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Fault Diagnosis for Distribution Feeder Base on Fuzzy Logic

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Abstract. Changes in the increased energy demand of the community cause a disturbance flow to the substation feeder. This paper describes fault diagnosis result in feeder distribution using soft computing approach namely, fuzzy logic. Fault diagnosis study is done by processing the data flow disturbance and the location of the disturbance point on the substation. The data used as learning input on fuzzy logic. The test results show that Fuzzy Rule-Based has a good accuracy level in indicating the type of fault current, but the accuracy level decreases when indicating the location of the fault current.

1. Introduction

Year 2016 PT PLN (PERSERO) West Java and Banten distribution area of Bandung issued data of disruption current on the repeater, the data indicate that the most disturbance flow occurs on the repeater of Nort Dago Jingga (NDJ) originating from North Bandung Substation. Total there is an interruption current of 18 times. Disturbances in the NDJ feeder are predicted to continue to grow in line with the addition of load and electrical energy capacity [1] [2].

SCADA sends information in the form of current, voltage, and OCR / GFR trip values, but can not transmit information where the disturbance flows, so that the normalization time of the disturbance lasts longer and this will negatively impact the quality of PLN service to the electricity consumer [3] [4].

There are several studies that discuss the indication of the type of interference flow using Artificial Intelligence method. Artificial Intelligence method has advantages in the level of accuracy and high speed, but the method of Artificial Intelligence has a weakness. The use of expert system method (expert system) has a weakness because it requires expert experience, making it difficult in doing maintenance. Then artificial neural networks (lack of artificial neural networks) have shortcomings due to the difficulty of determining the appropriate pattern so that the training process data tend to be long. Furthermore, genetic algorithm and particle swarm optimization have weaknesses because of the difficulty of determining the exact mathematical model. [5] [6] [7] [8] [9].

Fuzzy Logic is an exact Artificial Intelligence method in indicating the type of interference current and the location of the disturbance flow in the repeater, the advantages of fuzzy logic include fast decision-making, easy to implement data, and easy in maintenance. [10]. Therefore the authors use Fuzzy Rule Based method for indication of noise current and location of noise disturbance on NDJ feeder.

2. Methods

This study uses location data of disturbance point and noise current data at North Dago Jago (NDJ) refuter during 2016. Data location of disturbance point, short circuit data of North Bandung Substation, data of power transformer III North Bandung Substation, and data of impedance feeder NDJ obtained from PT PLN (PERSERO) West Java and Banten distribution area Bandung, while the data flow disturbance on NDJ penyulang obtained from the calculation. Furthermore, the results of the
calculation of the disturbance current and data location of the point of disturbance used as a range of membership function data on fuzzy logic that aims to knowing normal or not its NDJ repeater.

Table 1 is a short-circuit data of North Bandung Substation, short circuit data on substations obtained through the process of measuring short circuit on all equipment in substation. The data in Table 3.1 is used to find source impedances on the 150 kV side, since the short circuit current noise to be calculated is short-circuit disruption at 20 kV side, the source impedance on the 150 kV side must be converted to 20 kV side, already using a 20 kV source.

**Table 1. MVA Short Circuit 3 Phase**

| V (kV) | MVA SC 1 PHASA |
|--------|----------------|
| 150    | 2789.76        |

Table 2 is the transformer III data on GI. North Bandung, transformer III has power of 60 MVA, with impedance = 12.13%, neutral transformer power is grounded through 12 Ohm resistance. Table 3.2 is used to find the Ohm value at 100% transformer state, positive sequence reactance, negative \( X_{t1} = X_{t2} \) and zero order reactance \( X_{t0} \). This zero sequence reactance is obtained by observing the winding data of the transformer transformer III, the winding used on the transformer YNyn0 + d For the power transformer with the Yyd winding connection where the capacity of the delta winding is usually one-third of the winding capacity of Y (the winding used to supply power, Delta remains inside but not excluded unless one delta terminal is to be grounded.

