Reliability Analysis of Differential Relay as Main Protection Transformer Using Fuzzy Logic Algorithm

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Abstract. Electricity supply demand is increasing every year. It makes PT. PLN (Persero) is required to provide optimal customer service and satisfaction. Optimal service depends on the performance of the equipment of the power system owned, especially the transformer. Power transformer is an electrical equipment that transforms electricity from high voltage to low voltage or vice versa. However, in the electrical power system, is inseparable from interference included in the transformer. But, the disturbance can be minimized by the protection system. The main protection transformer is differential relays. Differential relays working system using Kirchoff law where inflows equal outflows. If there are excessive currents that interfere then the relays will work. But, the relay can also experience decreased performance. Therefore, this final project aims to analyze the reliability of the differential relay on the transformer in three different substations. Referring to the standard applied by the transmission line protection officer, the differential relay shall have slope characteristics of 30% in the first slope and 80% in the second slope when using two slopes and 80% when using one slope with an instant time and the corresponding ratio. So, the results obtained on the Siemens differential release have a reliable slope characteristic with a value of 30 on the fuzzy logic system. In a while, ABB a differential relay is only 80% reliable because two experiments are not reliable. For the time, all the differential relays are instant with a value of 0.06 on the fuzzy logic system. For ratios, the differential relays ABB have a better value than others brand with a value of 151 on the fuzzy logic system.

1. Introduction
In this modern era, the requirement for electrical energy in Indonesia is increasing. This is due to the increased population growth. In addition, electric energy is one of the most influential energy in society [1]. Usually, the electrical energy used by the society is supplied from the power system. The power system itself, composed of several sub-systems [2]. It is a generation system, transmission system, and distribution system. These three components need to be maintained in the process by which a general requirement is set for the electric power system [3], among others reliability, quality and stability.

Transmission system is a system used to distribute electrical energy from the generating system with a certain voltage level and then raised the voltage to a higher level before entering the substation. The voltage increase is intended to power the electricity to be supplied to the substation remains in accordance with the needs after experiencing power losses on the transmission line. Generally, the substation has several fixtures, such as power transformers, separators, breakers, busbars and insulators, measuring instruments, releases and safeguards [4].
In the process of distribution, the transmission system, cannot be separated from the appearance of disturbances that interfere with the process. Interference that occurs one of them can be found in the power transformer. Disturbance on the power transformer is avoided, but can still be minimized. In the operation of power transformers, there are 2 kinds of interference that may be experienced, namely internal disturbance and external disturbance [5]. Internal disturbance is a disturbance that occurs in the transformer itself such as short circuit short circuit and core, winding with the tank, as well as insulation (oil) interference on the transformer. While external interference is a disruption that occurs outside the power transformer but can cause interference on the transformer concerned such as short circuit network interference, overload, and lightning surge [6].

Transformer is a major element that is very instrumental in power distribution system because it must be in sync with the amount of electrical energy needed. Because the transformer is the main element and has a high price, the system of protection or protection of a transformer both to the disturbances that occur from the transformer or from outside the transformer is very important [7].

One of the main protective relays on a power transformer is a differential relay. The differential relay is a protection from internal disturbance. The principle of differential relay work is based on Kirchoff's law, where the incoming currents on the primary side will be equal to the amount of outflow on the secondary side [8]. Because as a primary safety, differential relay working time is also made instant so that interference can be overcome. If the relay does not work in instant time, it will be fatal. Therefore, the differential relay must be assured of its reliability. In this case, the cause of the stability problem is focused on analyzing the reliability of the differential relays on the power transformer by analyzing the slope. The determination of slope value is determined by manual calculation and using some software. After getting a slope graph of each method, it will be adjusted to a standard slope setting to determine whether the relay is considered reliable as a primary safety transformer power.

Research data taken from West Bandung Basecamp. In transformer 2 in GIS Cibabat Lama, the differential relays recorded in the substation are still branded GEC type MBCH 12 [9]. GEC type MBCH 12 is a mechanical type of differential relay. However, in the tests performed, the relay on the transformer 2 in GIS Cibabat Lama branded Siemens which is a numeric type of differential relay. From that point, it can be seen that there has been a change of differential relay on transformer 2 in GIS Cibabat Lama. Then there is also a differential ABB relay in transformer 3 GI Cianjur and Toshiba's differential relay in transformer IBT 2 GI Cigelereng which will also be researched.

