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# Analysis Study of Overcurrent Relay in the Underground Distribution Network System in the Business Area of Manado City

## Studi Analisis Relay Arus Lebih pada Sistem Jaringan Distribusi Bawah Tanah di Kawasan Bisnis Kota Manado

**Leony Ariesta Wenno*, Godeliva Ngala, Deitje S. Pongoh**
Politeknik Negeri Manado, Jalan Raya Politeknik Kelurahan Buha, Manado, Indonesia

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**Abstract**

Currently, the distribution network installed in the business area of Manado City still uses medium-voltage overhead lines (SUTM), while an underground cable system (SKTM) has been planned for implementation. To ensure the reliability of the planned underground distribution network, the selection of protection devices is crucial. In addition, there is still a lack of OCR analysis for underground distribution system protection in Manado City. Therefore, this study aims to obtain the settings for the overcurrent relay (OCR) on the underground cable conductors on the low voltage side. The data needed for this study was obtained through direct field surveys and interviews with relevant parties to gather additional information regarding the standards for underground cable construction. Considering the potential increase in load in the future, the calculation of the OCR protective settings was performed by calculating the cross-sectional area of the medium voltage conductors and the current-carrying capacity of the low voltage conductors. As a result, the setting value for the OCR was determined to be 5 Amperes with a Time Multiplier Setting (TMS) of 0.004.

***Keywords:*** overcurrent relay, setting value, low voltage underground cable, Manado.

***SDGs*:**

9 INDUSTRY, INNOVATION AND INFRASTRUCTURE

**Abstrak**

Saat ini, jaringan distribusi yang terpasang di kawasan bisnis Kota Manado masih menggunakan konstruksi saluran udara tegangan menengah (SUTM), sementara sistem saluran kabel tanah (SKTM) telah direncanakan untuk diterapkan. Untuk menjamin keandalan jaringan distribusi saluran kabel tanah yang telah dirancang tersebut, pemilihan pengaman menjadi sangat penting. Selain itu masih kurangnya analisa OCR untuk proteksi sistem distribusi bawah tanah di Kota Manado. Oleh karena itu, penelitian ini bertujuan untuk mendapatkan setting relai arus lebih (OCR) pada penghantar kabel tanah di sisi tegangan rendah. Data yang dibutuhkan dalam penelitian ini didapatkan melalui survey langsung dilapangan serta wawancara dengan pihak terkait untuk mendapatkan informasi tambahan mengenai standar konstruksi saluran kabel bawah tanah. Dengan memperhatikan kemungkinan kenaikan beban kedepannya, perhitungan setting pengaman OCR dilakukan dengan memperhitungkan luas penampang penghantar tegangan menengah dan kuat hantar arus penghantar tegangan rendah. Sehingga didapatkan hasil yaitu nilai arus setting OCR pada 5 Ampere dengan TMS 0,004.

***Kata Kunci:*** relay arus lebih, nilai arus setting, kabel tanah tegangan rendah, Manado.

*Correspondence Author
email : leonywenno@elektro.polimdo.ac.id

## 1. INTRODUCTION

The Distribution System is a part of the electric power system. This distribution system is useful for delivering electrical power from large power sources (Bulk Power Sources) to consumers. Distribution lines can be classified according to the type of conductor used, namely first, overhead lines, which are installed in open air with the help of supports (poles) and their accessories, differentiated into: overhead wire lines, when the conductors are bare, without insulation, and overhead cable lines, when the conductors are insulated. Second, underground lines are installed underground using ground cables, and submarine lines are installed on the seabed using submarine cables (Suhadi and Tri Wrahatnolo, 2008).

