ISSN 1412-2782 eISSN 2407-9103
**Vol 23. No. 2 Mei 2024**

Jurnal POLI-TEKNOLOGI

# Analysis of Fault Locations Using the Impedance Method on the GIS 150 kV Transmission Line Karang Pilang Surabaya

**Reza Sarwo Widagdo[a*], Gatut Budiono[a], Aris Heri Andriawan[a], Puji Slamet[a], Roy Wibatsu Putra[a]**
[a]Department of Electrical Engineering, Faculty of Engineering, Universitas 17 Agustus 1945 Surabaya, Indonesia
*email of corresponding author: rezaswidagdo@untag-sby.ac.id

***Abstract***

*Transmission lines often experience difficulties in determining the location of interference, due to the length of the transmission line. This interference can be secured by using relays, one of which is a distance relay, this tool secures the zone 1, zone 2, and zone 3 areas on the transmission line. Apart from relays, there is also a tool to determine the fault distance, namely a fault locator. These two tools are examples of protection on transmission lines. The method used in this research uses the impedance method to determine the distance the fault occurs and the settings on the distance relay. This technique is often used in electric power systems. It is very effective for transmission lines, such as those in Karang Pilang, because of its ability to detect disturbances in transmission lines and equipment. Based on the analysis results, calculating the fault distance using the impedance method shows that the calculated value is very close to the distance measured by the fault finder. Specifically, when a short circuit occurs, the impedance method calculates a distance of 14.35 km, while the fault locator measures it at 14.59 km with a margin of error of 1.5%.*

**Article History**
Submitted: 28/06/2024
Revised : 01/08/2024
Accepted : 02/08/2024
Published: 31/05/2024

**Keywords:**
Distance Relay
Impedance Method
Short Circuit

## Introduction

Technology is one of the factors that supports the increase in demand for electrical energy. The increasing demand for electrical energy is the same as the increasingly advanced technology in the modern era which can facilitate activities in various aspects of various sectors [1][2][3]. such as the industrial sector, agricultural sector, energy sector, etc. Every year electricity becomes a major need for all groups, causing an increase in electrical energy that must be met by consumers. PT. PLN (Perusahaan Listrik Negara) (Persero) is one of the main companies that provides electricity in Indonesia. PT. PLN (Persero) is increasingly required to produce electrical energy in large quantities with good quality and has a high effectiveness value, is more efficient and economical. The electricity sector has a structured generation, transmission, and distribution system to supply electrical energy to consumers. In every field of electricity, there are various disturbances that can occur. For example, in transmission, disturbances that occur in transmission are short circuit disturbances or short circuits.

As we know, interference is an unnatural change in shape that occurs due to unstable conditions, resulting in a decrease in the quality of the electrical power sent, subsequently reducing the level of reliability of the system, as well as damage to several electricity supply equipment. Disturbances that occur must be overcome to reduce and avoid the resulting losses and increase the level of reliability to meet consumer needs properly [4][5][6]. Therefore, it is necessary to design an electrical power system that is safe for workers, distributes electricity well and can minimize losses that occur with the protection system. The protection system is a security system that is used to secure all certain parts of the electrical field and minimize interference that will occur. PT. PLN (Persero) uses primary protection in the transmission system such as distance relays on transmission lines. Distance relays can determine the location of the disturbance by dividing the security areas into Zone 1, Zone 2, and Zone 3 to determine the coverage area achieved [7][8]. Distance relays are not always precise in determining the fault location point, this is due to the presence of certain factors, so mathematical calculations are required using a method to evaluate the accurate determination of the fault location point [9][10]. Thus, the long-distance coverage in the transmission system requires an analysis of accurate distance relay protection to speed up the recovery process after a disturbance occurs, because of this the author chose the title Analysis of Fault Locations Using the Impedance Method on the GIS 150 kV Transmission Line Karang Pilang Surabaya.

This research aims to determine the location of short circuits in an electric power system using the impedance method. Accurate location determination is essential to improve system reliability, as corrective actions can be taken immediately to minimize downtime and economic losses. In addition, by quickly identifying the location of a short circuit, the potential for further damage to the system can be reduced by isolating and repairing the affected part as quickly as possible. The impedance method was chosen for several main reasons, namely accuracy and speed in detecting the location of a short circuit, simplicity of implementation, cost efficiency, use of data already available in the power system, and robustness to variations in power system parameters. This method utilizes existing impedance data, so it does not require additional data collection that is time-consuming and costly. In addition, this method has also been widely used and accepted in the electric power industry, with many references and case studies supporting its effectiveness. Thus, the impedance method offers an optimal combination of accuracy, efficiency, and ease of implementation, making it the right choice for this research.

