Performance Analysis of Over Current Relay on 20 kV Distribution Network Feeders Using MATLAB

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Abstract: Short circuit disturbances in electrical distribution systems can cause severe damage to equipment and compromise system stability if not properly addressed. To mitigate these impacts and maintain system reliability, protection devices such as overcurrent relays (OCR) are widely used to detect and automatically isolate overcurrent conditions. This study aims to analyze the magnitude of short circuit current and evaluate the performance of OCR in responding to faults in a 20 kV medium-voltage distribution network. The analysis was conducted using MATLAB Simulink, modeling the distribution system with parameters adjusted to actual system conditions. The simulation was carried out under two scenarios: normal operating conditions to ensure the OCR remains inactive when the current is within safe limits, and fault conditions to evaluate the accuracy and speed of the OCR response to overcurrent events. Simulation results show that the magnitude of the short circuit current decreases with the distance from the source, with values of 5,565.92 A at 5% of the feeder length, 1,367.25 A at 25%, 698.52 A at 50%, 468.87 A at 75%, and 352.83 A at 100%. Under normal conditions, the current waveform remains stable throughout the 0.2-second simulation period. In contrast, under fault conditions, a current surge exceeding the threshold occurs at 0.1 seconds, triggering the OCR. The relay responds promptly and accurately in accordance with the designed inverse-time characteristics, demonstrating its effectiveness and reliability in detecting and clearing short circuit faults in 20 kV distribution networks.

Keywords: protection, overcurrent relay, short circuit current, MATLAB, Simulink

1. Introduction

The growing demand for electricity requires a reliable and stable power distribution system. One way to achieve this reliability is by optimizing the protection system within the electrical network [1]. The distribution system functions to deliver electrical energy from the source to consumers, and the rapid increase in population can lead to a higher frequency of disturbances in the system [2].

A protection system plays a crucial role in preventing damage to equipment and ensuring the safety for both users and maintenance personnel [3]. When a relay detects

abnormal electrical conditions, whether due to excess or deficiency, it sends a trip command to the circuit breaker (CB) to isolate the faulted section [4]. Protection relay settings must be carefully adjusted according to the type of relay used, such as differential relays, distance relays, or overcurrent relays, based on the location of the components being protected [5].

The reliability of power delivery is heavily influenced by the protection system in place. Disturbances in the power network can result from external factors, such as natural disasters and sabotage, as well as internal factors like overloads, operational errors, and control system issues [6]. To minimize the risk of disturbances and protect electrical equipment, it is essential to install protective relays, such as overcurrent relays, which can prevent damage caused by excessive current [7]. Overcurrent protection is the primary protection of the conventional and active distribution systems [8]. In primary interconnected systems, the directional overcurrent protection is used to avoid the disconnection of unnecessary parts due to fault currents flowing in both directions [9].

According to the Lhokseumawe Substation operator and data recorded in October 2023, the LW3 feeder has experienced several disturbances, including a maximum short-circuit fault current at 32.24 kW. Given this conditions, reliable and well-coordinated protection, particularly through the use of overcurrent relays, is critical to maintaining system stability and minimizing the impact of faults on the network [10].

2. Methods

OCR is the process of converting an image of a letter into an ASCII (American Standard Code for Information Interchange) character that can be recognized by a computer [8]. Overcurrent relay settings are carried out on the incoming side by calculating inverse time (low set), instantaneous (high set), and Time Multiplier Setting (TMS) [11]. The time of the relay is based on the severity of the fault [12]. It essentially modifies the time delay characteristic of the relay, influencing how quickly the relay trips when a fault condition is detected. One of the software programs that can be integrated for data is MATLAB [13], [14].