The low-voltage distribution network (JTR) is the final stage of the electric power distribution system (PLN, 2010a). Since disturbances in the electricity distribution system can cause losses to both the electricity provider and the consumers, the JTR must consider reliability factors. Reliability describes a measure of the level of availability/service of electricity supply from the system to the user/customer (Perdana, Hasanah and Dachlan, 2009; Arifani and Winarno, 2013; Perdana, Dachlan and Utomo, 2013). The reliability of the JTR is crucial to ensuring good and guaranteed service to customers (Manopo, Tumaliang and Similang, 2022).

In Manado City, most of the electricity distribution network uses overhead cable construction, so trimming and cutting down trees within a 2m radius from the Overhead Transmission System (SUTM) conductor must be done regularly to maintain the stability and reliability of electricity distribution. This, of course, hinders greening efforts in the city of Manado. In achieving a city layout with a Go Green concept, the Manado city government is creating distribution lines with underground construction or Subterranean Cable Transmission System in the Boulevard on Business (BOB) area of Manado City.

The distribution route with underground construction or Subterranean Cable Transmission System is a distribution channel that uses fully insulated conductors and is buried underground (Ilham, 2019). For low-voltage cable connections through underground systems, the type of cable used is NYFGbY (PLN, 2010b). This type of cable is made of copper as the conductor, has PVC insulation, is shielded with steel wire, and is protected by galvanized steel spiral tape with outer PVC insulation. The double PVC layer on the NYFGbY cable type provides additional protection for the conductor. Some advantages of this construction include (PLN, 2010a), first, supporting urban planning because the cables buried underground provide a neater appearance, making it easier to organize the city, and second, underground construction is known to be more reliable as the cable's position is not affected by bad weather, plants, animals, objects, or humans. The disadvantages include higher construction costs due to the relatively expensive materials used and limited free space, as the underground cable construction applied in busy urban centers can hinder community mobility.

Underground cables often experience faults due to insulation failure, mechanical damage, or moisture, leading to power supply disruptions and economic losses for network operators (Abd-Elaziz *et al.*, 2024). According to Zhang et al., in Reliability Evaluation Method for Underground Cables Based on Double Sequence Monte Carlo Simulation, it is concluded that the use of emergency loads can increase network flexibility but also accelerate cable aging, making failure risks an important consideration (Zhang *et al.*, 2025). The cable design risk factor (α) and the aging risk acceptance factor (β) play a crucial role in balancing network reliability and the risk of failure due to thermal aging. Integrating cable thermal characteristics into the network reliability model can help network operators optimize maintenance and cable replacement strategies (Zhang *et al.*, 2025). Additionally, common faults that occur in underground cables include single line-to-ground fault, double phase-to-ground fault, phase-to-phase fault, three-phase fault, and three-phase-to-ground fault (Hizam *et al.*, 2009). Therefore, to ensure the reliability of low-voltage cable channels, a good protection system is required that meets the criteria of protection systems (Annisa, 2019): Speed, Selectivity, Sensitivity, and Reliability.

Speed refers to the ability of the protection system or relays to quickly isolate the affected part from the rest of the system to minimize losses or damage caused by disturbances. Selectivity is the ability of the system or relays to isolate the affected part of the system as minimally as possible, meaning only the disturbed equipment is included in the primary protection area. Sensitivity is the ability of the system or relay to respond to disturbances in its area, even if those disturbances are minimal, and to provide a response. Reliability is the ability of the system or relay to secure the disturbed area without failure, incorrect operation, or delayed response.

Overcurrent relays are protective devices that serve to protect electrical equipment from overcurrent caused by short circuit faults (Sunaya and Widharma, 2020). This relay detects the presence of current exceeding its set value and then commands the circuit breaker to disconnect the circuit to prevent damage from the fault. Overcurrent relays are typically used as the primary protection for Medium Voltage Distribution Networks (Subterranean Cable Transmission System/Overhead Transmission System) to prevent damage to the Subterranean Cable Transmission System (SKTM) network from short circuit faults and to limit the affected area as much as possible. Based on their operating time characteristics, overcurrent relays are classified into three types: Instantaneous Relay, Time-Delay Relay, and Inverse Time Relay.