## Theory

Several scientific journals related to short circuits or related to impedance methods have become reference material for conducting research on Analysis of Short Circuit Fault Locations Using the Impedance Method on the GIS 150 kV Transmission Line Karang Pilang Surabaya. There is previous research that has been carried out by other researchers regarding determining the location of disturbances so that researchers who will carry out research will have the same relationship from the equations to the objects to be observed. From various previous studies, there are several points that have been carried out to determine the location of short circuit faults.

In research conducted by Kholid Hidayatullah et al [11], research was carried out regarding the addition of UGC (Under Ground Cable) cables and changes in equipment ratings for the need to reconfigure the Pesanggaran GI (Main Substation) into GIS (Gas Insulated Switchgear). Disability results in the need to re-set the distance relay so that the relay can work more selectively and reliably. By using manual calculations and simulations, the results of resetting the distance relay of GIS Pesanggaran - GI Pemecutan Kelod were obtained with impedance values of Zone 1 = 2,055 Ω, Zone 2 = 5,73 Ω and Zone 3 = 11,01 Ω with time delay Zone 1 = 0 seconds, Zone 2 = 0.4 seconds and Zone 3 = 1.6 seconds. This setting shows that the relay setting value can protect the line from 3-phase short circuit disturbances obtained from the simulation results.

Then, in research conducted by Chairul Nazalul Anshar and Budiman [12], research was carried out which discussed three-phase, two-phase and one-phase short circuit currents to the ground at the fault point of 1% to 100% from the Bungus GI source at the Sirih Bay feeder with a length of channel 30,6 km. From the calculation results, it is obtained that the largest fault current is a three-phase short circuit fault current, while the smallest fault current is a single-phase ground fault. If the disturbance is closer to the source, the disturbance will be greater, whereas if the disturbance is far from the source, the disturbance will be smaller. From the results of three-phase fault calculations, it can be seen that the fault current at the fault point is 1%, so the fault current will be 2,250 A greater if the fault is farther from the source or at the fault point of 100%, then the fault current will be 400 A smaller than the two-phase fault current, so The two-phase fault current is smaller than the three-phase fault current, so the fault current at the 1% fault point is 1,948 A, while at the 100% fault point the fault current is 346 A, while the single-phase fault current to ground is the largest fault current. small compared to three-phase and two-phase short circuit disturbances. From the calculation results, it was found that the fault current at the 1% fault point was 286 A, while at the 100% fault point the fault current was 207 A. The impact of the short circuit fault was that there was an overcurrent (over cureent), to reduce the disturbance. It is best to replace the A3C wire with an insulated cable, namely the A3CS wire.

After that, in research conducted by Faritto and Yulisman [13], research was carried out in the field of electricity which has various disturbances that can occur. Disturbances that occur in transmission include short circuits or short circuits. The protection system is a security system that is used to secure all certain parts of the electrical field and minimize interference that will occur. PT. PLN (Persero) uses primary protection in the transmission system such as distance relays on transmission lines. Distance relays can determine the location of the disturbance by dividing the security areas into Zone 1, Zone 2, and Zone 3 to determine the coverage area achieved. Electrical impedance is often referred to as the amount of electrical resistance an electronic component has to the flow of current in a circuit at a certain frequency. Then, in research carried out by Nita Nurdiana [14], good protection equipment helps influence system reliability so that it can minimize the occurrence of disturbances. Short circuit disturbances are the most common problems. By carrying out manual calculations on the Nakula feeder of the Talang Kelapa Main Substation, it was found that the short circuit fault current at the fault point of 10% of the line length was 186,962 A, while at the fault point of 100% of the line length was 184,396 A. The farther the fault point is from the source, the smaller the fault current that occurs. The short circuit fault current is influenced by the source impedance, capacity, and impedance of the power transformer as well as the fault point or length of the feeder. Setting the relay time for line protection at the 1% point of the line length is 0,71 seconds. The research conducted by the author presents several significant novel aspects in the field of fault location analysis on power transmission lines. This research focuses on the application of a special impedance method for the Gas Insulated Switchgear (GIS) system, which has not been widely applied to similar systems in the Karang Pilang area, Surabaya. Innovations in methodology include the development or improvement of the impedance method to more accurately detect fault locations on 150 kV transmission lines. In addition, this study uses real-time data or historical data from the transmission system in Karang Pilang, which directly contributes to improving the reliability of the electricity system in the area. The focus on a specific case study in Karang Pilang provides a deeper understanding and technical solutions to the problems faced by the local transmission system with unique characteristics. The test and validation results of the method used show increased accuracy and effectiveness compared to previous methods, confirming the practical contribution of this study.

