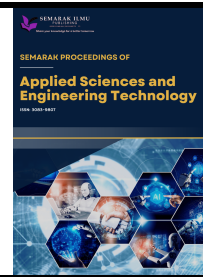




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Differential Relay Protection Testing on Strating Transformer of PLTU Units 3 and 4 at PT PLN Nusantara Power UP Gresik

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ABSTRACT

The reliability of the transformer protection system has an important role in maintaining the continuity of power plant operations. One of the main components in the protection system is a differential protection relay that functions to detect internal interference in the transformer. This study aims to evaluate the performance of differential protection relays on Starting Transformers at PLTU Unit 3 and Unit 4 of PT PLN Nusantara Power UP Gresik. This research is focused on the analysis of the accuracy and response of relay operations based on the results of the tests conducted. The testing process was carried out using the OMICRON CMC 356 test kit with the help of the Test Universe lubricant through the current injection method to simulate various system operating conditions. Some of the test parameters carried out include MV Side, LV Side, Balance Condition, Minimum Pickup, and Slope relay characteristics testing. The test results are then compared with the set value of the relay that has been set to find out the level of deviation between the value of the test result and the setting parameter used. The results showed that the highest differential current error value obtained from the test was 0.54% which was still far below the permissible tolerance based on the IEC 60255 standard, which was $\pm 5\%$ to $\pm 10\%$. In addition, the allowable relay operating time is in the range of 34.3 ms to 39.7 ms for various test conditions that are still within the permissible operating time range of 20 ms to 50 ms. Testing under balanced conditions also shows that the relay is in a No Trip condition so that it shows the stability of the protection system under normal conditions.

Keywords: Differential protection; relay testing; starting transformer; transformer protection system

1. Introduction

Steam Power Plants (PLTU) are one of the main sources of electrical energy plants that play an important role in maintaining the continuity of electricity supply in the electric power system [1]. The Electrical power system in the plant consists of several important components such as generators, transformers, internal distribution systems, and additional equipment that supports the process of generating electrical energy [2]. The reliability of each of these components greatly determines the overall performance of the power generation system because a malfunction of one of the components can cause interruption of the operation of the power plant and can even result in the cessation of operation of the entire power plant unit [3].

One of the important equipment in the power plant electrical system is a transformer that functions to distribute electrical energy from one voltage level to another voltage level according to

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the needs of the electric power system [4]. In a steam power plant system, there are several types of transformers that have different functions, one of which is a starting transformer. The starting transformer has an important role in providing the initial power supply to the auxiliary generation system when the generating unit is not operating normally [5]. The electrical energy from the initial transformer is used to operate various auxiliary equipment such as pumps, cooling systems, drive motors, as well as control equipment required during the start-up process in the generating unit [6].

The reliability of the starting transformer is very important because the failure of the transformer at the start-up stage can cause the generating unit to not be able to operate properly. In addition, transformers are also one of the electrical equipment that has a fairly high risk of interference due to various factors such as overcurrent, short circuits, insulation failures, internal disturbances of the transformer, and external disturbances in the power grid system [7]. If this fault is not dealt with immediately, it can cause serious damage to the transformer and disrupt the stability of the overall electric power system [8].

To prevent damage to electrical power system equipment, a protection system that is able to detect faults quickly and accurately is needed. The protection system in transformers generally uses several types of protective relays that function to detect abnormal conditions in the electric power system [9]. The protection relay works by monitoring the lyrical parameters such as current and voltage, then providing a trip signal to the circuit breaker when fault conditions are detected. With a protection system that works well and quickly, the disturbed parts of the system can be isolated immediately so that equipment damage can be minimized and the continuity of the electric power system is maintained [10].

The performance of the protection relay is greatly influenced by the setting value used as well as the condition of the supporting equipment such as current transformers (CT) and current measurement systems. A mismatch in the relay setting values can cause the relay to malfunction according to the protection characteristics that have been designed [11]. In addition, current measurement errors by CT can also affect the relay's response in detecting faults in the electric power system. Therefore, regular testing of protective relays is one of the important activities in the process of maintaining protection systems in power plants to ensure that the protection relay is still functioning according to predetermined setting parameters and has a rapid response to interference conditions [12].

