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Performance Analysis of SF_6 Circuit Breakers: Case Study of Rungkut 150 kV Main Substation

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Abstrak

Peralatan pengaman yang ada di Gardu Induk salah satunya adalah Pemutus Tenaga. Pemutus Tenaga merupakan peralatan saklar atau switching mekanis yang dapat menutup, mengalirkan, maupun memutuskan arus beban dalam kondisi normal maupun dalam kondisi abnormal seperti hubung singkat. Masalah pada pemutus tenaga dapat merugikan dan mengganggu proses operasi sistem tenaga listrik. Apabila pemutus tenaga tidak berkerja sesuai semestinya saat terjadi gangguan, maka gangguan tersebut dapat merusak perangkat lain dan menyebabkan ketidakstabilan penyaluran daya listrik. Oleh karena itu, pengujian dan pemeliharaan secara rutin harus dilakukan untuk memastikan pemutus tenaga layak beroperasi. Tahapan pengujian meliputi tekanan gas SF_6, tahanan isolasi, tahanan kontak, dan keserempakan kontak permutus tenaga. Hasil pengujian menunjukkan tekanan gas SF_6 dengan nilai diatas *nameplate* yang tertulis pada pemutus tenaga, tahanan isolasi dengan nilai di atas 150 MΩ, tahanan kontak dengan standar nilai di bawah 50 μΩ, dan pengujian keserempakan kontak dilakukan dengan perhitungan *delta time* saat *close* maupun *open* pada fasa masing-masing di bawah nilai 10 ms. Analisa dilakukan dengan membandingkan waktu operasi dan kondisi kontak dengan spesifikasi peralatan untuk menentukan apakah CB beroperasi dengan optimal. Sesuai dengan hasil pengujian tekanan gas SF_6, tahanan isolasi, resistansi kontak dan keserempakan pemutus tenaga yang ada pada Gardu Induk 150 KV Rungkut Bay Line Surabaya Selatan dalam kondisi layak beroperasi.

Abstract

One of the safety equipment in the main substation is the power breaker. A power breaker is a mechanical switch or switching device that can close, transmit or disconnect the load current under normal conditions or under abnormal conditions such as a short circuit. Problems with power breakers can be detrimental and disrupt the operation of the electric power system. If the power breaker does not work properly when a disturbance occurs, the disturbance can damage other devices and cause instability in the distribution of electrical power. Therefore, regular testing and maintenance must be carried out to ensure the circuit breaker is operational. The testing stages include SF_6 gas pressure, insulation resistance, contact resistance, and power

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breaker contact simultaneity. The test results show SF6 gas pressure with a value above the nameplate written on the power breaker, insulation resistance with a value above 150 MΩ, contact resistance with a standard value below 50 μΩ, and contact simultaneity testing is carried out by calculating the delta time when closing and opening the phase. each under a value of 10 ms. Analysis is carried out by comparing operating time and contact conditions with equipment specifications to determine whether the CB is operating optimally. In accordance with the results of SF_6 gas pressure testing, insulation resistance, contact resistance and power breaker synchronization at the 150 KV Rungkut Bay Line Surabaya Selatan Main Substation are in good operational condition.

Introduction

The transmission network with high voltage overhead lines in the electric power system is fully protected and controlled by the appropriateness of the circuit breaker, so that the presence of high voltage circuit breaker acts as a current flow breaker in the transmission line (Vianna et al., 2017), or in other words high voltage overhead lines are a fault. one piece of electrical equipment is very important in the electric power system (Cheng et al., 2018). The circuit breaker functions as an isolate of disturbed areas from the electrical power system during abnormal conditions, after a protection relay as a detector and sender of signals for the tripping process to the circuit breaker (Guo et al., 2022). The process after receiving the dropping command signal, circuit breaker with the action of isolating the disturbed area from the electrical power system (Díaz et al., 2020). Circuit breaker reliability is an indication of the reliability of the electrical power system, so the feasibility of circuit breaker operation plays an important role. The feasibility of operating a circuit breaker can be determined if monitoring is carried out regularly and continuously (Feiming et al., 2017)