## Method

The type of research carried out is quantitative research in the form of data processing. This research will rely on data sources taken through recording disturbances in distance relays. The object chosen in this research is the Bay Line Rungkut 1 GIS 150 kV Karang Pilang distance relay. In the process of collecting data at GIS 150 kV Karang Pilang, data was obtained by following existing procedures at the agency. Some of the data needed for further analysis is conductor data (impedance and conductor length), short circuit fault data and data on the potential transformer (PT) ratio and current transformer (CT) ratio on Bay Line Rungkut I at the Substation Main 150 kV Karang Pilang, Surabaya. Analysis was carried out after data collection at PT. PLN (Persero) GI 150 kV Karang Pilang. The analysis was carried out by comparing the results of mathematical calculations with data taken in GIS 150 kV Karang Pilang Bay Line I Rungkut. Table 1 regarding the specifications of the distance relay with fabrication from ALSTOM with a maximum working current of 5 A and AC voltage of 100-120 V with a working frequency of 50 Hz. In addition, the use of the permitted voltage for direct current (DC) is 110 V.

TABLE I. DISTANCE RELAY SPECIFICATION

| Parameter | Type |
|---|---|
| Product | ALSTOM |
| Type | Mi COM P443 |
| Nominal Current | 1/5 A |
| Nominal Voltage | 100-120 V |
| DC Voltage | 110 V |
| Frequency | 50 Hz |

In this research, results were obtained in the form of distance relay setting impedance values for area 1, area 2 and area 3 on the Karang Pilang 150 kV substation transmission line. Not only that, this research also obtained the results of calculating 1-phase ground faults and 2-phase faults. The distance relay used has Mho characteristics. The type of research carried out is quantitative research in the form of data processing. This research will rely on data sources taken through recording disturbances in distance relays.

### *A. Calculation of Total Transmission Impedance*

The first step that must be done to determine the settings for the distance relay is to calculate the impedance value. The impedance value along the 150 kV Karang Pilang Main Substation transmission system is calculated using the following equation [15]:

$$\text{Total Impedance (ohm)} = \text{Transmission Length (km)} \times \text{Impedance} \left(\frac{ohm}{km}\right) \quad (1)$$

### *B. Calculation of the Ratio of Potential Transformers and Current Transformers*

In determining the fault distance, first determine the ratio of the potential transformer (PT) and current transformer (CT) value on the primary side which will then be compared with the secondary side. So, the CT and PT ratio is determined by the following equation [16].

$$\text{Ratio CT}=\frac{\text{CT (Primary)}}{\text{CT (Secondary)}} \tag{2}$$

$$\text{Ratio PT}=\frac{\text{PT (Primary)}}{\text{PT (Secondary)}} \tag{3}$$

## *C. Determination of Protection Zones*

Distance relays divide the operating area into several areas (zones), where each area or zone has a different distance relay reaction. The following is an explanation of the coverage area (zone) of a distance relay. Figure 1 explains the division of the fault zone by determining the magnitude of the impedance in each zone. The division of fault zone is divided into 3, namely in zone 1 the impedance value is 80% of the total impedance, zone 2 with an impedance value of 120% of the total impedance, and zone 3 with a value of 140% of the total impedance.