Various tests on overcurrent relay settings have been conducted. According to Lia Sugesti et al. in Setting Analysis of Overcurrent Relay and Ground Fault Relay on Transformer Protection System of High Voltage Substation System, the calculation and testing results show that the Time Multiplier Setting (TMS) value for the Overcurrent Relay (OCR) on the 20 kV side is 0.20, while on the 150 kV side, it is 0.23. This study focuses on calculating the short-circuit current for three-phase, two-phase, and single-phase faults at 150 kV and 20 kV voltage levels in a high-voltage substation transformer (Sugesti, Afandi and Putranto, 2019). Idriana et al., concluded that the placement of the OCR significantly affects fault occurrences. Moreover, the TMS value is influenced by the actual current (Is) and operating time (T); the larger the Is and T, the greater the TMS value (Idriana *et al.*, 2021). The test results show that the highest short-circuit fault current at bus 2 is 6,130 A, while the lowest fault current at bus 46 is 1,565 A. Based on the relay setting calculations, the pickup current (Ip) and time multiplier setting (TMS) values show a decreasing trend from bus 3 to bus 46. This indicates that the farther the bus location is from the source, the lower the required pickup current and the faster the relay operates, ensuring effective and sequential protection coordination. The test analysis of various fault source scenarios at buses 3, 7, 17, 34, and 46 shows that the circuit breaker operates sequentially based on the fault source location (Idriana *et al.*, 2021). Pasaribu et al., concluded that OCR and recloser settings depend on the set current (Ip), TMS values, and curve characteristics, where the obtained time speed values are TMS for the incoming PLN side = 0.072 seconds and TMS for the outgoing BICT side = 0.085 seconds (Pasaribu *et al.*, 2021). The settings for each piece of equipment vary according to their placement in the network. The highest trip time comparison for faults on the incoming side is 0.044 seconds, while on the outgoing BICT side, it is 0.031 seconds (Pasaribu *et al.*, 2021). Suratno et al., concluded that the OCR settings obtained from manual calculations using the standard inverse characteristic are as follows: pick-up at 0.5 seconds, time dial at 1.29 seconds, instantaneous at 19.51, and time delay at 0.8 seconds (Suratno, Narsen and Abdurrahim, 2021). The relay OCR settings obtained from ETAP 12.6.0 simulation are: pick-up at 0.1255 seconds, time dial at 3.35 seconds, time delay at 0.01 seconds, and instantaneous at 40 seconds. These results demonstrate that the relay functions effectively, protecting against short-circuit currents with a responsive operation, especially for the case study at the Tengkawang Substation feeder T-13 (Suratno, Narsen and Abdurrahim, 2021). Gabriel Montolalu et al., concluded that the maximum short-circuit fault current is 6,011.9 A and the minimum short-circuit current is 5,026.3 A. The OCR settings for the 150/20 kV transformer at the Tangerang Substation are Ip = 7A and TMS = 0.24 s. A comparison with field OCR settings suggests that periodic relay setting updates are necessary to optimize the performance of the overcurrent relay and prevent protection relay failures in case of a fault (Montolalu, Mangindaan and Patras, 2023). Sheta et al., discussed the application of Directional Overcurrent Relays (DOCR) in distribution networks with Distributed Energy Resources (DERs) (Sheta *et al.*, 2024). The changes in fault currents caused by DERs pose challenges in ensuring stable system protection. Therefore, this paper proposes a novel approach using user-defined relay characteristics, enabling the shifting of protection curves to improve relay coordination and DER stability. This approach employs a Genetic Algorithm (GA) to determine the optimal DOCR settings, considering the Critical Clearing Time (CCT) of DERs. The testing was conducted on a modified IEEE 33-bus system with four synchronous-based DERs. Simulations using DIgSILENT and MATLAB demonstrated that the proposed method enhances protection system performance compared to conventional approaches (Sheta *et al.*, 2024).