Protection relay testing is generally carried out using relay test equipment with current and voltage injection methods to simulate fault conditions in electrical power systems [13]. Through the testing process, the working characteristics of the relay can be known such as the value of the pickup current, the operating time of the relay, and the response of the relay to a particular fault current [14]. The test results are then compared with the relay setting values to evaluate the suitability of the protection relay's performance with the standard protection system used in power plants.

Therefore, this study was conducted to test the protection relay on the starting transformer of PLTU Unit 3 and Unit 4 at PT PLN Nusantara Power UP Gresik to determine the performance of the transformer protection system based on the results of the tests carried out and ensure that the massih protection system works optimally in protecting the transformer from potential power outages.

2. Methodology

This research was carried out at PLTU Unit 3 and Unit 4 of PT PLN Nusantara Power UP Gresik which is one of the steam power plants that plays an important role in the Java-Madura-Bali electricity system. The object of this research is the relay protection system used in the Starting

Transformer which functions to provide the initial power supply for the auxiliary power system during the start-up process of the power plant. At this stage, problems related to the protection relay on the Strating Transformer are identified. The flow of the research is shown in Fig 1:

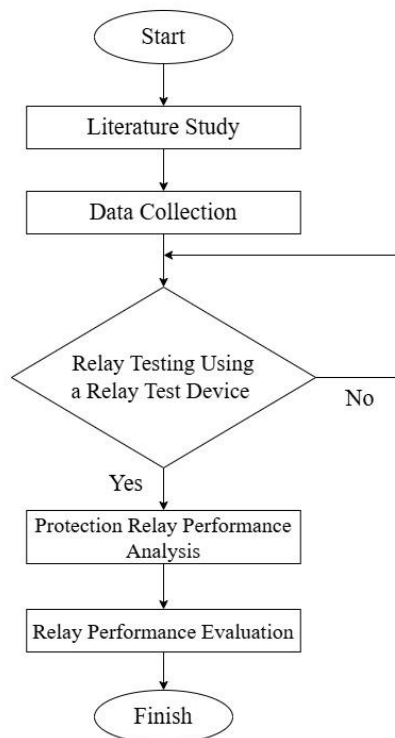


Fig. 1. Research flowchart

2.1 Research Place

This research was conducted at PT PLN Nusantara Power UP Gresik which is located on Jl. Harun Tohir No. 1, Sidorukun Village, Gresik Regency, East Java. PT PLN Nusantara Power UP Gresik until 2024 will still supply 14.68% of the East Java electricity system or 3.01% of the Java, Bali, and Madura systems. PT PLN Nusantara Power UP Gresik is one of the largest power generation units with an installed capacity of 2,234.33 MW with an area of 78Ha. PT PLN Nusantara Power UP Gresik operates several types of power plants, namely PLTU, PLTGU, PLTMG, and PLTGU. In this study, the object studied was focused on the Strating Transformer of PLTU Unit 3 and Unit 4. The location of PT PLN Nusantara Power UP Gresik is shown in Fig 2 in the form of a layout of the power plant area which shows the distribution of power units in the UP Gresik environment.



Fig. 2. Layout of the Gresik generation unit

2.2 Data Collection

Data collection in this study was carried out by collecting technical data related to the protection system at the Starting Transformer Unit 3 and Unit 4 of PLTU PT PLN Nusantara Power UP Gresik. The data used in this study includes data on the protection relay setting, transformer protection system parameters, and data on relay testing. The data was obtained from protection system maintenance documents, relay test results reports, and technical data on protection equipment used in the power plant's electrical system. Table 1, table 2 and table 3 are the data obtained before the test.