A circuit breaker with a nominal voltage of 150 kV equipped with sulfur hexafluoride gas (SF_6), is a circuit breaker device that has become part of the electrical power network system at the substation (Alidemaj & Nika, 2020). A circuit breaker with two operating states, namely open and closed circuit breaker contacts per phase with its own harmony (Da Silva et al., 2023). The process of opening or closing the moving contact point when the circuit breaker is loaded has an impact on the existence of an arc between the circuit breaker contacts. The arc is extinguished at the same time as the current having a value equal to zero. The termination process is successful, if the arc has been extinguished and the current is reached at zero, so that the disturbance can be eliminated.

As long as it operates under normal conditions, the circuit breaker can be opened or closed without resulting in losses. The automatic opening or closing of the moving contacts on the circuit breaker must be carried out properly by the drive system mechanism. Manual disconnection can be carried out by the operator for the purpose of manipulation or maintenance (Bizzarri et al., 2020). Installing circuit breaker continuously and for a long time can result in a decrease in the level of reliability of the circuit breaker. To guarantee operational reliability, circuit breaker must always and continuously evaluate and test its performance after a long period of operation. The level of reliability of circuit breaker is carried out through measurements and testing of its parts (Kim et al., 2014).

The research carried out provides an in-depth analysis of the performance of SF_6 circuit breakers, thereby providing specific insights into operating conditions at these locations that have not been widely discussed in previous literature. It also provides practical recommendations for improving the performance and reliability of SF_6 circuit breakers in substations based on research findings. This can be very useful for power grid engineers and managers. A number of characteristics of circuit breaker with SF_6 gas have a major influence on the level of circuit breaker performance (Obi et al., 2021). Inventory of technical specifications for circuit breaker with SF_6 gas at substations (Wijaya et al., 2022) and determination of research objectives with the main targets, namely (i) obtaining results of measuring the quality of SF_6 gas, (ii) obtaining results of measuring the simultaneous value of moving contacts during opening/closing operations on circuit breaker, and (iii) obtain the value of a certain amount of resistance. These three targets are an effort to obtain circuit breaker characteristics with SF_6 gas, so that the level of circuit breaker performance is known.

Method

SF_6 Gas Pressure Testing

SF_6 gas is an abbreviation for sulfur hexafluoride gas where this gas is obtained from a solution of sulfur and fluoride gas at a temperature of 300^0C and a purity of 99.9% is obtained. At a temperature of 150^0C, SF_6 gas has properties that do not damage metal, plastic and other equipment used in circuit breakers. As an electrical insulator, SF_6 gas has high dielectric strength where this dielectric strength will increase with increasing pressure. On the other hand, SF_6 gas has the ability to quickly restore the dielectric strength of the gas. Therefore, SF_6 gas is used as an arc extinguishing medium for 150 kV circuit breaker. SF_6

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gas testing usually aims to test the purity and pressure of SF_6 gas in circuit breaker equipment. This test uses a measuring instrument, namely the SF_6-Q-Analyzer. This tool will show various states of SF_6 gas in circuit breaker, including Dew Point, Moisture Content, Purity, SO_2 + SOF_2, and Pressure. When calculating SF_6 gas pressure, it is usually in units of bar. To be known in kPa units, the bar units must be converted into kPa. Where, 1 bar = 100 kPa. Mathematically, to determine the pressure of SF_6 gas you can use the following formula:

$$\text{Pressure of } SF_6 \text{ (bar)} = \text{Current Pressure (kPa)} \times 100 \quad (1)$$

The calculation of SF_6 gas pressure is expected to comply with standardization, namely greater than the pressure written on the circuit breaker nameplate.