There are several research methods in analyzing the reliability especially for differential relays. The method used is by direct experiment along with manual calculation [10] and some are using the fuzzy logic method to determine the rule trip [11] and analyze about power transformer [12]. Results from the study will be useful for reference as well as consideration of the reliability of protection applied.

2. Methods
This study was conducted to determine the reliability of a protection in power transformers. To determine the reliability, it will be examined slope characteristic value, work time and its pick-up ratio. In conducting the research, previously required direct testing using the DRTS test tool to determine the values required for the research material. Once obtained these values, then the research can be implemented. In the implementation of research, can be used two methods of calculation manually and using some software. In this study, the software used is Ms. Excel, 87T and Matlab. In the calculation, used Ms. Excel and 87T which have the ability to calculate especially on the 87T software that specifically calculates the differential relays on the transformer. After all values are obtained, it will be concluded on matlab software with fuzzy logic processing. In fuzzy logic, three aspects are given which refer to a reliability of the differential relay. These three aspects are the slope characteristic values, the working time and the pick-up ratio. This research takes the object of three power transformers at Bandung different substations with different types of differential relays.

Table 1 is a power transformer data on three different substations, namely Cibabat Lama, Cianjur and Cigelereng. Transformer studied at GIS Cibabat Lama is a transformer 2 branded Hyundai which has power of 60 MVA, with impedance = 12.50%. Then, the transformer study in GI Cianjur is a
transformer 3 branded GEC ALSTHOM which has a power of 60 MVA, with impedance = 12,20%. While the transformer under study in GI Cigelereng is a transformer IBT 2 branded PAUWELS that has a power of 31 MVA, with impedance = 12%. All three have the function of converting high voltage to medium voltage. The third group of the transformer vector is Ynyn0 with NGR resistance varying.

**Table 1. Transformer Research Data**

| Specification | Transformer 2 GIS Cibabat Lama | Transformer 3 GI Cianjur | Transformer IBT 2 GI Cigelereng |
|----------------|--------------------------------|--------------------------|--------------------------------|
| Brand          | Hyundai                        | GEC                      | PAUWELS                        |
| Type           | TL-128                         | ALSTHOM                  | QRF 31/275                    |
| Power          | 60 MVA                         | 60 MVA                   | 31 MVA                        |
| Voltage        | 150 / 20 kV                    | 150 / 20 kV              | 150 / 70 kV                   |
| Imp. (%Z)      | 12,50                          | 12,2                     | 12                             |
| Vec. Group     | YNyn0                          | YNyn0                    | YNyn0                          |
| R NGR          | 12 Ohm                         | 12 Ohm                   | 62 Ohm                         |

Table 2 is a differential relay data in each transformer to be studied. In transformer 2 GIS Cibabat Lama used Siemens type differential relay type 7UT61 with Is of 0,3In. Then on transformer 3 GI Cianjur used relay differential brand ABB type RXDSB4 with Is of 0,35In. While the transformer IBT 2 GI Cigelereng used relay differential Toshiba type GRT 100 with Is of 0,3pu. The three differential relays must have their own characteristics.

**Table 2. Differential Relay Research Data**

| Specification | Differential Relay Transform er 2 GIS Cibabat Lama | Differential Relay Transformer 3 GI Cianjur | Differential Relay Transformer IBT 2 GI Cigelereng |
|---------------|--------------------------------------------------|------------------------------------------|--------------------------------------------------|
| Brand         | Siemens                                         | ABB                                      | Toshiba                                          |
| Type          | 7UT61                                           | RXDSB4                                  | GRT 100                                         |
| No. Series    | BF1009109                                       | -                                       | N400082F                                        |
| CT Primary    | 300/5 A                                         | 300/5 A                                 | 150/5 A                                         |
| CT Secondary  | 2000/5 A                                        | 2000/5 A                                | 250/5 A                                         |
| In            | 5 A                                             | 5 A                                     | 5 A                                             |
| Is            | 0,3 x In                                        | 0,35 x In                               | 0,3 pu                                          |

The data will be a research material that will be proven its reliability. This research will be conducted in accordance with the order arranged on the flowchart. For more details, see Figure 1 of the research flowchart.
3. Results and discussion
Checking of differential relay settings can be seen in Figures 2, 3 and 4. Checking is done by manual calculation or using 87T software. After checking, it goes into the differential testing phase using the DRTS tool. After the differential relay testing, it can be determined the value of restrain currents and differential currents. The result of manual calculation of restrain current and differential current then compared with 87T software calculation to strengthen the calculation result. Comparison of restrain currents can be seen in Figures 5, 6 and 7 while differential current can be seen in Figures 8, 9 and 10.