Table 1

Transformer parameters

Yes	Parameters	Value
1	Brands	Toshiba
2	Nominal Capacity	12000/20000 kVA
3	Serial No.	860900048
4	Frequency	50 Hz
5	Phase	3
6	Standard	JEC
7	Temperature Rise	55°C
8	Nominal Voltage (Primary)	154000 V
9	Nominal Voltage (Secondary)	4160 V
10	Impedance Voltage	10.87 %

Table 2

Relay parameters

Yes	Parameters	Value
1	Equipment	Transformer Strating Protection Relay
2	IP/ Serial Number	192.168.32.-
3	Setting Slope 1	35 % ; 2 Guns
4	Setting Slope 2	95 % ; 8.00 am

Table 3

Test equipments parameters

Yes	Parameters	Value
1	Brand/ Type	OMICRON CMC 365
2	Capacity	Max. 20 A

2.3 Data Analysis

Data analysis in this study was carried out to evaluate the performance of the protection relay on the Starting Transformer based on the results of the relay tests that have been carried out. The test results data in the form of pickup current values, injection currents, and relay operation time are then compared with the relay setting values that have been determined on the transformer protection system. The performance evaluation of the protection relay is carried out by calculating the deviation between the test value and the set value of the relay that has been set. The deviation calculation was done using the following equation [15]:

$$I_d \text{ Error } (\%) = \frac{I_d(\text{Setting}) - I_d(\text{Test})}{I_d(\text{Setting})} \times 100\% \quad (1)$$

In addition, an analysis was also carried out on the operating time characteristics of the relay to determine whether the relay was working in accordance with the protection characteristics that had been designed [16]. The results of the analysis are then used to determine whether the protection relay is still working optimally or requires adjustment of settings or further maintenance actions.

3. Results

Testing of the protection relay was carried out in CCR 3 and 4 rooms as the power plant's electrical system control center. This test aims to ensure that the protection relay on the starting transformer works according to the settings and characteristics that have been determined so that it can provide good protection against interference in the electrical power system. The testing process is carried out following the procedure that has been systematically arranged as shown in the fig 1 which contains a flowchart of the test stages.

In its implementation, the OMICRON CMC 356 test tool is used which is integrated with the Software Test Universe to simulate current and voltage disturbance conditions and record the relay work response. The data obtained from this test is then used as a basis for evaluating the performance of the protection relay on the starting transformer system.



Fig. 3. Trial of protection relays

3.1 Test Results

The test results showed that the differential current error value was still below the tolerance limit of the IEC 60255 standard, which is $\pm 5\%$ to $\pm 10\%$ [4,7]. This shows that the accuracy of the relay is still in good condition. In addition, the relay operating time obtained is also in the standard range of 20 ms to 50 ms, thus demonstrating a fast and reliable response of the protection system [8,12]. These findings are also in line with previous research that stated that differential relays have a high level of accuracy in detecting internal disturbances of transformers [19,20]

3.1.1 Comparison of setting values with MV side tests (0 A)

Before the presentation of the test results, a process of testing the characteristics of the differential current on the MV (Medium Voltage) side is carried out to evaluate the suitability between the relay setting value and the actual response of the relay when given the test current injection. This test was carried out using a three-phase injection method with the aim of determining the performance of the relay in detecting interference based on differential current and restraint current parameters. The parameters observed in this test include differential setting current (I_d), slope value of protection characteristics, differential current test results (I_d), restrain current (I_r), and relay operation time.

The data obtained from the test is then analyzed by comparing the predetermined setting value with the measured test results to determine the level of accuracy of the relay's work. A summary of the test parameters and measurement results on the MV side is presented in Table 4, which is the basis for calculating the differential current error value and evaluating the performance of the protection relay under test conditions.