Insulation Resistance Testing

Circuit breaker insulation resistance testing is a measurement process using a measuring instrument to obtain the circuit breaker insulation resistance value between the part (phase) that is energized against the body (case) which is grounded and the part (phase) that is energized against the lower terminal on the same phase. Basically, measuring the circuit breaker insulation resistance aims to determine the amount of leakage current that occurs between the part that has voltage at the top terminal and the bottom terminal towards the ground. Leakage current penetrating the circuit breaker insulation cannot be avoided. Therefore, one way to ensure that a circuit breaker is safe enough to be energized is to measure its insulation resistance. Insulation resistance testing uses an insulation tester by inputting the equipment voltage to the target object at 5 kV. After the test has been carried out, the leakage current value will be calculated using the formula (Purnomoadi et al., 2020):

$$\boldsymbol{I_{leakage}} = \frac{\boldsymbol{V}}{\boldsymbol{R}} \quad (2)$$

Where,

$\boldsymbol{I_{leakage}}$: circuit breaker leakage current value [Ampere]

V : Injection Voltage [Volt]

R : Circuit Breaker Insulation Resistance [Ohm]

Contact Resistance Testing

An electric power circuit consists of many connection points, namely two or more conductors that physically meet so that electrical energy can be transmitted without significant obstacles. The meeting of these conductors causes resistance or resistance to the current passing through the equipment, which will cause the connection point to heat up and

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cause losses. This loss is very significant if the resistance value is high. The connection point between the circuit breaker equipment and other equipment is a contact resistance which meets the power loss rules as follows (Purnomoadi et al., 2020):

$$\boldsymbol{P_{loss}} = \boldsymbol{I^2} \times \boldsymbol{R} \tag{3}$$

Where,

$\boldsymbol{P_{loss}}$: Power Losses of Circuit Breaker [Watt]

I : Injection Current [Ampere]

R : Contact Resistance of Circuit Breaker [Ohm]

Basically, contact resistance measurements are the same as measurements in general. When measuring the contact resistance of circuit breakers, a current of 100 amperes is used. Using a current of 100 amperes will make it easier to determine the resistance value more quickly because the divider is 100. The contact resistance value limit is based on the IEC 60694 standard, R value ≤ 50 µΩ / 120% FAT value (Arias Velásquez & Mejía Lara, 2020).

Contact Simultaneity Testing

The circuit breaker contact synchronization test is used to determine the working time of the circuit breaker and to determine the synchronization of the circuit breaker when the circuit breaker opens and closes. The synchronization of circuit breaker contacts is very influential in the operation of the electric power system, especially in electric power transmission. The circuit breaker must open and close simultaneously on each phase R, S, and T. If not, it could become an anomaly in the distribution of electric power which results in the protection system not working according to its function. When the circuit breaker trips due to an anomaly in the distribution of electrical power, it is hoped that the circuit breaker can work quickly so that the expected clearing time is in accordance with the standards used. Mathematically, the delta time (Δt) can be calculated using the following formula (Purnomoadi et al., 2020):

$$\Delta t\,[ms] = highest\ time[ms] - lowest\ time[ms] \tag{4}$$

In the circuit breaker simultaneous testing, a measuring instrument is used, namely the CB analyzer CT – 6500, where the time difference that occurs between the R, S and T phases when the circuit breaker is open and closed can be determined. The value that can be known from the contact simultaneity test is Δt which is the highest and lowest time difference between the R, S and T phases when the circuit breaker is open and closed. The limit value for the difference in simultaneity time is $\Delta t \leq 10$ ms based on references from the manufacturer ABB (Harunanda & Fauziah, 2021).

Results and Discussion

Data collection in this research was obtained from the results of direct measurements of the research object. Several methods were used to collect this data, including measuring SF_6 gas pressure, insulation resistance, contact resistance, and circuit breaker contact simultaneity. This testing is a predictive maintenance activity. The object chosen in this research is the Bay Line Surabaya Selatan 1, Rungkut 150 kV main substation, where the Bay Line Surabaya Selatan 1 circuit breaker is a three poles type circuit breaker with a spring drive and uses SF_6.