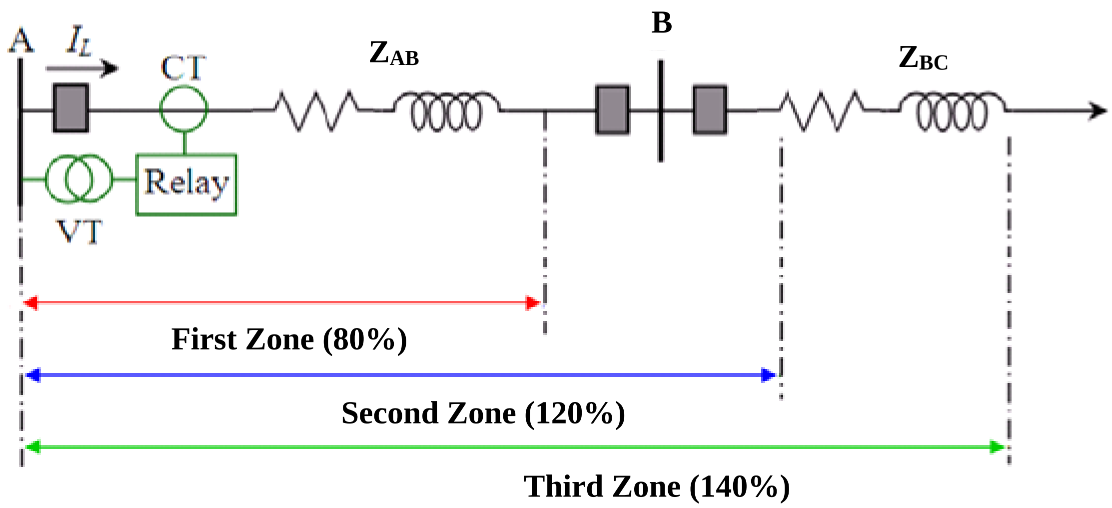


**Figure 1: Distance Relay Diagram**

a. Determination of Zone 1 on Distance Relay

Zone 1 relay covers the area as far as possible from the secured channel, but must not extend beyond the transmission wire in front of it. By considering the existence of errors in channel data, CT ratio, PT ratio, and other equipment of 20%, zone I begins to be set with a percentage of 80% of the secured channel length and to determine the range of relays [17].

$$Z_1 = 0,8 \times Z_{L1} \tag{4}$$

Where,

$Z_{L1}$ = Impedance of secured transmission line in Zone 1 (ohm), Zone 1 relay working time is without time delay, t = 0 seconds.

b. Determination of Zone 2 on Distance Relay

Zone 2 on the distance relay covers the remaining channel area that is not secured by Zone I, but must not overlap with Zone 2 in the next section. By assuming that the errors in Zone I settings are around 20%, the length of the channel that is secured to determine the range of Zone 2 relays is obtained as follows [17]:

$$Z_2 = 0{,}8\ (Z_{L1} + (0{,}8 \times Z_{L2})) \quad (5)$$

Where,

$Z_{L1}$ = Impedance of secured transmission line in Zone 1 (ohm)

$Z_{L2}$ = Impedance of secured transmission line in Zone 2 (ohm)

Zone 2 relay working time is t = 0,4 seconds

c. Determination of Zone 2 on Distance Relay

The protected area in Zone 3 can be determined by considering the remaining conductors that are not protected by Zone 1 and Zone 2, at least until the end of the next section. Determination for Zone 3 applies the formula [17]:

$$Z_3 = 1{,}2 \times (Z_{L1} + Z_{L2}) \quad (6)$$

Where,

$Z_{L1}$ = Impedance of secured transmission line in Zone 1 (ohm)

$Z_{L2}$ = Impedance of secured transmission line in Zone 2 (ohm)

## *D. Determine the Location of the Fault*

Distance relays are used in transmission lines as primary protection. The working principle of a distance relay is to measure the voltage at the relay point and the fault current that is read from the relay point. Then, by dividing the ratio value of the voltage transformer and current transformer, the impedance at the point where the fault occurs can be determined. With the impedance value read by the distance relay, interference in the transmission system can be secured. How far away the fault is in the transmission system can be calculated using the following equation [18]:

$$\text{Fault Location} = \frac{\text{Impedance measured at the distance relay} \times \frac{\text{CT}}{\text{PT}} \times \text{L}}{\text{Z}} \quad (7)$$

Where,

Z = Total Impedance (ohm)

CT = Ratio of Current Transformer

PT = Ratio of Potential Transformer

L = Total length of transmission line (km)

To calculate the error or the magnitude of the error value from the results obtained in the experiment, you can use the following equation [18].

$$\text{Error} = \frac{\text{Actual Location-Prediction Location}}{\text{Actual Location}} \times 100\% \quad (8)$$

# Results and Discussion

ISSN 1412-2782 eISSN 2407-9103
**Vol 23. No. 2 Mei 2024**

The initial step in conducting research was carried out by means of field observations to find out the object to be studied, where the object was the 150 KV Karang Pilang Bay Line Rungkut I Main Substation. Then, collecting conductor data (impedance and conductor length), short circuit fault data, and data ratio of current transformer (CT) and voltage transformer (PT) Bay Line Rungkut I at the 150 kV Karang Pilang main substation. Then carry out data processing using the impedance method, calculations using data read on the distance relay from Figure 2 and calculating the distance to the disturbance in kilometers (km). Analysis is carried out by comparing the actual distance when the disturbance occurs to determine the success of the analysis carried out.