Table 4

MV side Differential relay test results (0 A)

87Test	Injection 3 ϕ		Setting up		Test Result			Error Time	
	CT 1 (HV) (A)	CT 2(LV) (A)	ID (A)	Slope (%)	ID (A)	IR (A)	Slope (%)	Max (ms)	Time (ms)
MV_SIDEside (0 A)	0.2<0°	-	0.37	> 35	0.368	0.368	100	<50	34.3
	0.2 <-120°	-	0.37	> 35	0.371	0.371	100		
	0.2<120°	-	0.37	> 35	0.368	0.368	100		

- CTI Injection: 0.2 < 0°, -120°, 120°

$$I_d \text{Error} (\%) = \frac{I_d(0.37) - I_d(0.368)}{I_d(0.37)} \times 100\% \quad (2)$$

$$I_d \text{Error} (\%) = 0.54 \%$$

The calculation results showed an error value of 0.54%. If referring to the IEC 60255 standard, the measurement error tolerance limit of the protection relay is in the range of $\pm 5\%$ to $\pm 10\%$ of the setting value, so the error value obtained is still far below the set limit and indicates that the accuracy of the differential current setting of the relay is still in good condition. In addition, the relay operation time recorded at 34.3 ms is also still below the maximum limit of 50 ms. Based on the standard, the error tolerance of the relay operation time is in the range of $\pm 1\%$ of the maximum time with a working range of about 20-50 ms, so it can be concluded that the relay's performance and response to interference is still in accordance with the applicable standards.

3.1.2 Comparison of setting values with LV side tests (0 A)

Before the presentation of the test results, an analysis was carried out on the comparison of the value of the differential current setting (I_d Setting) with the value of the differential current of the test result (I_d Test) on the LV (Low Voltage) side to determine the degree of conformity between the parameters of the relay setting and the actual response of the relay when the test was carried out. The test was carried out using a three-phase injection method on the side of CT 2 (LV) with phase angle variations of 0° , -120° and 120° to simulate balanced three-phase system conditions. The parameters observed in this test include differential current (I_d), restrain current (I_r), and relay operating time.

The comparison process between the setting value and the test result value is then used to calculate the differential current error orientation (I_d error) shown in equation (3). A summary of the test parameters and measurement results on the LV side is presented in Table 5, which is the basis for evaluating the accuracy of the setting and the performance of the differential relay.

Table 5
LV side differential relay test results (0 A)

87Test	Injection 3 ϕ		Setting up		Test Result			Error Time	
	CT 1 (HV) (A)	CT 2(LV) (A)	ID (A)	Slope (%)	ID (A)	IR (A)	Slope (%)	Max (ms)	Time (ms)
LV_SIDE Side (0 A)	-	$0.371 < 0^\circ$	0.37	> 35	0.368	0.37	100	<50	39.7
	-	$0.371 < -120^\circ$	0.37	> 35	0.37	0.37	100		
	-	$0.371 < 120^\circ$	0.37	> 35	0.37	0.37	100		

- CT2 Injection: $0.371 < 0^\circ, -120^\circ, 120^\circ$

$$I_d \text{Error} (\%) = \frac{I_d(0.37) - I_d(0.37)}{I_d(0.37)} \times 100\% \quad (3)$$

$$I_d \text{Error} (\%) = 0 \%$$

The calculation results show an error value of I_d of 0%, which means that the differential current value of the test result is equal to the relay setting value of 0.37 A so that there is no deviation between the setting value and the test result. Based on the IEC 60255 standard, the measurement error tolerance limit of the protection relay is in the range of $\pm 5\%$ to $\pm 10\%$, so the value is still within the permissible limit. In addition, the relay operating time of 39.7 ms is also still below the maximum limit of 50 ms, so it can be concluded that the performance and response of the relay is still in accordance with applicable standards.

3.1.3 Comparison of I_d setting values with I_d test balanced condition

Before the presentation of the test results, a comparative analysis was carried out between the value of the differential current setting (I_d Setting) and the differential current of the test result (I_d Test) under balanced conditions to ensure that the differential relay does not work under normal or balanced system conditions. Balanced condition testing is carried out by providing three-phase injection on the CT 1 (HV) and CT 2 (LV) sides with the appropriate phase angle setting so that the incoming and outgoing currents from the protection zone are in a balanced condition. In this condition, theoretically the differential current formed is close to zero, so the relay should not issue a trip command.