In general, almost all results have the same results. But at the time of testing directly, there are different things, especially on the relay differential brand Toshiba type GRT 100. In the differential relay data listed, the differential relay Toshiba type GRT 100 have nominal current of 5 A. However, the value of the pick-up current at the test is of little value. When a nominal current of 5 A is used, the ratio value will be too far from the standard. But if the nominal current used is 1 A, then the ratio result will still be in standard. Selectable nominal current of 1 A because the nominal current commonly used in the protection system is 1 A and 5 A. Therefore, 1 A is used with the assumption that data on differential relays must be updated. Checking is limited to the current transformer (CT) because there are several differential relays which automatically determine the setting value when given the data. So, to be more efficient enough in doing the check up to CT only.
Figure 2. Checking Settings Differential Relay Siemens

Figure 3. Checking Settings Differential Relay ABB

Figure 4. Checking Settings Differential Relay Toshiba
From the comparison graph of $I_{rest}$ in the above three differential relays there is no difference between manual and 87T software except Siemens. That's because the 87T software is made to calculate the general formula while Siemens different formulas.
Figure 8. Comparison $I_{\text{diff}}$ Differential Relay Siemens

Figure 9. Comparison $I_{\text{diff}}$ Differential Relay ABB

Figure 10. Comparison $I_{\text{diff}}$ Differential Relay Toshiba
From Idiff comparison graph in the above three relay relays, there is no difference between manual and 87T software. The values obtained also rise from the first to the fifth experiments, as desired from the differential relay testing.

Having obtained the value of the restrain current and differential current of each differential relay, it can be in the plot of the graphical characteristics of the differential relay slope. The characteristic graph of the differential relay slope refers to the restrain current as the numerator (X) and the differential current as the denominator (Y). From the results graph slope characteristics obtained differential relays form of charts moving up and no decrease, in accordance with the standards of differential relays. To be clearer, the graph of differential relay characteristics can be seen in figures 11, 12 and 13.

Table 3 is the characteristic slope value of the differential relay brand Siemens type 7UT61 on the transformer 2 GIS Cibabat Lama. The value of slope characteristics obtained has values that almost
resemble each other in each experiment. This indicates that the performance of the simulated differential relays resembles each other in each phase.

**Table 3. Values of Characteristics Slope Siemens 7UT61**

| Experiment to- | Phasa R     | Phasa S     | Phasa T     |
|---------------|-------------|-------------|-------------|
| 1 & 2         | 35,8974359  | 36,30573248 | 35,8974359  |
| 1 & 3         | 36,1022364  | 36,10223642 | 35,8974359  |
| 1 & 4         | 36,0341151  | 36,03411514 | 35,8974359  |
| 1 & 5         | 36          | 36          | 36          |
| 2 & 3         | 36,3057324  | 35,8974359  | 35,8974359  |
| 2 & 4         | 36,1022364  | 35,8974359  | 35,8974359  |
| 2 & 5         | 36,0341151  | 35,8974359  | 36,0341151  |
| 3 & 4         | 35,8974359  | 35,8974359  | 35,8974359  |
| 3 & 5         | 35,8974359  | 35,8974359  | 36,1022364  |
| 4 & 5         | 35,8974359  | 35,8974359  | 36,3057324  |

Table 4 is the slope characteristic value of the differential relay branded RBDSB4 type ABB in the transformer 3 GI Cianjur. The value of slope characteristics obtained has various values. Even in two experiments, the slope characteristic values were outside the slope 1 or slope 2 area and found values that exceeded the allowed tolerance limit. Then on each phase, there are some experiments whose values are not similar. This indicates that the performance of the differential relay ABB brand is different from each other in each phase.