**Table 2. Specification of Transformer III at GI BDG UTR**

| Transformer III | Brand     | Type     | S/N       | Op. Year | Made | V. Group | Capacity | Delta Capacity | Primer Voltage | Scondary Voltage | Impedance | NGR |
|-----------------|-----------|----------|-----------|----------|------|----------|----------|---------------|---------------|----------------|-----------|-----|
|                 | SIEMENS   | TLSN 7852| D416375   | 2004     | -    | YNyn0 + d| 60 MVA   | 20 MVA        | 150 kV        | 20 kV          | 12.13 %   | 12 Ohm |

Table 3 is data of cable type on NDJ feeder, based on data from APD West Java and Banten, NDJ penyulang using SKTM type cable that is NA2XSEBY and PILC, in calculation of impedance of cable NA2XSEBY and PILC replaced by cable AL, this is because APD West Java and Banten has no positive impedance datasheet, negatives and zero impedance of NA2XSEBY and PILC cables. The selection of replacement cables is based on the diameter and core characteristics of NA2XSEBY and PILC cables. Furthermore table 3 is used as a reference in the creation of a connection group.

**Table 3. Type of NDJ Feeder**

| No. | Main Cable   | Size   | New Cable | Size        |
|-----|--------------|--------|-----------|-------------|
| 1.  | NA2XSEBY     | 3 × 150 mm² | AL        | 3 × 150 mm² |
| 2.  | NA2XSEBY     | 3 × 240 mm² | AL        | 3 × 240 mm² |
| 3.  | NA2XSEBY     | 3 × 300 mm² | AL        | 3 × 300 mm² |
| 4.  | PILC         | 3 × 150 mm² | AL        | 3 × 150 mm² |
Table 4 is used to simplify the network impedance calculation process, this is because the NDJ repeater has 18 connections, the group making on the NDJ feeder is based on the diameter of the AL cable. Group 1 is a group with cable diameter $150 \text{ mm}^2$, then group 2 with cable diameter $240 \text{ mm}^2$, group 3 using cable with diameter $150 \text{ mm}^2$, then group 4 diameter cable used $240 \text{ mm}^2$, group 5 with cable diameter $150 \text{ mm}^2$, group 6 consisting of $240 \text{ mm}^2$, diameter cable, group 7 using cable with diameter $150 \text{ mm}^2$, group 8 using cable with diameter $240 \text{ mm}^2$, then group 9 with cable diameter $150 \text{ mm}^2$, group 10 consist of cable diameter $240 \text{ mm}^2$, then group 11 diameter cable used $300 \text{ mm}^2$, group 12 with cable diameter $240 \text{ mm}^2$, group 13 with cable diameter $150 \text{ mm}^2$, group 14 with cable diameter $240 \text{ mm}^2$, group 15 with cable diameter $150 \text{ mm}^2$, group 16 with cable diameter $240 \text{ mm}^2$, group 17 with diameter cable $150 \text{ mm}^2$, and group 18 with cable diameter $240 \text{ mm}^2$.

| No. | Group | Substation | Length of Feeder |
|-----|-------|------------|-----------------|
| 1.  | A     | BCAS       | 1.0 Km          |
| 2.  | BCAS  | TSB        | 1.2 Km          |
| 3.  | TSB   | HHS        | 2.1 Km          |
| 4.  | HHS   | MPD01      | 0.037 Km        |
| 5.  | MPD01 | UPJ04      | 0.652 Km        |
| 6.  | UPJ   | STT04      | 1.111 Km        |
| 7.  | STT   | BM         | 0.958 Km        |
| 8.  | BM    | BBR        | 0.135 Km        |
| 9.  | BM    | EEP2       | 1.030 Km        |
| 10. | EEP2  | EEP1       | 0.214 Km        |
| 11. | EEP1  | DKL1       | 0.179 Km        |
| 12. | DKL1  | DPZ1       | 0.315 Km        |
| 13. | DPZ1  | DPZ        | 0.046 Km        |
| 14. | BB    | BKS        | 0.064 Km        |
| 15. | DPZ   | ABT1       | 0.173 Km        |
| 16. | ABT1  | GLL1       | 0.094 Km        |
| 17. | GLL1  | BIPA1      | 0.675 Km        |
| 18. | BIPA1 | DAGO       | 1.156 Km        |

