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Derleme Makalesi / Review Article

Developing Directional Overcurrent Relay Without Voltage Input

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Abstract

With the rapidly increasing population and industrialization, the demand for electrical energy is constantly rising. This situation makes it inevitable to adopt new and innovative approaches in the production and distribution of electrical energy. In order to reduce dependence on traditional fossil fuel sources and minimize environmental impacts, there is a growing demand for renewable energy sources. In this context, electricity generated from renewable energy sources such as wind, solar, and hydroelectric power is becoming increasingly important. However, the use of these renewable energy sources poses some challenges in electricity transmission and distribution systems. Particularly, the uncontrolled power flow in power distribution, in addition to traditional energy transmission networks, can hinder the efficient and safe operation of integrated renewable energy sources in electrical systems. At this point, Directional Overcurrent Relays offer an effective solution to enhance safety and efficiency in electrical systems. Directional overcurrent relays detect the direction of overcurrent in electrical systems, ensuring maximum power transfer even in fault conditions, and play a significant role in the integration of renewable energy sources into the system, thereby enhancing its stability and reliability. In this study, a prototype of a Voltage Transformerless Directional Overcurrent Relay, which brings a new perspective to Directional Overcurrent Relays, has been developed, tested in fault conditions, and the results have been shared. Additionally, recommendations will beprovided for the wider implementation of Voltage Transformerless Directional Overcurrent Relays in existing electrical transmission and distribution systems.

Keywords: Renewable energy, electrical power system faults, directional overcurrent relay

1. Introduction

Energy sector dynamics are evolving rapidly, propelled by the widespread adoption of renewable energy sources. This transition introduces a new paradigm in energy management, characterized by decentralized generation and fluctuating supply patterns. Solar panels dot rooftops, wind turbines adorn landscapes, and hydroelectric dams harness the power of flowing water, all contributing to a diverse and distributed energy landscape.

However, this decentralization also poses challenges. Unlike centralized power plants, renewable energy sources are often intermittent and geographically dispersed. This decentralized nature increases the complexity of energy distribution, making the grid more susceptible to disruptions such as short circuits and overloads.

In response to these challenges, innovative solutions are imperative. Directional overcurrent protection systems play a pivotal role in safeguarding the grid against faults by swiftly detecting and isolating abnormal conditions. These systems not only enhance grid reliability but also enable the seamless integration of renewable energy resources, facilitating the transition towards a sustainable energy future.

Directional overcurrent relays consist of a typical overcurrent unit along with an additional component that determines the power flow direction in the connected distribution system element. This additional component generally needs a reference signal, apart from the relay current, to measure the fault angle and decide whether the relay should be triggered. Typically, this reference or polarization signal is a voltage, though it can also be provided as a current input. (Gers et al., 2004).

2. Essential features of over-current relays

Overcurrent relays constitute a fundamental part of safety and protection measures in power systems. The specific features that overcurrent relays need to possess are critical to ensuring the reliability of power systems and minimizing faults.

Firstly, sensitivity is crucial. Overcurrent relays must swiftly and accurately detect any abnormal conditions within the network. This allows for immediate response to overloads, short circuits, or other fault conditions, preventing significant damage to the system.

Secondly, selectivity is important. Relays should isolate only the affected area by accurately identifying fault conditions. This helps maintain normal operation in other parts of the network, minimizing disruptions.

Thirdly, flexibility and programmability are required. Considering the complexity and dynamics of power systems, overcurrent relays need to adapt to various scenarios and be adjustable when necessary. This ensures appropriate responses are provided in cases of changing system requirements or updates.

Lastly, communication capabilities are essential. Overcurrent relays should be able to communicate with other protection equipment and control systems. This facilitates easy integration within a comprehensive energy management system, enabling monitoring and management of overall system performance (Elmore, 2003).

All these features enable overcurrent relays to function effectively in terms of reliability, efficiency, and flexibility, thereby optimizing the safety and performance of power systems.

3. Transition to the Digital Relays

The transition from electromechanical to digital protective relays in power system protection is a pivotal advancement reflecting a shift towards more sophisticated technology and operational capabilities. Unlike their electromechanical counterparts, digital protective relays harness digital processing capabilities to provide a myriad of advanced functions and features, including precise fault detection algorithms, accurate fault classification, and extensive data logging capabilities

(Horowitz et al., 2013). One of the key strengths of digital relays lies in their remarkable flexibility and adaptability, allowing for easy configuration to meet evolving system requirements and operational needs. This adaptability makes them particularly well-suited for modern power systems characterized by dynamic operating conditions and evolving network architectures. Moreover, digital protective relays boast improved reliability and robustness owing to their solid-state components and reduced reliance on mechanical parts, resulting in enhanced longevity and reduced maintenance requirements. Furthermore, their seamless integration with smart grid technologies facilitates real-time data exchange and interoperability with advanced monitoring, control, and automation systems, enabling utilities to optimize grid operations, enhance resilience, and support the integration of renewable energy resources. Overall, the transition to digital protective relays signifies a significant leap forward in power system protection, offering unparalleled functionality, flexibility, reliability, and integration capabilities compared to traditional electromechanical relays.

All newly developed next-generation protective relays in recent years are microprocessor-based electronic devices. These devices are also referred to as Intelligent Electronic Devices (IEDs). Analog signals obtained from current and voltage transformers are passed through a filter that protects against high voltages and currents, and then through an antialiasing filter. This filter removes high-frequency components and noise signals from the analog signals, resulting in a smoother waveform.