**Table 4. Values of Characteristics Slope ABB RXDSB4**

| Experiment to- | Phasa R     | Phasa S     | Phasa T     |
|---------------|-------------|-------------|-------------|
| 1 & 2         | 67,549668   | 67,549668   | 93,617021   |
| 1 & 3         | 69,706840   | 69,706840   | 83,040935   |
| 1 & 4         | 71,244635   | 71,244635   | 80,239520   |
| 1 & 5         | 72,813990   | 72,408293   | 79,154078   |
| 2 & 3         | 71,794871   | 71,794871   | 70,129870   |
| 2 & 4         | 73,015873   | 73,015873   | 72,204472   |
| 2 & 5         | 74,476987   | 73,949579   | 73,417721   |
| 3 & 4         | 74,213836   | 74,213836   | 74,213836   |
| 3 & 5         | 75,776397   | 75          | 75          |
| 4 & 5         | 77,300613   | 75,776397   | 75,776397   |

Table 5 is the slope characteristic value of the differential relay branded Toshiba type GRT 100 in the transformer IBT 2 GI Cigelereng. The value of slope characteristics obtained has various values. Even in two experiments, the slope characteristic values were outside the slope 1 or slope 2 area and found values that exceeded the allowed tolerance limit. Then on each phase, there are some experiments whose values are not similar. This indicates that Toshiba's differential relay performance is different from each other in each phase.
Table 5. Values of Characteristics Slope Toshiba GRT 100

| Experiment to- | Phasa R | Phasa S | Phasa T |
|----------------|---------|---------|---------|
| 1 & 2          | 49,62406| 50,74626| 50,74626|
| 1 & 3          | 66,66666| 66,66666| 67,10963|
| 1 & 4          | 71,52034| 71,52034| 70,96774|
| 1 & 5          | 73,41772| 73,61769| 73,41772|
| 2 & 3          | 80,23952| 79,51807| 80,23952|
| 2 & 4          | 80,23952| 79,87987| 79,15407|
| 2 & 5          | 79,75951| 79,75951| 79,51807|
| 3 & 4          | 80,23952| 80,23952| 78,04878|
| 3 & 5          | 79,51807| 79,87987| 79,15407|
| 4 & 5          | 78,78787| 79,51807| 80,23952|

In addition to the differential relay slope values, determining a reliability also refers to the work time and the pick-up ratio. Its reason is the character of the differential relay which is a major protection on the transformer, so the working time of the relay must be instantaneous in overcoming the interference. In addition, there is a pick-up ratio where the pick-up current must match with the current setting of the differential relay. That is because, if the pick-up current is too large, the ratio will exceed the current rating setting. That is, the new differential relays work when the current exceeds the setting with a great distance. It is not allowed because of the role of differential relay as the main protection. Smaller pick-up currents are also not allowed because it means the relays work when there is a current that is smaller than the current setting.

Table 6. Work Time and Pick-Up Ratios Differential Relays

| Brand        | Phasa | Side | Time (s) | Ratio (%) |
|--------------|-------|------|----------|-----------|
| Siemens 7UT61| R     | Prim | 0,0288   | 115,3333  |
|              |       | Sec  | 0,0236   | 129,3333  |
|              | S     | Prim | 0,0263   | 115,3333  |
|              |       | Sec  | 0,078    | 129,3333  |
|              | T     | Prim | 0,0332   | 115,3333  |
|              |       | Sec  | 0,0388   | 129,3333  |
|              | R     | Prim | 0,0318   | 101,7143  |
|              |       | Sec  | 0,0776   | 101,7143  |
| ABB RXDSB4   | S     | Prim | 0,0252   | 100,5714  |
|              |       | Sec  | 0,0282   | 100,5714  |
|              | T     | Prim | 0,0659   | 101,1429  |
|              |       | Sec  | 0,0179   | 101,1429  |
|              | R     | Prim | 0,0357   | 136,6667  |
|              |       | Sec  | 0,0356   | 173,3333  |
| Toshiba GRT 100| S   | Prim | 0,0354   | 140       |
|              |       | Sec  | 0,046    | 173,3333  |
|              | T     | Prim | 0,0532   | 140       |
|              |       | Sec  | 0,0638   | 173,3333  |

Table 6 is the work time and pick-up ratio differential relay under study. Working time and ratio are reviewed from two sides, namely primary and secondary. From the table above got the value of working time under 0,01 seconds. As for the pick-up ratio has a diverse value. However, the greatest pick-up
ratio was in the Toshiba differential relay on the transformer IBT 2 GI Cigelereng with a value on the primary side of phase R is 136.67%, on the primary side of S and T is 140%. Then on the secondary side has the greatest value with a value of 173.33%.