Table 5 is used to calculate the repeater equivalent impedance. The calculation is to calculate the magnitude of positive impedance ($Z_{1\,eq}$), negative ($Z_{2\,eq}$) and zero impedance ($Z_{0\,eq}$) from the point of the disturbance to the source. The repeater equivalent impedance to be calculated depends on the magnitude of the impedance per km of the corresponding repeater, where the value is determined by the type of cable used. The impedance generated from the source to the point of interference is the series connected, then the calculation ($Z_{1\,eq}$) and ($Z_{2\,eq}$) can directly add up the impedances, while for the calculation ($Z_{0\,eq}$) starts from the point of disruption to the neutralized power transformer.

Table 6 shows the location of the disturbance current that occurs in the NDJ repeater, during 2016 there is a current interruption of 18 times, the type of disturbance that dominates the phases to the soil disturbance with total interference 13 times, while the type of phase to phase disorder occurs only 5 times. When the normal state of the current at the buffer ranges from 10A to 300A, but when the fault current occurs the current flowing in the feeder ranges from 400A to 8000A.

The data in table 6 is used as input in the indication of noise current on the NDJ feeder using fuzzy rule-based and the comparison of the indication of fuzzy rule-based noise flow current, the data used as input is the current value when the normal state and the current value in the event of interference, In the event of current noise current flows ranging from 400A to 5000A. The indication of the type of
noise current and the amount of noise current using the fuzzy rule-based method is then compared with the disturbance findings in table 6.

| No. | Cable Group | Cable Size (MM²) | Impedance Positive/Negative Z₁/Z₂ | Impedance zero Z₀ |
|-----|-------------|------------------|-----------------------------------|------------------|
| 1. AL | 150         | 0.206            | 0.104                             | 0.356            |
| 2. AL | 125         | 0.125            | 0.097                             | 0.275            |
| 3. AL | 240         | 0.125            | 0.125                             | 0.275            |
| 4. AL | 240         | 0.125            | 0.097                             | 0.275            |
| 5. AL | 240         | 0.125            | 0.275                             | 0.029            |
| 6. AL | 240         | 0.125            | 0.275                             | 0.029            |
| 7. AL | 240         | 0.125            | 0.275                             | 0.029            |
| 8. AL | 240         | 0.125            | 0.275                             | 0.029            |
| 9. AL | 240         | 0.125            | 0.275                             | 0.029            |
| 10. AL | 240       | 0.125            | 0.275                             | 0.029            |
| 11. AL | 300         | 0.100            | 0.100                             | 0.250            |
| 12. AL | 240         | 0.125            | 0.275                             | 0.029            |
| 13. AL | 240         | 0.125            | 0.275                             | 0.029            |
| 14. AL | 240         | 0.125            | 0.275                             | 0.029            |
| 15. AL | 240         | 0.125            | 0.275                             | 0.029            |
| 16. AL | 240         | 0.125            | 0.275                             | 0.029            |
| 17. AL | 240         | 0.125            | 0.275                             | 0.029            |
| 18. AL | 240         | 0.125            | 0.275                             | 0.029            |

This research requires some support to optimize the results. Some of the required devices are hardware (hardware) and software (software). Hardware (hardware) used is a set of laptops with specifications Operating System Windows 8.1 Pro 64-bit (6.3, Build 9600); Processor Intel (R) Celeron (R) CPU N2840 @2.16Ghz (2 CPUs), ~2.2Ghz with Intel (R) HD Graphics 1.0GHz; Memory
2048MB RAM. While the software (software) used is Matlab R2014b, Microsoft Office Word 2016, Microsoft Excel 2016, Mendeley Desktop ver. 1.17.9, and Microsoft Office Visio 2013.