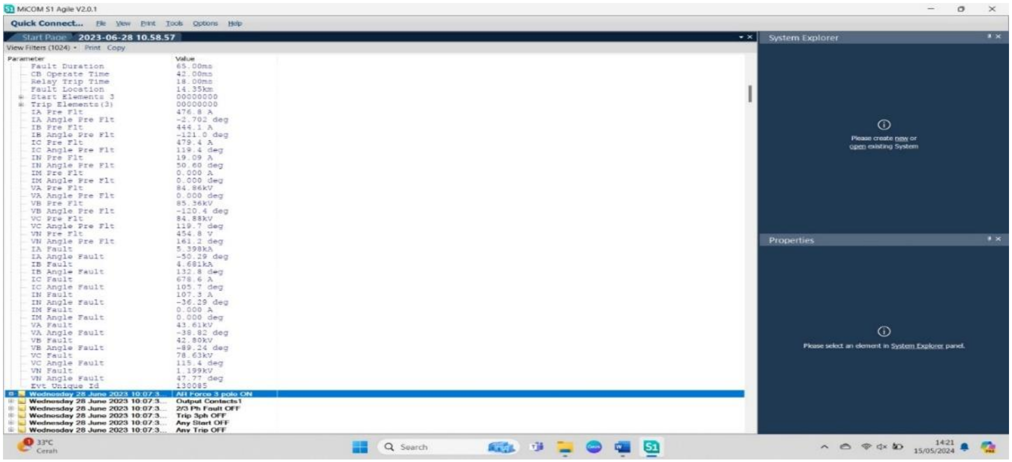

**Figure 2: Monitoring result data on distance relay**

## *A. General Description of the GIS 150 kV Transmission Line Karang Pilang, Surabaya*

Data parameter was carried out at the GIS 150 KV Karangpilang Bay Line Rungkut 1. From the distance relay data, it can be seen that the distance relay on the GIS 150 kV Karangpilang is the MiCOM P40 Agile P443 brand. The data obtained from GIS 150 KV Karang Pilang and literature studies are described in Table II. From the parameters specified in Table 2, it is explained that the ratio of the Potential Transformer (PT) is 154,000 in the primary section to 110 in the secondary section, while for the Current Transformer (CT) it is 2000 in the primary section to 5 in the secondary section. Then to determine the short circuit fault that occurs, several impedance parameters are needed, namely zero impedance of 0.106 ohm/km, positive sequence impedance of 0.017 ohm/km, and negative sequence impedance of 0.017 ohm/km.

TABLE II. EQUIPMENT PARAMETER

| Parameter | Value |
|---|---|
| Ratio of Potential Transformer (PT) | 154.000 / 110 |
| Ratio of Current Transformer (CT) | 2000 / 5 |
| Positive Sequence Impedance | 0,017 ohm/km |
| Negative Sequence Impedance | 0,017 ohm/km |
| Zero Sequence Impedance | 0,106 ohm/km |

## *B. Calculation of Impedance Values Before a Fault Occurs*

To determine the distance relay settings, it is necessary to calculate the impedance value along the 150 kV Bay Line Rungkut I Substation transmission system before a disturbance occurs. The value of the channel impedance can be calculated using equation (1):

$$Z_L = 15{,}41\ km \times 1{,}1\ \Omega/km$$

$$Z_L = 16{,}9\ \Omega$$

After determining the total impedance value over the entire length of the transmission line, then proceed with dividing the zone into 3 areas with different impedance values. The division of the three zones can be solved by Equation (4) to Equation (6).