After obtained three aspects to determine the reliability of differential relays, then used Matlab software with fuzzy logic processing. The fuzzy logic used in this study is named Fuzzy_Keandalan with seven inputs and three outputs as needed. For more details, see Figure 14 on fuzzy logic design.

![Fuzzy Logic Design](image)

Table 7 is the result of reliability of work time and of pick-up ratio using Fuzzy_Keandalan for the three differential relays discussed in this study. The reliability of the differential relay working time is instantaneous with a fuzzy value of 0.06 which is included in the instant set. As for the tolerance of the pick-up ratio is good only on the differential relay ABB. The ABB differential relay is good in all three phases with a fuzzy value of 151. The differential relays of Siemens and Toshiba have a bad pick-up ratio in three phases with a fuzzy value of 49 that belong to a bad set.

| Name   | Phasa | Reliability of Work Time | Reliability of Ratio Pick-up | Explanation  |
|--------|-------|--------------------------|-------------------------------|--------------|
| Siemens 7UT61 | R    | 0.06                     | 49                            | Instant & Bad |
|         | S    | 0.06                     | 49                            | Instant & Bad |
|         | T    | 0.06                     | 49                            | Instant & Bad |
| ABB RXDSB4 | R    | 0.06                     | 151                           | Instant & Good |
|         | S    | 0.06                     | 151                           | Instant & Good |
|         | T    | 0.06                     | 151                           | Instant & Good |
| Toshiba GRT 100 | R    | 0.06                     | 49                            | Instant & Bad |
|         | S    | 0.06                     | 49                            | Instant & Bad |
|         | T    | 0.06                     | 49                            | Instant & Bad |

Table 8 is the reliability result of slope characteristics using Fuzzy_Keandalan for the three differential relays discussed in this study. The differential relay which has the best slope characteristic reliability is the differential relay brand Siemens. The Siemens differential relay is reliable in each experiment because it has a fuzzy value of slope reliability of 30 for slope 1 that belongs to a reliable set. The differential relay ABB and Toshiba have two unreliable experiments with a fuzzy value of 55 that fall within the unreliable set. However, in other experiments, they belong to a reliable set with a fuzzy value of 80.
From both tables above, it can be determined the final result of research reliability of differential relays on three different substations in the Bandung area. In the Siemens type 7UT61 differential relay in transformer 2 GIS Cibabar Lama has 100% reliable slope characteristics with instant working time. But on the ratio, this relay has a bad value. Then on the differential relay brand ABB type RXDSB4 in transformer 3 GI Cianjur has 80% reliability slope characteristics and 20% slope characteristics are not reliable. However, the working time of this relay is still relatively instant and has the best ratio among other differential relays with a value of 100% on both sides of each phase. Similarly, in the differential relays brand Toshiba type GRT 100 in transformer IBT 2 GI Cigelereng which has 80% reliability slope characteristics and 20% slope characteristics are not reliable. The working time of this relay is still relatively instant, but the ratio of the differential relay is quite bad on both sides of each phase. To be clearer, it can be seen in Figure 15.

![Figure 15. Reliability Graph of Differential Relays](image)

