT) is a process of determining the insulation resistance value using a Megger device. This measurement is performed by applying DC voltage to the circuit breaker's insulation. The insulation resistance limit for a circuit breaker (PMT), according to the Equipment Maintenance Manual SE.032/PST/1984 and VDE Standard (Catalogue 228/4), is a minimum of "1 kiloVolt = 1 MegaOhm." The permissible leakage current for each kV is 1 mA [1], [6], [9].

RESULTS AND DISCUSSION

Insulation Resistance Measurement Results

The measurement of insulation resistance on the 150 kV Circuit Breaker (PMT) aims to determine the quality of the insulation so that it can function properly in isolating the voltage passing through the PMT and preventing electrical disturbances.

The insulation resistance measurement was conducted at GI Kota Baru, specifically at Bay Line Kota Baru – Parit Baru, Bay Line Kota Baru – Cendana, Bay Trafo 1, and Bay Trafo 2. The following are the insulation resistance measurement results for each bay and the calculation of leakage resistance.

Table 1. Insulation Resistance Measurement Results of Bay Line Kota Baru-Parit Baru

Measurement Point	Standard	Measurement Voltage (V)	Insulation Resistance (MΩ)		
			Phase R	Phase S	Phase T
Top - Bottom	1 kV / 1MΩ (PMT Maintenance Guide)	5000	4410	3750	4020
Top - Grounding System			5520	4630	3450
Bottom - Grounding System			5120	4420	4420

Based on the results of the insulation resistance measurement on the Bay Line Kota Baru – Parit Baru in Table 1 above, the values are generally high, exceeding 150 kV, indicating that the insulation condition of the Bay Line Kota Baru – Parit Baru is in good condition. The measurement results remain above the standard, which is 1 kV at 1 MΩ or still above 150 MΩ. Phase R shows consistent results with relatively higher values compared to the other phases, whether in the measurement of the upper terminal to the lower terminal, the upper terminal to the grounding system terminal, or the lower terminal to the grounding system terminal. This indicates that the insulation in phase R is more optimal compared to the other phases.

The results of the insulation resistance measurement on the Bay Line Kota Baru - Cendana can be seen in the table below.

Table 2. Insulation Resistance Measurement Results of Bay Line Kota Kota Baru - Cendana

Measurement Point	Standard	Measurement Voltage (V)	Insulation Resistance (MΩ)		
			Phase R	Phase S	Phase T
Top - Bottom	1 kV / 1MΩ (PMT Maintenance Guide)	5000	4630	5520	3450
Top - Grounding System			4420	4030	3850
Bottom - Grounding System			5250	4420	4420

Based on the results of the circuit breaker insulation resistance measurement on the Bay Line Kota Baru – Cendana in Table 2 above, the overall insulation resistance values remain high. The insulation resistance is significantly higher than the specified standard of 150 MΩ for a voltage of 150 kV. Among the terminal combinations, phase T shows the lowest resistance compared to phases R and S, requiring extra attention to ensure no insulation degradation in phase T. Phases R and S exhibit more consistent values, while phase T shows significant variation. The high insulation resistance values indicate good insulation. All results are in the Mega-ohm (MΩ) range, which generally meets the standards for a 150 kV electrical system.

Measurement Point	Current Leakage (mA)		
	Phase R	Phase S	Phase T
Top - Bottom	1,1337	1.1333	1,2437
Top - Grounding System	0,9057	1,0799	1,4429
Bottom - Grounding System	0,9765	1,1312	1,1312

The results of the insulation resistance measurement on the Bay Transformer 1 can be seen in the table below.

Table 3. Insulation Resistance Measurement Results of Bay Transformer 1

Measurement Point	Standard	Measurement Voltage (V)	Insulation Resistance (MΩ)		
			Phase R	Phase S	Phase T
Top - Bottom	1 kV / 1MΩ (PMT Maintenance Guide)	5000	22000	24500	24600
Top - Grounding System			30000	26700	24400
Bottom - Grounding System			30600	26200	24200

Based on the results of the insulation resistance measurement on Bay Transformer 1 in Table 3 above, it can be seen that the upper terminal – lower terminal has a fairly high resistance value, indicating no significant degradation in this path. The upper terminal – grounding system terminal also has a sufficiently high value, effectively maintaining insulation integrity. The lower terminal – grounding system terminal shows varying values, with phase R being relatively high, while phase T has a slightly lower value. All values fall within the good category for high-voltage systems, where insulation resistance is expected to exceed 150 MΩ in a 150 kV system.

The results of the insulation resistance measurement on the Bay Transformer 2 can be seen in the table below.