This research utilizes MATLAB 2018a for simulating an overcurrent relay (OCR). Data collection is conducted to enhance the simulation that will be carried out in the evaluation of OCR performance [15], [16]. Two types of data are outlined in the data collection: primary data and secondary data. Calculations to be performed include determining the values of capacity, impedance, short-circuit faults, and relay settings. The formula for short circuit disturbance is seen in equations (1) and (2) [17].

$$I_{1\phi} = \frac{3V_{f-n}}{Z_{0eq} + Z_{1eq} + Z_{2eq}} \tag{1}$$

$$I_{3\phi} = \frac{V_{f-n}}{Z_{1eq}} \tag{2}$$

2.1. Modeling in MATLAB Simulation

Protective relays for overcurrent protection are the most widely used relays in a power system [18]. Modeling of the Over Current Relay (OCR) in the simulation using MATLAB 2018a involves the use of various functional blocks representing components of the protection system and relevant electrical environments. These blocks include those that describe the characteristics of the OCR, electrical network components, and the disturbances that occur [5].

Blocks have numeric parameters that determine how they calculate output values. Block parameters in MATLAB refer to the parameters used to configure the behavior or settings of the blocks in a simulation model [19]. The blocks used in MATLAB include Power GUI, Three Phase Source, Three Phase Breaker, Three Phase VI Measurement, Distributed Parameter Line, Three Phase Fault, Three Phase Series RLC Load, and other parameter blocks according to the simulation circuit model [6]. The overcurrent relay block circuit in the MATLAB simulation is presented in Figure 1.

Figure 1. Overcurrent relay block circuit in MATLAB simulation.
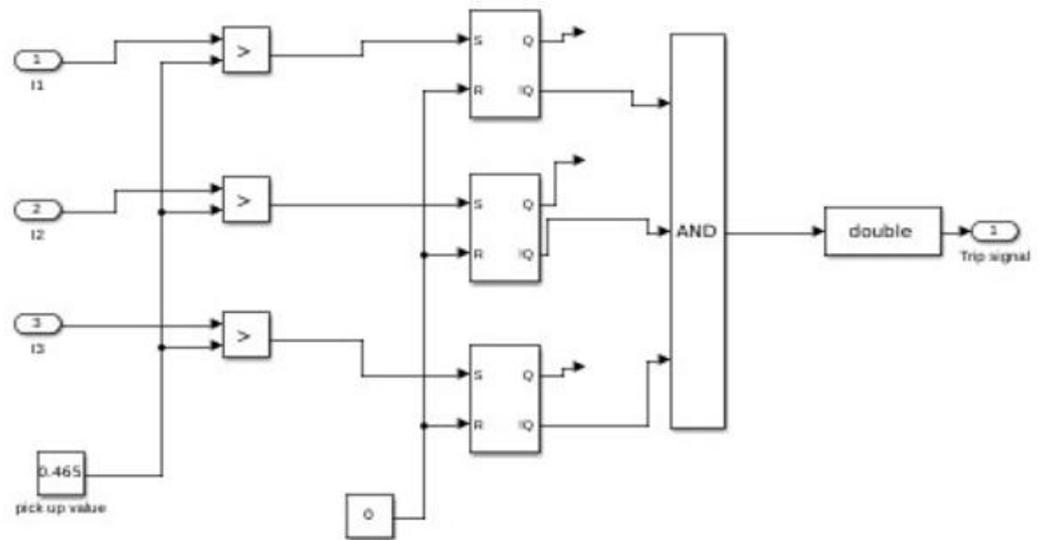
Testing scenarios encompass normal conditions, short-circuit disturbances, and evaluation of the MCB response time concerning the length of the feeder. The normal condition of the system will first be evaluated, which represents a state without disturbances or significant changes in operational parameters [20]. The simulation scenario for disturbances during a short circuit aims to evaluate the system's response and performance in emergency situations. This simulation includes the addition of short-circuit disturbances and the protective measures that have been implemented according to the data [10].