3. Results and discussion

Table 7 shows the calculation of short circuit current flows, the calculation of short circuit current flows is obtained after the equivalent impedance value corresponds to the location of the disturbance, then the calculation of short circuit current can be calculated by using the basic equation, where the value of the noise current is the result of the comparison between the voltage with impedance Equivalent, only the equivalent impedance entered into the base equation depends on the type of current interference, short-circuit interference that can occur short circuit 1 phase to the ground, 2 phases, or 3 phases.

Single line to ground Fault, Double Line Fault, and three phases fault is contained in table 7, indicate that the closer to the source at 20 kV side or on the 0.05% repeater length the noise current will be greater, otherwise the fault current away from the source at Side 20 kV then the noise current value is smaller. The three-phase noise flow value will be greater than the two-phase noise and one phase to the ground.

| % Feeder | Feeder | 3 Phase | 2 Phase | 1 Phase |
|----------|--------|---------|---------|---------|
| 5%       | 0.56   | 11411.47| 9882.63 | 944.17  |
| 20%      | 2.23   | 9370.70 | 8116.26 | 916.85  |
| 35%      | 3.91   | 7477.82 | 6475.98 | 882.33  |
| 50%      | 5.58   | 6345.88 | 5495.69 | 858.041 |
| 65%      | 7.26   | 5419.71 | 4693.61 | 832.56  |
| 70%      | 7.82   | 5109.58 | 4425.03 | 822.21  |
| 85%      | 9.49   | 4503.56 | 3900.20 | 799.97  |
| 100%     | 11.17  | 4067.93 | 3522.93 | 781.57  |

Figure 1 shows the fuzzy logic designer to indicate the fault current and the location of the interrupt current on the NDJ feeder, the designed fuzzy logic designer consisting of 4 inputs and 10 outputs. Feeder-Current ($I_R$, $I_S$, $I_T$) and Neutral-Current ($I_N$) are input variables, while those including output variables are SLG-FAULT (SLG-R, SLG-S & SLG-T), DL-FAULT (DL-RS, DL-ST & DL-RT), DLG-FAULT (DLG-RS, DLG-ST & DLG-RT), and RST-FAULT.

Figure 2 shows the membership function (MF) in Feeder-Currents ($I_R$, $I_S$, $I_T$). MF used Feeder-Currents include Normal and High with rangedata [0 1000]. In the data field the noise current can reach 8000 A, but to see the slices of MF Normal and High type clearly, then the maximum data range
used is 1000. When the current value flowing in the NDJ repeater below 300 A, then this condition is said Normal or equal 1. But if the current value on the repeater exceeds the number 300 A then degrees continue to fall to 0, whereas when the High condition of the current will continue to increase, this indicates that there is a current interruption on the NDJ repeater, the greater the value of the current then the value is 1. Because The MF Normal has the characteristics of the shrinkage curve while the High has growth curve characteristics, so the MF type is suitable for Normal ie ZMF with data range [300 400] and High is SMF with data range [300 400].

Figure 2. input variable “Feeder-Current”

Figure 3 shows the MF at a neutral current, when the current flows neutrally in the NDJ feeder, it is certain that there is a ground fault current. Membershipfunction on Neutral-Current ($I_N$) that Normal and High, MF Normal and High characteristics are the same as MF feeder-current characteristic, MF Normal uses MF ZMF type whereas High uses MF SMF type only the range of data on different MF Neutral-Current. For ($I_N$) the range of data ranges [0 100] while for Normal params [20 60], and High [20 60]. The data range on Neutral-Current is minimized to make the Normal and High MF slices clear.