Previous studies have shown extensive optimization of OCR settings in Low Voltage Overhead Distribution Networks (SUTR), whereas the optimization of OCR settings in Low Voltage Underground Cable Networks (SKTM) in Indonesia, particularly in Manado City, remains limited. Therefore, a study on OCR settings is needed to improve the reliability and efficiency of the protection system in Manado's underground distribution network.

## 2. METHODOLOGY

### 2.1. Location

The research location is situated in the Boulevard on Business (BOB) area of Manado City, along Jl. Piere Tendean, Sario Utara, Sario District, Manado City. The location can be seen in Figure 1.

### 2.2. Method

The methods used are observation (direct survey) and interviews. The observation method is conducted through direct field visits to obtain documentation and accurate data, facilitating data processing. The types of data collected include the length of the distribution network of overhead lines along Jl. Piere Tendean, the distance between the poles supporting the medium voltage network, the number of substations and their installed capacity, and checking the urban planning conditions of the business area along Jl. Piere Tendean.

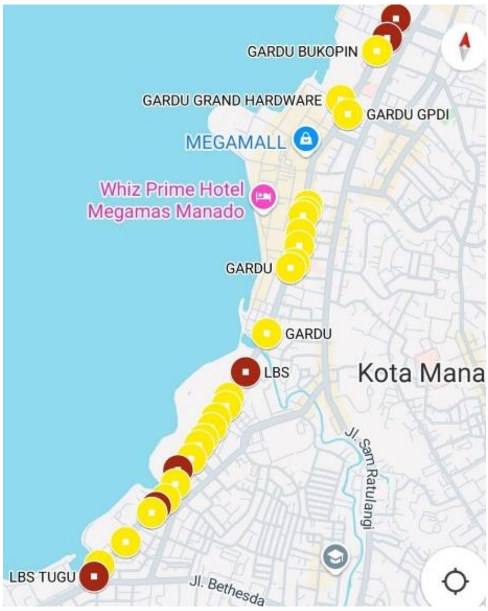


**Figure 1.** The research location.

The interview method is employed to gather data in the form of information related to the research through communication or question-and-answer discussions with PT. PLN and relevant parties, aim to support the data obtained through direct observation. The research flowchart can be seen in Figure 2.

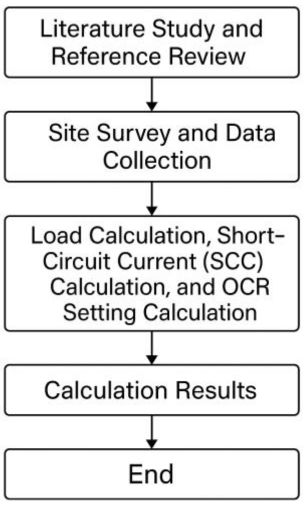


**Figure 2.** The research flowchart.

### 2.3. Calculation Analysis

The methods used are observation (direct survey) and interviews. The The OCR setting current must be greater than its maximum load current. The overcurrent relay (OCR) must trip at the minimum two-phase short-circuit current or $Imax < Iset < If\ min$.

The tuning current must also consider the pick-up error in accordance following British Standard Pick Up = 1.05 to 1.2 Iset. If the $Imax$ is unknown, then $In$ of the conductor or $In$ of the transformer can be used (Haz and Adityaa, 2020).