3. Results and Discussion

One of the feeders' substation in Lhokseumawe City, LW3, was recorded on 9 March 2022, that there was an outage of 4,024 kWh at 19:52 WIB with a fault current of 407 kA, which is 160.95% of the peak load and indicated by the instant OCR relay. Meanwhile, on 5 November 2022, it was recorded that it was not plugged for 100 minutes from 14:42 to 14:50 WIB, with a fault current of 5.4 kA, which is equivalent to 1.25% of the peak load and indicated by the Instant OCR relay.

Simulation of the Overcurrent Relay (OCR) protection system was carried out using MATLAB Simulink version 2018a, with parameter settings based on the calculated equivalent impedance at five fault locations along the feeder, namely at 5%, 25%, 50%, 75%, and 100% of the feeder length. The simulation was performed under two conditions: normal operation and short-circuit fault. Calculation of the short-circuit current is either 3 phases, 2 phases, or 1 phase to the ground. The result of impedance and impedance equator LW3 was presented in Table 1, and the result of short-circuiting calculation LW3 was presented in Table 2.

Table 1. Impedance and impedance equator of LW3.

Channel Length		Impedance		Impedance Equator	
km	%	$Z+$ (Ω)	$Z-$ (Ω)	$Z_{eq}+$ (Ω)	$Z_{eq}-$ (Ω)
0.55475	5%	0.22533 + 0.09114j	0.6759 + 0.22780j	0.22533 + 0.21460j	0.6759 + 1.42863j
2.77375	20%	1.12665 + 0.45570j	3.3799 + 1.13925j	1.26650 + 0.57918j	3.3799 + 2.34004j
5.54750	50%	2.25331 + 0.91140j	6.7599 + 2.27850j	2.25331 + 1.03488j	6.7599 + 3.47930j
8.32125	75%	3.37997 + 1.36710j	10.1399 + 3.41700j	3.37997 + 1.49059j	10.3990 + 4.61855j
11.09500	100%	4.50660 + 1.82280j	13.5199 + 4.55700j	4.50663 + 1.94629j	13.5199 + 5.75780j

Table 2. Short-circuiting calculation results for LW3.

Channel Length		Short Circuit Current (A)			Fault Resistance	TMS (s)
km	%	1-Phase	2-Phase	3-Phase	(Ω)	
0.55475	5%	2,391.450	2,782.970	5,565.940	0.0036	0.107
2.77375	20%	783.591	683.625	1,367.250	0.0146	0.045
5.54750	50%	413.739	349.259	698.519	0.0286	0.016
8.32125	75%	280.418	234.437	468.874	0.0427	0.001
11.09500	100%	211.978	176.417	352.835	0.0567	0.013

A series of OCR relay response tests modeled on MATLAB Simulink, then parameters are input on each component to evaluate the response and performance of the system in the face of short-circuit disturbances, is presented in Figures 2 and 3.