ISSN 1412-2782 eISSN 2407-9103
**Vol 23. No. 2 Mei 2024**

a. Impedance Value in Zone 1:

$$Z_{L1} = 0{,}8 \times 16{,}9\ \Omega$$

$$Z_{L1} = 13{,}52\ \Omega$$

The security in Zone 1 has a time delay $T_1$ = 0 seconds due to the main security of the transmission system so it works instantly.

b. Impedance Value in Zone 2:

$$Z_2 = 0{,}8\ \big(16{,}9\ \Omega + (0{,}8 \times 16{,}9\ \Omega)\big)$$

$$Z_2 = 24{,}33\ \Omega$$

Zone 2 has a delay time of $T_2$ = 0.8 seconds because Zone 2 can work as a backup for Zone 1, so it is set with a longer working time.

c. Impedance Value in Zone 3:

$$Z_3 = 1{,}2 \times (13{,}52\ \Omega + 24{,}33\ \Omega)$$

$$Z_3 = 45{,}42\ \Omega$$

Zone 3 has a time delay $T_3$ = 1.2 seconds - 1.6 seconds, which has the longest working delay time of Zone 1 and Zone 2. Determination of Zone 1 to Zone 3 will later become a reference or parameter used to analyze the location of the short circuit fault that occurs. Later, the Distance Relay depicted in Figure 3 will detect the location of the short circuit fault based on the previously determined Zone.

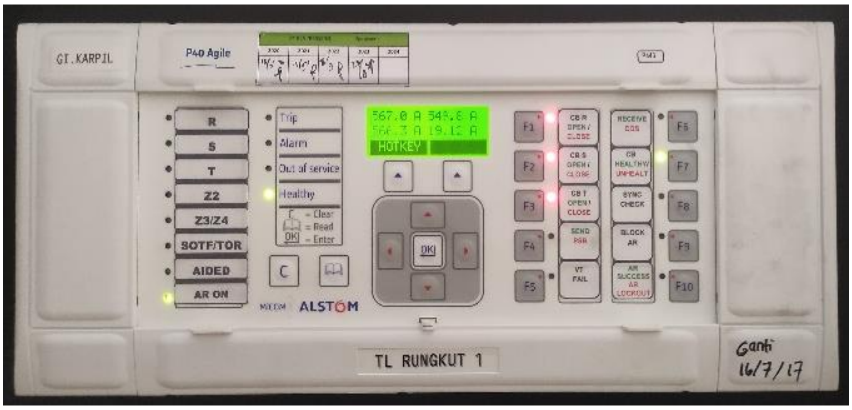


**Figure 3: Distance Relay at Bay Line Rungkut 1**

## C. *Determination of Impedance Values for Settings on Distance Relays*

The impedance value seen in the impedance relay is on a small scale because it is based on the ratio of the potential transformer (PT) and current transformer (CT). Determining the impedance setting on a distance relay in Figure 3 is calculated as follows[19]:

$$Z_{relay} = n \times Z_{zone} \tag{9}$$

$$n = \frac{CT}{PT} = \frac{2000/5}{154000/110} = \ 0{,}28$$

a. Zone 1

$Z_1 = 0{,}28\ x\ 13{,}52\ \Omega$
$Z_1 = 3{,}78\ \Omega$

b. Zone 2
$Z_2 = 0{,}28\ x\ 24{,}33\ \Omega$
$Z_2 = 6{,}81\ \Omega$

c. Zone 3
$Z_3 = 0{,}28\ x\ 45{,}42\ \Omega$
$Z_3 = 12{,}71\ \Omega$

TABLE III. COMPARISON OF ACTUAL SETTINGS AND CALCULATION SETTINGS

| Zone | Impedance Actual | Impedance based on Calculation |
|---|---|---|
| 1 | 3,45 Ω | 3,79 Ω |
| 2 | 6,47 Ω | 6,81 Ω |
| 3 | 12,38 Ω | 12,71 Ω |

## *D. Determination of Impedance Values When a Short Circuit Occurs*

When the research was carried out, a 2-phase short circuit occurred. In this short circuit condition, positive sequence impedance ($Z_1$) and negative sequence impedance ($Z_2$) values are required. From this case the calculated impedance values are as follows [20]:

a. 2-Phase Short Circuit

$$I_{2\emptyset} = \frac{V}{Z1+Z2} \quad (10)$$

$$I_{2\emptyset} = \frac{\sqrt{3} \times 150\ kV}{0{,}017\ \Omega + 0{,}017\ \Omega}$$
$$I_{2\emptyset} = 4{,}411\ kA$$

$$Z_{Fault} = \frac{V_{Fault}}{I_{Fault}} \quad (11)$$

$$Z_{Fault} = \frac{43{,}61\ kV}{4{,}411\ kA} = 9{,}88\ \Omega$$

## *E. Determine the Location of the Fault*

Calculations using this impedance-based method can determine the distance of the disturbance by using the impedance value of the network where the disturbance occurs. Based on the impedance results obtained, the distance and impedance will then be adjusted. We can determine the distance to the location of the disturbance by calculating using equation (7).