The parameters observed in this test include the differential current of the test result (I_d Test), restrain current (I_r), characteristic slope value and relay operation time. The comparison between the setting value and the test result is then used to calculate the percentage of differential current error (I_d Error) as shown in equation (4). A summary of the test parameters and measurement results under the balanced conditions is then presented in Table 6, which is the basis for evaluating the ability of differential relays to distinguish between normal and faulty conditions in the electric power system.

Table 6

Differential balanced condition relay test results

87Test	Injection 3 ϕ		Setting up		Test Result			Error Time	
	CT 1 (HV) (A)	CT 2(LV) (A)	ID (A)	Slope (%)	ID (A)	IR (A)	Slope (%)	Max (ms)	Time (ms)
Balanced Condition	$0.2 < 0^\circ$	$0.371 < -180^\circ$	0	0	0	0.37	0	No Trip	No Trip
	$0.2 < -120^\circ$	$0.371 < 60^\circ$	0	0	0	0.371	0		
	$0.2 < 120^\circ$	$0.371 < -60^\circ$	0	0	0	0.368	0		

- T1 Injection: $0.2 < 0^\circ, -120^\circ, 120^\circ$
- CT2 Injection: $0.371 < -180^\circ, 60^\circ, -60^\circ$

$$I_d \text{ Error (\%)} = \frac{I_d(0) - I_d(0)}{I_d(0)} \times 100\% \quad (4)$$

$$I_d \text{ Error (\%)} = 0 \%$$

Balanced condition testing is performed to ensure that the differential relay is working when the current on the HV and LV sides is in a balanced condition. In this test, a three-phase injection ($0^\circ, -120^\circ, 120^\circ$) was carried out with the same amount of current so that it did not cause differential current. The test results showed that the I_d setting was 0 A and the I_d test was 0 A with an I_d error of 0%, and the relay was in a no trip condition. This shows that the relay is working properly and does not suffer from maloperation under normal conditions according to the IEC 60255 standard.

3.1.4 Comparison of setting values with minimum pickup tests

Before the presentation of the test results, a comparative analysis was carried out between the differential current setting (I_d Setting) and the differential current of the test result (I_d Test) at the minimum condition of the pickup to determine the minimum current limit that caused the differential relay to start operating. The test was carried out by a three-phase injection method on the CT 1 (HV) and CT 2 (LV) sides with a certain phase angle variation so as to produce a differential current that is close to the value of the relay pickup.

The observed parameters included differential current (I_d), restrain current (I_r), slope value and relay operation time. The percentage of differential current error (I_d Error) is calculated by comparing the setting value and the test results as shown in equations (5) – (7). A summary of the test results is presented in Table 7 as the basis for evaluating the sensitivity and working accuracy of differential relays.

Table 7

Pickup minimum differential relay test results

87Test	Injection 3 ϕ		Setting up		Test Result			Error Time	
	CT 1 (HV) (A)	CT 2(LV) (A)	ID (A)	Slope (%)	ID (A)	IR (A)	Slope (%)	Max (ms)	Time (ms)
Minimum Pickup	0.401 <0°	0.371 <-180°	0.37	> 35	0.37	0.739	50.07	<50	34.9
	0.401 <- 120°	0.371<60°	0.37	> 35	0.371	0.739	50.20		
	0.401 <120°	0.371 <-60°	0.37	> 35	0.37	0.74	50.00		