Figure 3. input variable “Neutral-Current”

Figure 4 shows the output noise current variable in the NDJ repeater, the disturbance current in the NDJ repeater encompassing one-phase to ground (SLG-FAULT), intermediate (DL-FAULT) interference, two-phase to DLG-FAULT interference Three phases (RST-FAULT). SLG-FAULT consists of SLG-R, SLG-S, and SLG-T. Further DL-FAULT include DL-RS, DL-ST, and DL-RT. Then DLG-FAULT includes DLG-RS, DLG-ST, and DLG-RT while the RST-FAULT interference type already includes all three phases, because RST-FAULT is a three phase noise.
The ten types of interference currents are designed to have the same MF ie L (Km). L (Km) denotes the location when the fault current occurs. MF L (Km) has a range of data [0 22.33]. The number 22.33 is used as the maximum range, it is intended that when the degrees of truth are 0.5 then the output indicates 11.16. The value of 11.6 itself is the total length of the NDJ repeater. MF L (Km) uses the MF ZMF type with params [0 25], this is because the noise current characteristic of the location of the noise current indicates the shrinkage. The smaller the value of the current disturbance the further distances disturbance of the substation, or in other words the output shows the value of 11.16, while the greater the value of the interruption current the closer the disturbance distance, or close to the number 0.

Table 8 shows the IF-THEN Rule used in FIS NDJ, IF THEN Rule is used to determine the type of fault current that occurs. IF-THEN Rule in FISNDJ is obtained based on the knowledge of the experts at PLN and based on related research, there are 4 fault current Occurs in the NDJ feeder, the interference current is SLG-FAULT, DL-FAULT, DLG-FAULT, and RST FAULT.

SLG-FAULT occurs when \( I_B = \text{normal} \) dan \( I_C = \text{normal} \), in other words a single phase to ground flow occurs when the current value is in one phase and the neutral current flowing in the feeder exceeds the normal MF limit (300 A), therefore IF- THEN Rule in the event of SLG-FAULT ie "If I_A is high and I_B is normal and I_C is normal and I_N is High than SLG-FAULT is L (Km)."

DL-FAULT occurs when \( I_a = \text{normal dan} I_n = \text{normal} \), in other words the inter-phase noise occurs when the current value on both phases is high or enter the data range of membership function High, therefore IF THEN Rule when DL-FAULT happens "If I_A Is normal and I_B is high and I_C is high and I_N is normal than DL-FAULT is L (Km)."

DLG-FAULT occurs when \( I_a = 0 \), in other words the interfacial current occurs when the current value on both phase is high and the neutral current is high, therefore IF THEN Rule occurs when DLG-FAULT is "If I_A is normal and I_B is High and I_C is high and I_N is high than DLG-FAULT is L (Km)."

RST-FAULT occurs when the current flowing in the phases R, S, and T is too large or in other words the current flowing in the NDJ feeder exceeds 4000 A, RST-FAULT is also accompanied by high neutral currents, therefore IF THEN Rule occurs RST-FAULT ie "If I_A is high and I_B is high and I_C is high and I_N is normal than RST-FAULT is L (Km)." And IF THEN Rule is the second when RST-FAULT happens "If I_A is high and I_B is high and I_C is high and I_N is high than RST-FAULT is L (Km)."
The first test is comparing the indication of the type of noise current using the Fuzzy Rule-Based method with the indication of the current type of interference using relays, the test results are found in table 9, in table 6 there is a noise current value during 2016, then the noise current we enter as input In the Fuzzy Rule Viewer, the indication of maturity compared to the current type of interference from the relay, when there is a fault current, the relay displays the current type of interference, the relay can be used as an indication of the type of noise current due to the relay nature of sensitive, selective and reliable

Test results show that Fuzzy Rule-Based can be used as a method of indication of the type of noise current, the difference is only in relays given information about the direction of the noise current, whether the noise current is close to the source (moment) or away from the source (time delay).

The second test is to compare the results of the indication of the location of the disturbance current using the Fuzzy Rule-Based method with the PLN method and the method of current noise calculation, the results obtained are shown in table 10, from table 10 it is obtained that Fuzzy Rule-Based information does not have accurate results in determining The location of the noise current in the NDJ feeder, this is due to the range of data obtained from the calculation of the interrupt current differs from the real-time interruption current value, or the field noise current value.
PT PLN (PERSERO) Distribution West Java and Banten Area Bandung using manual method in locating disturbance, Technician of PLN will see first information from Relay OCR / GFRyang protecting NDJ penyulang, technician will see whether the disturbance moment or time delay, if moment mean interference close to the source, whereas if the disturbance delay time is far from the source. After knowing the direction of the disturbance PLN technicians will down the indicator lights in each substation cantol in the NDJ penyulang, to get the indicator lights are off, and indicate where the disruption of the location.