Table 1

Circuit Breaker Bay Line Surabaya 1 Specifications

Parameters	Value
Voltage	170 [kV]
Current	2000 [Ampere]
Insulation Type	SF_6
Air Pressure	6 [Bar]
SF_6 Weight	11,2 [Kg]
Rated Duration Of Short - Circuit	1 [Sec]
Frequency	50 [Hz]

SF_6 Gas Pressure Testing Result

Pressure testing aims to test the purity and pressure of SF_6 gas in circuit breaker equipment. This test uses a measuring instrument, namely the SF_6-Q-Analyser.

Table 2

Pressure Test Results on Circuit Breaker

Test Type	Standart	R	S	T	Result
Dew Point	< -31^{0}C	-60^{0}C	-60^{0}C	-60^{0}C	**Good**
Moisture Content	≤ 500 ppmv	11 ppmv	11 ppmv	11 ppmv	**Good**
Purity	> 97 % ; > 99,7 % for new SF_6	100 %	100 %	100 %	**Good**
SO_2 +SOF_2	< 12 ppmv	0 ppmv	0 ppmv	0 ppmv	**Good**

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Pressure	According to template	7,479 bar	7,479 bar	7,479 bar	**Good**

Based on table 2, namely the analysis of SF_6 gas pressure testing at Circuit Breaker Bay Line Surabaya Selatan 1 which includes several types of tests, namely dew point, moisture content, purity, SO_2 + SOF_2, and pressure, it can be concluded that the SF_6 gas at circuit breaker Bay Line Surabaya Selatan 1 is in good condition. normal and still suitable for use.

Insulation Resistance Testing Result

The aim of measuring the circuit breaker insulation resistance is to determine the amount of leakage current that occurs between the part with voltage at the top terminal and the bottom terminal towards the ground. Leakage current penetrating the circuit breaker insulation cannot be avoided. Therefore, to ensure that the circuit breaker is safe enough to be energized is to measure its insulation resistance. In insulation resistance testing, the terminals that will be tested include (1) Top part with body/ground, (2) Bottom with body/ground, (3) Upper–lower phase section.

Table 3

Insulation Resistance and Leakage Current Result on Circuit Breaker

Point of Test	Standart	Insulation Resistance [GΩ]			Leakage Current [mA]			Result
		R	S	T	R	S	T	
Top – Ground	1 kV = 1 MΩ	7350	14900	10000	0,00068	0,000335	0,0005	**Good**
Bottom – Ground		480000	530000	435000	0,0000104	0,0000094	0,0000114	**Good**
Top – Bottom		34200	38700	38400	0,000146	0,000129	0,00013	**Good**

Table 3 is an analysis of the insulation resistance test of circuit breaker Bay Line Surabaya Selatan 1 which can be concluded that each phase has a different insulation resistance value. This is caused by the influence of the condition of the insulator. The presence of dust and dirt will affect the measured insulation resistance value. However, the difference in these values does not affect the performance of the circuit breaker as long as the insulation resistance value is still in accordance with the standards used. From the data from

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the insulation resistance testing results on circuit breaker Bay Line Surabaya Selatan 1, it can be concluded that circuit breaker Bay Line Surabaya Selatan 1, based on its insulation resistance, is still suitable for operation because the test results are in accordance with the standard, namely 1 kV = 1 MΩ. On the other hand, based on leakage current calculations, circuit breaker Bay Line Surabaya Selatan 1 is still in normal condition. This can be known based on the calculation of the leakage current value which still meets the standards used, namely 1 kV = 1 mA.

Contact Resistance Testing Result

Contact resistance testing uses a measuring instrument, namely the Megger ATO 600. The Megger ATO 600 is a measuring instrument used to measure the contact resistance of circuit breakers where the working principle of this measuring instrument is the same as a pure resistance measuring instrument. When measuring the circuit breaker, a current of 100 ampere can be used, then the value of the contact resistance at the circuit breaker connection with other equipment can be measured so that the power loss from the circuit breaker caused by the contact resistance can be calculated.