- Injection CT1: 0.401 < 0° CT2: 0.371 <-180°

$$I_d \text{Error} (\%) = \frac{I_d(0.37) - I_d(0.37)}{I_d(0.37)} \times 100\% \quad (5)$$

$$I_d \text{Error} (\%) = 0 \%$$

- Injection CT1: 0.401 <-120° CT2: 0.371<60°

$$I_d \text{Error} (\%) = \frac{I_d(0.37) - I_d(0.371)}{I_d(0.37)} \times 100\% \quad (6)$$

$$I_d \text{Error} (\%) = 0.27 \%$$

- CT1 injection: 0.401 <120° CT2: 0.371 <-60°

$$I_d \text{Error} (\%) = \frac{I_d(0.37) - I_d(0.37)}{I_d(0.37)} \times 100\% \quad (7)$$

$$I_d \text{Error} (\%) = 0 \%$$

The minimum test of the pickup was carried out to determine the minimum current value that caused the differential relay to start working according to the setting value I_d of 0.37 A. In this test, a three-phase injection was carried out with a current at CT 1 of 0.401 A and CT 2 of around 0.371 A with a difference in certain phase angles so as to cause differential current. The calculation results showed an error of 0% and 0.27% which means that the difference between the setting value and the test results is very small. Based on the IEC 60255 standard, the error tolerance limit for protection relays is in the range of $\pm 5\%$ to $\pm 10\%$, so the error value is still within the permissible limits. In addition, the relay operating time recorded at 34.9 ms is also still below the maximum limit of 50 ms, so it can be concluded that the relay's performance in detecting the minimum pickup current is still working well and according to standards.

3.1.5 Comparison of setting values with I_d test slope 1 (No Trip)

Slope 1 (No Trip) testing is performed to verify that the differential relay is not working When the differential current is still below the predetermined setting value. This test aims to ensure that the relay remains stable and does not give a trip command under normal conditions or conditions that are still within the restraint area. In addition, this test is also used to evaluate the suitability between the differential current value of the test result and the relay setting value.

The test results are shown in Table 8, which shows the comparison between the three-phase injection value, the relay setting value, and the test results in the form of differential aruss and slope values produced. The data is then used to calculate the percentage of differential current error using equations (8) – (10) to determine the deviation between the setting value and the test result value. From the results of this test, it can be analyzed whether the differential relay remains in a no trip condition in accordance with the work characteristics of the differential protection relay.

Table 8

Slope 1 differential relay test results (No trip)

87Test	Injection 3 Ø		Setting up		Test Result			Error Time	
	CT 1 (HV) (A)	CT 2(LV) (A)	ID (A)	Slope (%)	ID (A)	IR (A)	Slope (%)	Max (ms)	Time (ms)
Slope 1 (no trip)	0.707<0°	2<-180°	0.37	> 35	0.692	1.997	34.65	No Trip	No Trip
	0.707<-120°	2<60°	0.37	> 35	0.693	1.996	34.72		
	0.707 <120°	2<-60°	0.37	> 35	0.695	1.996	34.82		

- Injection CT1: 0.707<0° CT2: 2<-180°

$$I_d Error (\%) = \frac{I_d(0.37) - I_d(0.692)}{I_d(0.37)} \times 100\% \quad (8)$$

$$I_d Error (\%) = - 87.03 \%$$

- Injection CT1: 0.707<-120° CT2: 2<60°

$$I_d Error (\%) = \frac{I_d(0.37) - I_d(0.693)}{I_d(0.37)} \times 100\% \quad (9)$$

$$I_d Error (\%) = - 87.30 \%$$

- Injection CT1: 0.707 <120° CT2: 2<-60°

$$I_d Error (\%) = \frac{I_d(0.37) - I_d(0.695)}{I_d(0.37)} \times 100\% \quad (10)$$

$$I_d Error (\%) = - 87.84 \%$$

Slope 1 (no trip) testing is performed to ensure the differential relay is not working when the differential current is still below the setting characteristics. In this test, current injection was carried out on the HV and LV side CT with phase angle variations to simulate the condition of the three-phase system. The test results showed an I_d value of 0.692 – 0.695 A, I_r of around 1.996 – 1.997 A, and a slope value of around 34.65 – 34.82%, so that the relay did not experience trips. This shows that the relay is working well and remains stable because it is still in the area of restrain slope 1 (>35%), so it does not give a trip command in conditions that do not show internal interference.