Fuzzy Rule-Based conducts an indication of the location of the noise current based on the noise current calculation data, defuzzification, and membership function type. In this study Fuzzy Rule-Based in the setting to show the location of the L (Km) disturbance near the source if the noise current value is large, Disturbance L (Km) away with the source, but the conditions in the field are not always the case, sometimes the disturbance location away with the source but has a large current value, so the range of data, membership function, and defuzzification plays an important role in the accuracy of indication of the location of the fault current.

| Relay Method | Fault Location (L (Km)) | PLN Method | Short Circuit Calculation Method | Fuzzy Rule-Based Method |
|--------------|-------------------------|------------|----------------------------------|------------------------|
| RST-FAULT    | 7.084                   | 10.41      | 11.2                             |
| DLG-RT       | 8.235                   | 9.77       | 9.04                             |
| RST-FAULT    | 9.622                   | 9.47       | 9.16                             |
| SLG-R        | 11.165                  | 6.94       | 11.2                             |
| SLG-R        | 9.287                   | 4.33       | 7.7                              |
| SLG-R        | 4.801                   | 0.00       | 6.92                             |
| SLG-R        | 7.399                   | 6.17       | 7.82                             |
| DLG-RT       | 7.589                   | 11.17      | 11.2                             |
| SLG-T        | 6.126                   | 0.36       | 7.03                             |
| SLG-R        | 6.126                   | 1.46       | 7.26                             |
| SLG-R        | 4.801                   | 5.57       | 7.82                             |
| SLG-S        | 6.126                   | 3.70       | 7.59                             |
| SLG-T        | 7.589                   | 7.43       | 8.04                             |
| SLG-R        | 6.126                   | 0.00       | 11.2                             |
| DLG-RT       | 7.819                   | 9.29       | 8.93                             |
| SLG-T        | 7.399                   | 4.69       | 7.7                              |
| SLG-S        | 6.126                   | 5.07       | 7.82                             |
| SLG-R        | 7.589                   | 7.73       | 8.04                             |

Table 10 shows the fact that Fuzzy Rule-Based lacks good accuracy in performing indication of fault current location, out of 18 fault current, Fuzzy Rule-Based method can only indicate the location of fault current 5 times, this is because of the difficulty of determining the range of data In Fuzzy rule-based, if the range of data is too high then the relatively small disturbance current will not be properly indicated otherwise, if the range of data is too small then the disturbance flows that should be away from the source are indicated close to the source.

4. Conclusion
Firstly, the replacement of the impedance value of the NA2XSEBY and PILC cables with the AL cable causes the calculation of the 3-phase short-circuit current location, 2 phases, and 1 phases in the NDJ rectifier to be less accurate, as evidenced by the only precise test results indicating 3 times the disturbance of a total of 18 Interference, the reference data is the data of disturbance current on the NDJ feeder during 2016.
Secondly, Fuzzy Rule-based has good accuracy in performing indication of current type of interference, it is seen from the same test result as the information provided by numeric relay in North Bandung Substation, the type of interference indicated by Fuzzy Rule-based ie SLG-R , SLG-S, SLG-T, DL-RS, DL-ST, DL-RT, DLG-RS, DLG-ST, DLG-RT, and RST-FAULT.

Third, Fuzzy Rule-based lacks good accuracy in performing indication of fault current location, test result from 18 fault point location location indicates that Fuzzy Rule-based method only precisely indicates disturbance of 4 pieces with RST-FAULT interference type. Due to the range of data obtained from the calculation of short circuit current flows not in accordance with current conditions short circuit short circuit.

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