$$Fault\ Location = \frac{9{,}88\ \Omega \times \frac{2000/5}{154000/110} \times 15{,}41\ km}{2{,}92\ \Omega}$$
$$Fault\ Location = 14{,}59\ km$$

When compared with the actual distance of the disturbance read on the distance relay, the results of this calculation have a percentage error:

$$\%\boldsymbol{error} = \frac{\mathbf{14,35 - 14,59}}{\mathbf{14,35}}\ \boldsymbol{x}\ \mathbf{100\%}$$

$$\%error = 1{,}5\ \%$$

Analysis of the location of short circuit faults using the impedance method on the 150 kV GIS transmission line in Karang Pilang Surabaya includes a detailed examination of the electrical properties of the transmission line to identify the location of the short circuit fault. This method is particularly useful in high voltage transmission systems such as 150 kV GIS lines, where fault location can be critical in ensuring the stability and reliability of the power supply. The impedance method is based on the principle that the impedance of a transmission line changes significantly when a fault occurs. By measuring the line impedance at different points, the location of the fault can be determined. This method is commonly used in electric power systems because it is relatively simple to implement and provides accurate results. In summary, short circuit fault location analysis using the impedance method on the 150 kV GIS transmission line in Karang Pilang, Surabaya, involves measuring the line impedance at different points to identify the location of the short circuit fault. This method is commonly used in electric power systems and is especially useful on transmission lines such as the one in Karang Pilang because of its ability to identify faults in transmission lines and equipment.

## Conclusions

From the results of the analysis that has been carried out, the calculation of determining the fault distance using the impedance method shows that the calculated value is close to the fault distance read by the fault locator. When a short circuit occurs, the distance calculated using the impedance method is 14,35 km, while the fault distance read on the fault locator is 14,59 km, so an error value of 1,5% is obtained. The protection system on transmission lines and at substations must always be ready when a disruption occurs to maintain reliability and avoid damage to transmission lines and substations, in addition to carrying out routine testing and maintenance of equipment to determine the condition and readiness of protective equipment such as fault locator, distance relay, lightning arrester in dealing with disturbances that occur.

## References

[1] R. S. Widagdo, A. H. Andriawan, and R. Hartayu, “Harmonic Mitigation in Microgrids to Improve Power Quality,” *J. Teknol. Elektro*, vol. 15, no. 01, p. 11, 2024, doi: 10.22441/jte.2024.v15i1.003.

[2] R. Sarwo Widagdo, D. Hartono, P. Slamet, A. H. Andriawan, I. A. Wardah, and B. Hariadi, “Assessment of Power System Equipment to Enhance the Power Quality at Dr. Saiful Anwar General Hospital Malang,” *BERNAS J. Pengabdi. Kpd. Masy.*, vol. 5, no. 2, pp. 1596–1604, 2024, [Online]. Available: https://doi.org/10.31949/jb.v5i2.8945

[3] R. S. Widagdo and A. H. Andriawan, “Prediction of Age Loss on 160 KVA Transformer PT. PLN ULP Kenjeran Surabaya using The Linear Regression Method,” *J. Ris. Rekayasa Elektro*, vol. 5, no. 2, p. 83, 2023, doi: 10.30595/jrre.v5i2.18140.

[4] J. Doria-García, C. Orozco-Henao, R. Leborgne, O. D. Montoya, and W. Gil-González, “High impedance fault modeling and location for transmission line☆,” *Electr. Power Syst. Res.*, vol. 196, 2021, doi: 10.1016/j.epsr.2021.107202.

[5] M. B. R. Widodo, A. Soeprijanto, and O. Penangsang, “Analysis of Fault Location on Distribution System Using Impulse Injection learned by ANFIS,” *Proc. - 2020 Int. Semin. Intell. Technol. Its Appl. Humanification Reliab. Intell. Syst. ISITIA 2020*, pp. 38–43, 2020, doi: 10.1109/ISITIA49792.2020.9163769.

[6] S. Xu, J. Ouyang, J. Chen, and X. Xiong, “A Section Location Method of Single-Phase Short-Circuit Faults for Distribution Networks Containing Distributed Generators Based on Fusion Fault Confidence of Short-Circuit Current Vectors,” *Electron.*, vol. 13, no. 9, 2024, doi: 10.3390/electronics13091741.