**Table 8. Reliability Characteristics Slope of Differential Relay**

| Name      | Phasa | Experiment | Reliability Slope | Explanation |
|-----------|-------|------------|-------------------|-------------|
| Siemens 7UT61 | R, S & T | 1 & 2 | 30 | Reliable |
|           |       | 1 & 3 | 30 | Reliable |
|           |       | 1 & 4 | 30 | Reliable |
|           |       | 1 & 5 | 30 | Reliable |
|           |       | 2 & 3 | 30 | Reliable |
|           |       | 2 & 4 | 30 | Reliable |
|           |       | 2 & 5 | 30 | Reliable |
|           |       | 3 & 4 | 30 | Reliable |
|           |       | 3 & 5 | 30 | Reliable |
|           |       | 4 & 5 | 30 | Reliable |
|           |       | 1 & 2 | 55 | Unreliable |
|           |       | 1 & 3 | 55 | Unreliable |
|           |       | 1 & 4 | 80 | Reliable |
|           |       | 1 & 5 | 80 | Reliable |
|           |       | 2 & 3 | 80 | Reliable |
|           |       | 2 & 4 | 80 | Reliable |
|           |       | 2 & 5 | 80 | Reliable |
|           |       | 3 & 4 | 80 | Reliable |
|           |       | 3 & 5 | 80 | Reliable |
|           |       | 4 & 5 | 80 | Reliable |
|           |       | 1 & 2 | 55 | Unreliable |
|           |       | 1 & 3 | 55 | Unreliable |
|           |       | 1 & 4 | 80 | Reliable |
|           |       | 1 & 5 | 80 | Reliable |
| ABB RXDSB4 | R, S & T | 2 & 3 | 80 | Reliable |
|           |       | 2 & 4 | 80 | Reliable |
|           |       | 2 & 5 | 80 | Reliable |
|           |       | 3 & 4 | 80 | Reliable |
|           |       | 3 & 5 | 80 | Reliable |
|           |       | 4 & 5 | 80 | Reliable |
| Toshiba GRT 100 | R, S & T | 1 & 3 | 55 | Unreliable |
|           |       | 1 & 4 | 80 | Reliable |
|           |       | 1 & 5 | 80 | Reliable |
|           |       | 2 & 3 | 80 | Reliable |
|           |       | 2 & 4 | 80 | Reliable |
|           |       | 2 & 5 | 80 | Reliable |
|           |       | 3 & 4 | 80 | Reliable |
|           |       | 3 & 5 | 80 | Reliable |
|           |       | 4 & 5 | 80 | Reliable |
4. Conclusion
First, the calculation result of check setting and testing differential relay with brand Siemens type 7UT61 on transformer 2 150/20 kV 60 MVA in Cibabat Lama, differential relay with brand ABB type RXDSB4 on transformer 3 150/20 kV 60 MVA in Cianjur and differential relay with brand Toshiba type GRT 100 on transformer IBT 2 150/70 kV 31 MVA in Cigelereng has a calculation setting value very close to that applied so that it can be done differential relay testing to find out the values needed to determine reliability. However, in the differential relay testing with brand Toshiba type GRT 100, the pick-up ratio is not suitable if I nominal used for 5 A as in the data transformer. Therefore, 1 A is used for the results to be in accordance with the assumption that the transformer data needs to be updated.

Second, the calculation results slope characteristics, working time and the ratio of the pick-up of third differential relays are different. On differential relays with brand Siemens type 7UT61 on transformers 2 150/20 kV 60 MVA in Cibabat Lama Has a better slope characteristic value than the other two differential relays because the result of the calculation is in accordance with the standard set for the differential relay having two slopes where the value of the Siemens brand differential relay slope characteristic is ± 30% with a tolerance of ± 10% which is classified in the slope 1. While the differential relay brands ABB and Toshiba only have one slope with a standard value of ± 80% with a tolerance of ± 10%. However, for the best working time and pick-up ratios are held by differential relay with brand ABB RXDSB4 type on transformer 3 150/20 kV 60 MVA in Cianjur because it has a pick-up ratio that is still within the limits of tolerance so categorized well. But overall, the working time in all the differential relays is still instant because it works under 0.01 seconds.

Third, the results of reliability decisions through fuzzy logic for differential relays with Siemens brand type 7UT61 on transformers 2 150/20 kV 60 MVA in Cibabat Lama is declared reliable for a while with records to be replaced because it has a ratio that exceeds tolerance. Then on a differential relay with brand ABB type RXDSB4 on transformers 3 150/20 kV 60 MVA in Cianjur declared reliably for a while with the record should be replaced because it has 2 unreliable results from 10 experiments. Finally, the differential relay with brand Toshiba type GRT 100 on the transformer IBT 2 150/70 kV 31 MVA in Cigelereng is not reliable because it has 2 unreliable results from 10 trials and has a bad pick-up ratio value.

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