Table 4. Insulation Resistance Measurement Results of Bay Transformer 2

Measurement Point	Standard	Measurement Voltage (V)	Insulation Resistance (MΩ)		
			Phase R	Phase S	Phase T
Top - Bottom	1 kV / 1MΩ (PMT Maintenance Guide)	5000	116000	311000	231000
Top - Grounding System			43500	26000	26800
Bottom - Grounding System			192000	108000	142000

Based on the results of the insulation resistance measurement on Bay Transformer 2 in Table 4 above, it was found that the contact resistance value in the measurement between the upper terminal – grounding system terminal shows a significant difference compared to the measurements between the upper terminal – lower terminal and the lower terminal – grounding system terminal. This requires special attention due to a considerable drop compared to other test results. This discrepancy may be caused by various factors, such as measurement errors or environmental factors like dust on the tested equipment.

In general, the measurement results for the upper terminal – grounding system terminal are still well within acceptable limits, considering the insulation resistance standard of 1 MΩ per kV, meaning that for a 150 kV system, the expected insulation resistance should exceed 150 MΩ. The insulation resistance measurement on Bay Transformer 2 remains well above the specified standard. Overall, the insulation resistance values are still very good. Additionally, the circuit breaker installed in Bay Transformer 2 is new.

Contact Resistance Measurement Results

The contact resistance measurement is conducted to determine the resistance value at the connection points of the circuit breaker (PMT). The measurement is performed using a testing device called Omicron CPC 100. The test is carried out by applying a current of 100 A. The current flows through the circuit breaker contacts, and the device measures the voltage across the contacts. The measured voltage is then divided by the applied current, and the contact resistance value is displayed on the device's screen.

The contact resistance measurement results of the 150 kV circuit breaker at Bay Line Kota Baru – Parit, Bay Line Kota Baru – Cendana, Baru, Bay Transformer 1 and Bay Transformer 2 can be seen in the following table.

Table 5. Contact Resistance Measurement Results

Location	Measurement Point	Standard	Contact Resistance (μΩ)			Current (A)
			Phase R	Phase S	Phase T	
Bay Line Kota Baru – Parit Baru	Top - Bottom	IEC 60694 R ≤ 50 μΩ / 120 % FAT Value	42	40	47	100
Bay Line Kota Baru – Cendana			43	43	48	
Bay Transformer 1			45	44	39	
Bay Transformer 2			34	33	34	

In the contact resistance measurement results of the 150 kV circuit breaker at Gardu Induk Kota Baru, specifically at Bay Line Kota Baru–Parit Baru, Bay Line Kota Baru–Cendana, Bay Transformer 1, and Bay Transformer 2, as presented in Table 5 above, all values are below 50 μΩ. This indicates that the contact resistance of each circuit breaker installed at Gardu Induk Kota Baru is still in good and safe condition, in accordance with the IEC 60694 standard, which requires R ≤ 50 μΩ or 120% of the manufacturer's specified value or FAT (Factory Acceptance Test) measurement value.

If the contact resistance does not meet the established standard, it may result in uncontrolled current flow or disruptions in the electrical system. Consequently, equipment may suffer damage, leading to power outages, and in extreme cases, excessive heat buildup that could cause fires or explosions in the circuit breaker.

To prevent such issues, regular maintenance is necessary to ensure the proper functioning of the equipment. If damage occurs, the faulty components within the circuit breaker contacts must be replaced to maintain system safety. After replacement or readjustment, a re-measurement of the circuit breaker contact resistance must be conducted."

Contact Simultaneity Measurement Results

The 150 kV circuit breaker contact simultaneity measurement is conducted to evaluate the performance of the circuit breaker contacts in opening and closing, both per phase and simultaneously for phases R, S, and T. The circuit breaker contacts are expected to have minimal time differences when opening or closing between phases.

If the circuit breaker contacts do not operate according to the specified standards, it may lead to disturbances in the power system, triggering the protection system automatically. If the protection system fails to address the issue caused by a high contact simultaneity difference, the circuit breaker's protection function may be compromised. Since the circuit breaker is designed to protect electrical power system equipment, excessive current may flow through and damage the protected equipment. Therefore, it is essential to perform measurements to determine the time differences in the operation of the circuit breaker contacts for each phase during opening and closing.

The contact simultaneity measurement results of the 150 kV circuit breaker at Bay Line Kota Baru – Parit, Bay Line Kota Baru – Cendana, Baru, Bay Transformer 1 and Bay Transformer 2 can be seen in the following table.