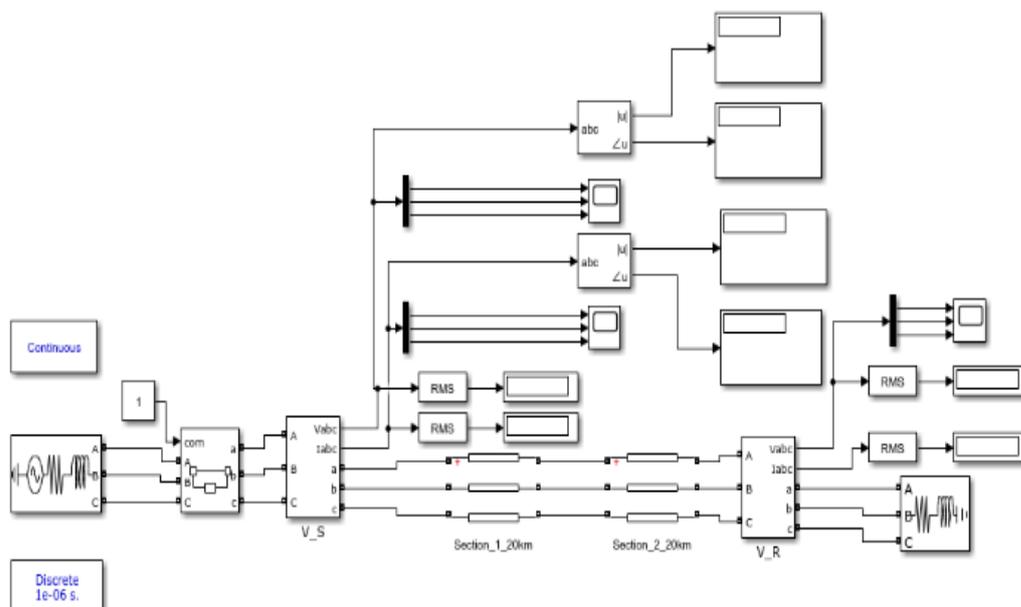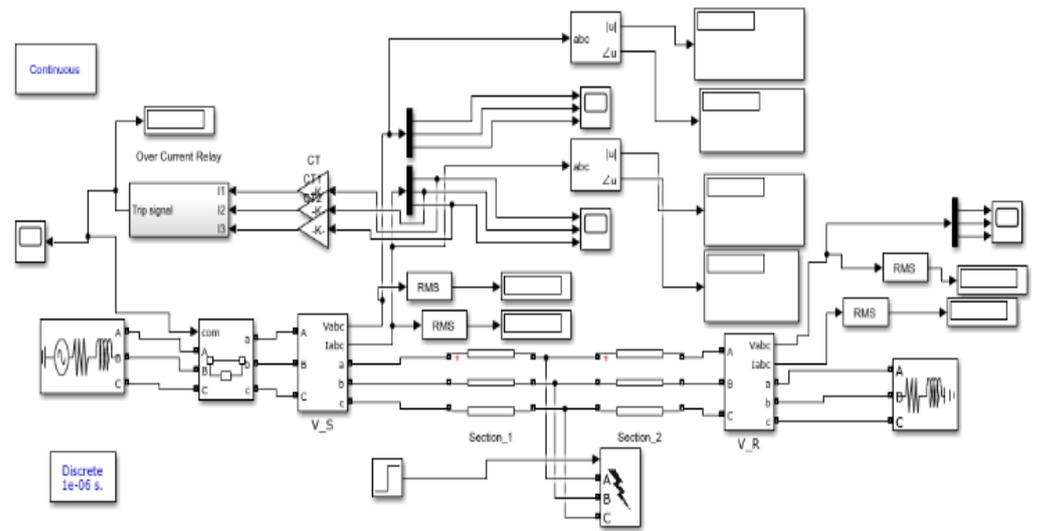**Figure 2.** Simulated relay OCR in normal conditions.

Figure 3. Simulated relay OCR with short-circuited relay conditions.

The output of the OCR relay response wave displayed by the MATLAB scope under normal conditions and short circuit interference conditions is presented in Figure 4.

Figure 4. Output of OCR relay response wave in MATLAB: **(a)** in normal condition, **(b)** in short-circuited condition.


(a)

(b)

The OCR response was simulated using MATLAB 2018a, with the circuit breaker initially in the closed position for a duration of 0.2 seconds. Under normal operating conditions, the current waveform remains steady and does not exceed the predefined threshold. This means that the relay does not issue a trip signal. However, in the short-circuit simulation, a sudden surge in current occurs at 0.1 seconds. This triggers the relay to interrupt the current flow, as shown in Figure 3. The relay continuously measures the actual current and responds according to its inverse time-current characteristics. As expected, higher fault currents cause the relay to operate more quickly. A lower Time Multiplier Setting (TMS) also results in a faster relay response, while a higher TMS value delays the trip time. These characteristics are illustrated in the inverse time-current curve presented in Figure 5.