3.1.6 Comparison of setting values with setting values with setting values with trip test 1 (Trip)

Slope 1 (Trip) testing on differential relays is carried out to verify the compatibility between the differential current setting value (I_d) that has been determined on the relay and the current value of the test result (I_d Test). This test aims to ensure that the relay will work (trip) when the detected differential current exceeds the set value. In addition, this test is also used to evaluate the accuracy of differential current pickup values as well as the operation time of the relay.

The test results are shown in Table 9, which shows the comparison between the three-phase injection value, the relay setting value, and the test results in the form of differential current value and relay operation time. The data in the table is then used to calculate the percentage of differential

current error using equations (110 – (13) to determine the level of deviation between the setting value and the test results.

Table 9

Slope 1 differential relay test results (Trip)

87Test	Injection 3 Ø		Setting up		Test Result			Error Time	
	CT 1 (HV) (A)	CT 2(LV) (A)	ID (A)	Slope (%)	ID (A)	IR (A)	Slope (%)	Max (ms)	Time (ms)
Slope 1 (trip)	0.704<0°	2<-180°	0.37	> 35	0.7	1.998	35.04	<50	37.8
	0.704<-120°	2<60°	0.37	> 35	0.697	1.996	34.92		
	0.704<120°	2<-60°	0.37	> 35	0.698	1.998	34.93		

- Injection CT1: 0.704<0° CT2: 2<-180°

$$I_d Error (\%) = \frac{I_d(0.37) - I_d(0.7)}{I_d(0.37)} \times 100\% \quad (11)$$

$$I_d Error (\%) = - 89.19 \%$$

- CT1 injection: 0.704<-120° CT2: 2<60°

$$I_d Error (\%) = \frac{I_d(0.37) - I_d(0.697)}{I_d(0.37)} \times 100\% \quad (12)$$

$$I_d Error (\%) = - 88.38 \%$$

- CT1 injection: 0.704 <120° CT2: 2<-60°

$$I_d Error (\%) = \frac{I_d(0.37) - I_d(0.698)}{I_d(0.37)} \times 100\% \quad (13)$$

$$I_d Error (\%) = - 88.65 \%$$

Slope 1 (trip) testing is performed to ensure the differential relay is working When the differential current passes through the setting value. The test results showed an Id value of 0.697 – 0.700 A, greater than the setting of 0.37 A, so that the relay issued a trip command with an operating time of 37.8 ms. Based on the IEC 60255 standard, the protection current error tolerance limit is in the range of ±5% to ±10%, while the relay operation time is generally in the range of 20-50 ms with a tolerance of about ±1% of the maximum time. With a trip time of 37.8 ms, the relay response is still within the operating time range allowed by the standard, so it can be concluded that the performance of the differential protection relay has worked in accordance with the characteristics and test standards.

4. Conclusion

Based on the results of analysis and testing of differential protection relays on the starting transformers of PLTU Units 3 & 4 at PT PLN Nusantara Power UP Gresik, it can be concluded that the performance of the relay shows conformity with applicable standards. Testing using OMICRON CMC 356 through the current injection method resulted in a maximum differential current error value of 0.54% which is still well below the IEC 60255 tolerance limit of ±5% to ±10%. In addition, the relay operation time is in the range of 34.3 ms to 39.7 ms which still meets the standard limit, which is 20 ms to 50 ms. In balanced conditions, the relay does not experience a trip (no trip) which indicates that the protection system has good stability and selectivity in distinguishing normal and disturbance conditions.

Overall, the differential protection relay on the starting transformers of PLTU Units 3 and 4 can be declared to work accurately, responsively and reliably in protecting equipment from internal interference. This shows that the transformer protection system is in optimal condition and is able to support the continuity of plant operations. For further research development, it is recommended to conduct further analysis by considering the influence of external disturbances, load variations, and system imbalances on the performance of the relay. In addition, the application of digital-based methods such as artificial intelligence or machine learning can be an alternative to improve the reliability of the protection system in the future.

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