Table 6. Contact Simultaneity Measurement Results

Location	Measurement Condition	Contact Simultaneity (ms)			Delta Time (ms)
		Phase R	Phase S	Phase T	
Bay Line Kota Baru – Parit Baru	Open	39,05	36,15	39,15	3,00
	Close	69,85	70,75	68,25	2,50

Bay Line Kota Baru – Cendana	Open	37,25	38,35	38,25	1,10
	Close	66,84	68,44	67,94	1,60
Bay Transformer 1	Open	34,67	34,47	35,17	0,70
	Close	65,28	65,48	65,08	0,40
Bay Transformer 2	Open	25,20	25,40	25,50	0,30
	Close	57,60	57,30	57,20	0,40

Delta time between phases R, S, and T during the opening and closing of the circuit breaker (PMT) is determined by calculating the time difference (Δt). The time difference is obtained by measuring the gap between the phase with the longest operating time and the phase with the shortest operating time when opening or closing the circuit breaker contacts. The simultaneity time difference limit is set at $\Delta t \leq 10$ ms, based on the reference from ABB. This delta time indicates the level of simultaneity of a circuit breaker. The smaller the contact time difference between phases when opening or closing, the more synchronized the circuit breaker operates.

The calculated contact simultaneity time difference for the 150 kV circuit breaker at Bay Line Kota Baru – Parit Baru, as shown in Table 6 above, is 3.00 ms when opening and 2.50 ms when closing. The standard states that the phase simultaneity difference should not exceed 10 ms, both when opening and closing. When opening, the time difference occurs between phase T and phase S, with a difference of 3.00 ms, indicating good and responsive contact performance with no significant delays that could cause imbalance between phases. When closing, the time difference of 2.50 ms is also very small, reflecting a well-calibrated and uniform contact mechanism. The 150 kV circuit breaker at Bay Line Kota Baru – Parit Baru demonstrates excellent performance in terms of contact simultaneity.

The calculated contact simultaneity time difference for the 150 kV circuit breaker at Bay Line Kota Baru – Cendana, as presented in Table 6 above, is 1.10 ms when opening and 1.60 ms when closing. The results show that the contact simultaneity time difference is well below the specified standard of $\Delta t \leq 10$ ms. A simultaneity discrepancy exceeding the 10 ms tolerance could lead to voltage and current imbalance, posing a risk to system stability. However, the test results for Bay Line Kota Baru – Cendana indicate excellent simultaneity, ensuring that such risks do not occur.

The calculated contact simultaneity time difference for the 150 kV circuit breaker at Bay Trafo 1, as shown in Table 6 above, is 0.70 ms when opening and 0.40 ms when closing. The time difference diagram indicates that the contact simultaneity of the 150 kV circuit breaker at Bay Trafo 1 exhibits excellent performance. The mechanical system is operating optimally, and no corrective actions are currently required. Routine maintenance and periodic testing are recommended to ensure continued performance.

The calculated contact simultaneity time difference for the 150 kV circuit breaker at Bay Trafo 2, as shown in Table 6 above, is 0.30 ms when opening and 0.40 ms when closing. The diagram demonstrates that the time differences for both opening and closing remain well below the ≤10 ms standard, indicating that the 150 kV circuit breaker at Bay Trafo 2 performs exceptionally well in opening and closing contacts. The 150 kV circuit breaker at Bay Trafo 2 operates optimally, with excellent contact simultaneity that meets the required standards. The system is in an ideal condition to ensure stable, reliable, and safe operation within the transmission network.

CONCLUSION

Based on the analysis and evaluation of the testing conducted on the 150 kV circuit breakers (PMT) at Gardu Induk Kota Baru, the following conclusions can be drawn.

The insulation resistance tests conducted on the 150 kV circuit breakers at Bay Line Kota Baru – Parit Baru, Bay Line Kota Baru – Cendana, Bay Trafo 1, and Bay Trafo 2 indicate that the electrical system insulation is still in good condition. The results comply with the maintenance manual SE.032/PST/1984 and VDE standard (catalogue 228/4), which specifies a minimum insulation resistance of "1 kilo volt = 1 Mega Ohm." The measured insulation resistance values for all circuit breakers are well above the minimum standard of 150 MΩ for the 150 kV power system.

The contact resistance tests on the circuit breakers at Bay Line Kota Baru – Parit Baru, Bay Line Kota Baru – Cendana, Bay Trafo 1, and Bay Trafo 2 confirm that the measured contact resistance values remain within the established standard limits. According to IEC 60694, the acceptable contact resistance is $R \leq 50\ \mu\Omega$ or 120% of the FAT (Factory Acceptance Test) value. The obtained test results show contact resistance values below 50 μΩ.

The simultaneity tests conducted on the circuit breakers at Bay Line Kota Baru – Parit Baru, Bay Line Kota Baru – Cendana, Bay Trafo 1, and Bay Trafo 2 produced excellent results, with all phase time differences remaining within the standard tolerance limit of $\Delta t \leq 10$ ms, as referenced from ABB specifications. Proper contact simultaneity ensures optimal system protection, preventing current or voltage imbalances that could potentially damage critical equipment such as transformers.

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