Table 4

Power Losses Test Result of Circuit Breaker

Phase	Point Measurement	Current Injection [Amp]	Standart	Resistance [μΩ]	P_{loss} [Watt]	Result
R				31,91	0,3191	Good
S	Main Contact (Top Terminal – Bottom Terminal)	100	R ≤ 50 μΩ / 120 % FAT	34,71	0,3471	Good
T				35,89	0,3589	Good

Data from contact resistance testing results of circuit breaker Bay Line Surabaya Selatan 1 can be concluded that testing the main terminal, namely the upper terminal - lower terminal, obtained a value of $\leq 50\ \mu\Omega$. This means that the circuit breaker Bay Line Surabaya Selatan 1 based on contact resistance is in good condition and suitable for operation.

From Table 4, which is an analysis of the data from the calculation of power losses for circuit breaker Bay Line Surabaya Selatan 1, it can be concluded that circuit breaker Bay Line Surabaya Selatan 1 based on its contact resistance is still suitable for operation because the calculation value for power losses gets a good value. This was obtained from the results of the circuit breaker Bay Line Surabaya Selatan 1 contact resistance test which was in accordance with the standard used, namely $\leq 50\ \mu\Omega$. From the power loss calculation data, it can also be concluded that the smaller the contact resistance value, the smaller the power losses caused by the contact resistance.

Contact Simultaneity Testing

The circuit breaker contact synchronization test is used to determine the working time of the circuit breaker and to determine the synchronization of the circuit breaker when the circuit breaker opens and closes. The circuit breaker must open and close simultaneously on each phase R, S, and T. If not, it could become an anomaly in the distribution of electric power which results in the protection system not working according to its function. When the circuit breaker trips due to an anomaly in the distribution of electric power, it is hoped that the circuit breaker can work quickly so that the expected clearing time is in accordance with the standards.

Table 5

Contact Simultaneity Test Results

Condition	Standart	Time [ms]			Δt	Result
		R - S	S – T	T - R	[mS]	
Open	Δt < 10 ms	35,70	38.00	38,60	2,9	Good
Close		94,40	100,80	95,85	6,4	Good

From Table 5, namely the results of the delta time calculation analysis of circuit breaker Bay Line Surabaya Selatan 1. From the delta time calculation data, it can be concluded that circuit breaker Bay Line Surabaya Selatan 1 based on the synchronization of contacts is still suitable for operation because the delta time calculation value (Δt) has an open condition value. = 2,9 ms and close = 6,4 ms. So, the synchronization of circuit breaker Bay Line Surabaya Selatan 1 contacts is based on delta time calculations in accordance with the standard, namely Δt less than 10 ms. Circuit breaker with SF_6 insulating media can be used to interrupt currents up to 40 kA in circuits with voltages up to 765 kV.

Conclusion

After conducting research entitled "Analysis of Circuit Breaker Insulation Resistance Testing at the Rungkut 150 kV Main Substation Bay Line South Surabaya 1," we can draw several conclusions. First, the process of measuring circuit breaker insulation resistance involves using an Insulation Tester (megger) to determine the insulation resistance value between the energized part (phase) and the grounded body (case), or between the input terminals (I/P terminal) and the output terminals (O/P terminal) within the same phase. Second, it is crucial to follow the work instruction manual precisely during the measurement process to minimize the risk of damage to the test equipment and to ensure the accuracy of the test results, which is essential for the circuit breaker analysis. Lastly, according to the Equipment Maintenance Book SE.032pst/1984 and the VDE standard (Catalogue 228/4), the minimum required insulation resistance at operating temperature is defined as "1 kV = 1 MΩ," with 1 kV representing the phase- to-ground voltage and the permissible leakage current per kV being 1 mA.

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