The current setting for the OCR relay on both the primary and secondary sides of the transformer can be calculated using the following equation (Ramlan, 2022):

$$I_{set(primer)} = 1{,}1 \times I_n \quad (1)$$

$$I_{set(sekunder)} = I_{set(primer)} \times \frac{1}{Ratio\ CT} \quad (2)$$

where:

$I_{set(primer)}$ = Primary Current Setting (A)
$I_{set(sekunder)}$ = Secondary Current Setting (A)
$I_n$ = Nominal Load Current (A)
Ratio CT = Ratio of the Primary and Secondary Winding of the Current Transformer

The short-circuit current value is needed to obtain the relay time multiple setting (TMS), according to IEC 60255 grading time for a relay operating time of 0.3 seconds. The time multiple setting (TMS) for the overcurrent relay can be calculated using the equation (Haz and Adityaa, 2020):

$$TMS = \frac{(\frac{Ip}{I_{Set}})^{0.02} - 1}{0.14} \times t \quad (3)$$

where:

$I_p$ = Pick up Current (A)
$I_{Set}$ = Setting Current (A)
$t$ = Relay Operating time (s)

## 3. RESULTS AND DISCUSSION

### 3.1. Calculation of Current Setting on OCR

Based on the calculating the load installed on the boulevard on business Jl. Piere Tendean in the city of Manado, a nominal current 〖(I〗_n) of 68.2 A on the primary side and 3410 A on the secondary side is obtained. The nominal current of the transformer is 100 A on the primary side and 4000 A on the secondary side. Therefore, on the primary side, a 20 kV CT 100:5 is used, and on the secondary side, a CT 4000:5 is used, indicating that the relay set on both sides is 5A. Using equation (1), the primary current is obtained as 110 A, and using equation (2), the secondary current is 5.5 A.

Meanwhile, considering the reliability of the network under load conditions for the next 10 years, we need to calculate the safety settings with the projected load increase over the next 10 years. Using equation (1), the primary current is obtained as 240 A, and using equation (2), the secondary current is 5.5 A. From the calculation results, 5.5 A is obtained for the existing condition and the load condition for the next 10 years. Therefore, the OCR is set to 5 A.

### 3.2. Calculation of Time Setting on OCR

According to IEC 60255, the grading time for relay operation is 0.3 seconds. Since the OCR setting for the current load and the load in the next 10 years is the same, which is 5 Amperes, the OCR TMS can be calculated using equation (3) is set to 0.004. The results can be seen in Table 1.

**Table 1.** OCR setting calculation results.

| | $I_n(A)$ | Ratio CT | Iset (A) | TMS |
|---|---|---|---|---|
| Current Primary Load Side | 68.2 | 100:5 | 5 | 0.004 |
| Current Secondary Load Side | 3410 | 4000:5 | 5 | 0.004 |
| Primary Side Load for the Next 10 Years | 176 | 200:5 | 5 | 0.004 |
| Secondary Side Load for the Next 10 Years | 8800 | 9000:5 | 5 | 0.004 |

Based on the results, compared to previous studies, according to Sugesti et al., the greater the values of Is and T, the greater the TMS value (Sugesti, Afandi and Putranto, 2019). This is because the calculated CT ratio remains at 5 A, not increasing the TMS value. According to Dewi Narsen et al., the standard inverse characteristic with a small TMS can protect against short-circuit currents with responsiveness, as shown by the obtained TMS value of 0.004. According to Montolalu et al., it is advisable to periodically update relay settings to prevent failures in the protective relay operation in case of faults (Montolalu, Mangindaan and Patras, 2023). In this study, with a low TMS value (fast reaction speed), the relay will trip faster, which is useful for more severe faults or faults closer to the power source (such as transformers or generators). In addition, the projection over the next 10 years is expected to assist in the process of periodic checking and setting of the OCR. This study is also conducted on an underground cable network, so periodic inspections of both OCR and CT are highly recommended to ensure system reliability.

## 4. CONCLUSION

Based on the results of the time setting and current setting calculations at I_n 68.2 A and CT 100:5 for the current load, and I_n 176 A and CT 200:5 for the load 10 years from now, the OCR setting is obtained as 5 Amperes with a TMS of 0.004. This indicates that if the current passing through the primary side exceeds 100 A or the reading on the relay exceeds 5 A, the relay will operate and protect the underground cable network system. Proper OCR settings are crucial to ensure that larger faults are cleared quickly, while smaller faults do not cause further disturbances to the system.

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