Figure 5. Inverse time curve of OCR.
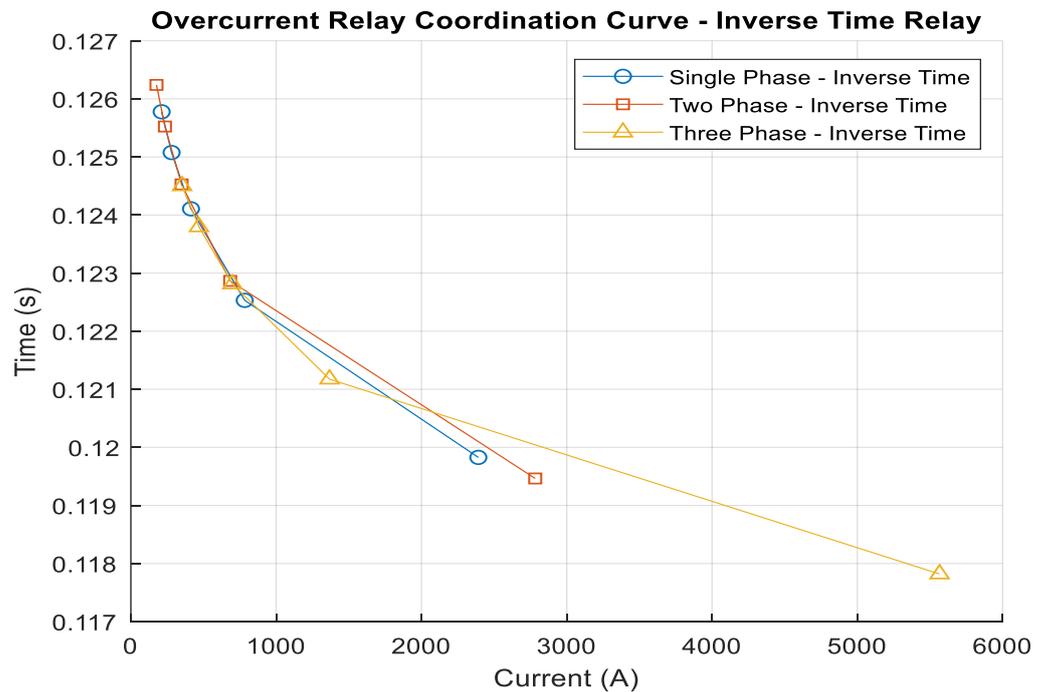
Further analysis of the curve confirms that the relay operates faster as the fault current increases. The type of fault also significantly affects the response time: single-phase faults result in the longest trip times, followed by two-phase faults, while three-phase faults produce the shortest trip times. This behavior demonstrates the relay's highest sensitivity to more severe fault conditions. Overall, the simulation verifies that the relay functions effectively in accordance with standard inverse-time protection characteristics.

4. Conclusions

The short-circuit current on the LW3 main feeder of the Lhokseumawe distribution network decreases progressively with distance along the 11.95 km line. Simulation results indicate that the fault current is 5565.92 A at 5% of the feeder length, 1367.25 A at 25%, 698.52 A at 50%, 468.87 A at 75%, and 352.83 A at 100%. The highest short-circuit current among the three fault types is used as the reference for setting the Overcurrent Relay (OCR). The OCR demonstrates a response time of approximately 0.1 seconds to fault current surges, with faster operation observed at locations closer to the substation due to higher current levels. As the feeder length increases, the impedance also increases,

resulting in a corresponding decrease in fault current. The relay system responds promptly and accurately according to its inverse-time characteristic curve, confirming its effectiveness and reliability in detecting and isolating faults in a 20 kV distribution network. This study is limited to simulations on the Lhokseumawe Main Substation using MATLAB. Future research is recommended to broaden the scope by including additional feeders or substations and utilizing other software tools to enhance efficiency and modeling capabilities.

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Conflicts of Interest: The authors declare no conflicts of interest.

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