[7] A. K. Abbas and M. A. A. Al-Tak, “A Review of methodologies for Fault Location Techniques in Distribution Power System,” *Iraqi J. Electr. Electron. Eng.*, vol. 17, no. 2, pp. 27–37, 2021, doi: 10.37917/ijeee.17.2.4.

[8] R. Dashti, M. Daisy, H. Mirshekali, H. R. Shaker, and M. Hosseini Aliabadi, “A survey of fault prediction and location methods in electrical energy distribution networks,” *Meas. J. Int. Meas. Confed.*, vol. 184, no. July, p. 109947, 2021, doi: 10.1016/j.measurement.2021.109947.

[9] M. Sarwar, F. Mehmood, M. Abid, A. Q. Khan, S. T. Gul, and A. S. Khan, “High impedance fault detection and isolation in power distribution networks using support vector machines,” *J. King Saud Univ. - Eng. Sci.*, vol. 32, no. 8, pp. 524–535, 2020, doi: 10.1016/j.jksues.2019.07.001.

[10] M. Dashtdar *et al.*, “Fault Location in Distribution Network by Solving the Optimization Problem Based on Power System Status Estimation Using the PMU,” *Machines*, vol. 11, no. 1, 2023, doi: 10.3390/machines11010109.

[11] K. Hidayatullah, R. Sari Hartati, and I. W. Sukerayasa, “Analisis Penentuan Setting Distance Relay Penghantar Sutt 150 Kv Gis Pesanggaran – Gi Pemecutan Kelod,” *J. SPEKTRUM*, vol. 6, no. 1, p. 134, 2019, doi: 10.24843/spektrum.2019.v06.i01.p19.

[12] J. Teknik, A. Sains, and C. N. Anshar, “Studi Analisa Arus Gangguan Hubung Singkat Berdasarkan

Lokasi Titik Gangguan Pada Saluran Udara Tegangan Menengah 20 kV," vol. 1, no. 1, pp. 140–148, 2022.

[13] Faritto, F., & Yulisman, Y. (2022). Analisa Penentuan Titik Lokasi Gangguan Pada Rele Jarak Menggunakan Metode Impedansi. *Ensiklopedia Research and Community Service Review*, *1*(3), 93-99.

[14] N. Nurdiana, N. N. Dosen, T. Yayasan, P. Studi, and T. Elektro, "Analisa Gangguan Arus Hubung Singkat Pada Penyulang Nakula Gardu Induk Talang Kelapa," *J. Ampere*, vol. 1, no. 1, pp. 26–36, 2016, [Online]. Available: https://jurnal.univpgri-palembang.ac.id/index.php/ampere/article/view/475

[15] N. M. Khoa, M. V. Cuong, H. Q. Cuong, and N. T. T. Hieu, "Performance Comparison of Impedance-Based Fault Location Methods for Transmission Line," *Int. J. Electr. Electron. Eng. Telecommun.*, vol. 11, no. 3, pp. 234–241, 2022, doi: 10.18178/ijeetc.11.3.234-241.

[16] E. Personal, A. García, A. Parejo, D. F. Larios, F. Biscarri, and C. León, "A comparison of impedance-based fault location methods for power underground distribution systems," *Energies*, vol. 9, no. 12, 2016, doi: 10.3390/en9121022.

[17] R. Dashti, M. Daisy, H. R. Shaker, and M. Tahavori, "Impedance-Based Fault Location Method for Four-Wire Power Distribution Networks," *IEEE Access*, vol. 6, pp. 1342–1349, 2017, doi: 10.1109/ACCESS.2017.2778427.

[18] S. A. S. Al Kazzaz, I. Ismael, and K. K. Mohammed, "Fault detection and location of power transmission lines using intelligent distance relay," *Int. J. Power Electron. Drive Syst.*, vol. 11, no. 2, pp. 726–734, 2020, doi: 10.11591/ijpeds.v11.i2.pp726-734.

[19] A. Zamora-Mendez *et al.*, "Two effective methods for impedance estimation in distance relays based on the DC offset removal," *Electr. Power Syst. Res.*, vol. 194, 2021, doi: 10.1016/j.epsr.2021.107102.

[20] J. S. Hong, G. Do Sim, J. H. Choi, S. J. Ahn, and S. Y. Yun, "Fault location method using phasor measurement units and short circuit analysis for power distribution networks," *Energies*, vol. 13, no. 5, 2020, doi: 10.3390/en13051294.