After being cleansed of high-frequency components by the antialiasing filter, the analog signals proceed to the analog-to-digital converter. Depending on the manufacturer and technology, the number of samples taken varies, but typically, between 4 and 64 samples are taken per cycle to convert the analog signal into a digital one. These samples are converted into a digital signal by the analog-to-digital converter. Following this conversion, a digital filtering process is applied to separate harmonics and the DC component from the digital signal. After digital filtering, the relay calculates the phase values of the digital signal. Depending on the structure of the relay, the calculated values (such as impedance value for distance protection relays, effective value of current for overcurrent protection, and application time, etc.) are evaluated according to the relay characteristic. If a fault is detected that requires the protective relay to send a trip command to the circuit breaker according to its characteristic, a trip signal is generated to be applied to the trip coil of the circuit breaker by the numerical relay (Sachdev et al., 2004).

4. Directional over current relays

Directional relays are indispensable components of modern power systems, providing essential protection against faults and disturbances. Their primary function is to detect the direction of current flow and activate protective measures when abnormal conditions are detected. By selectively isolating faulted sections of the network, directional relays prevent cascading failures and minimize downtime, ensuring the reliability and stability of the power grid.

These relays operate based on the principle of current direction detection, responding to current flow in a specific direction and remaining inactive when current flows in the opposite direction. This directional sensitivity is achieved through specialized sensing elements such as current transformers and directional elements, which provide information about the direction of current flow relative to the relay's location. When a fault occurs and current flows in the predetermined direction, the directional relay activates protective tripping mechanisms to isolate the faulted section and restore system integrity.

There are several types of directional relays commonly used in power systems, including impedance relays, directional overcurrent relays, and directional power relays. Each type has its unique characteristics and applications, ranging from protecting transmission lines against faults to coordinating protection in distribution networks.

Directional relays offer several advantages, including selective fault detection, rapid response times, and improved system reliability. By accurately identifying fault locations and isolating affected sections, directional relays minimize disruption to the power supply and prevent widespread outages. However, the proper coordination and setting of directional relays can be challenging, especially in complex network configurations with multiple interconnected components. Additionally, false tripping due to external factors such as load fluctuations or system transients can pose operational challenges and require careful calibration and testing.

As power systems continue to evolve with advancements in technology and infrastructure, the role of directional relays in ensuring grid resilience and stability will become increasingly critical. The integration of smart grid technologies, such as synchrophasor measurements and digital communication systems, will further enhance the performance and capabilities of directional relays. By leveraging real-time data and advanced analytics, directional relays can provide predictive fault detection and adaptive protection strategies, enabling more efficient operation and maintenance of power systems in the future (Horak, 2006).

5. How relay can sense the direction of the current flow?

In situations where fault currents can travel bidirectionally through the relay's position, it becomes crucial to ensure the relay's response is directional. This is accomplished by implementing a directional control mechanism, which employs supplementary voltage inputs to the relay. Fault current can flow in both directions at the relay location, making it necessary to implement a directional control feature to ensure the relay responds appropriately. This feature is achieved by introducing additional voltage inputs to the relay. The traditional directional element operates based on the phase difference between voltage and current phasors at the measurement site. During a fault, the voltage phasor remains relatively stable and is thus referred to as the polarizing quantity, while the current phasor is known as the operating quantity. As shown in Figure 1, because power lines are nearly purely inductive, the current lags the voltage by the fault loop impedance, approximately 90^0, for forward faults. Conversely, for reverse faults, the current leads the voltage by 180^0 minus the fault loop impedance, which is also roughly 90^0. Therefore, the sign of the torque product of voltage and current indicates the current flow direction: a positive sign for forward faults and a negative sign for reverse faults. (Alpaslan, 2019).

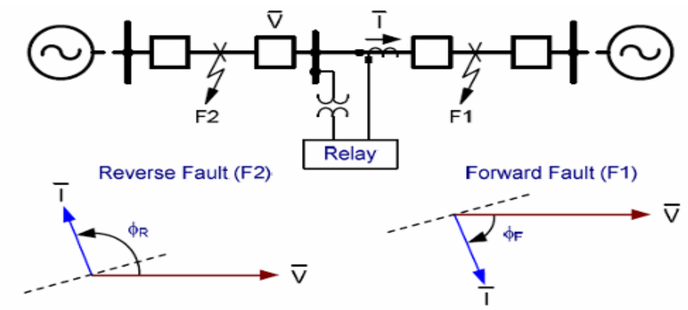

Figure 1. Phase differences in fault conditions

6. Can fault current direction be determined with current alone?

Detecting the direction of a fault by looking only at the current can be challenging in some situations. However, studies have shown that it is indeed possible. The transmission system, as shown in Figure 2, can be simplified into a single-line diagram

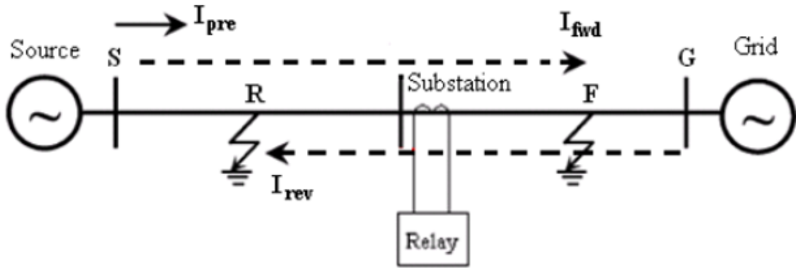

Figure 2. Directional Relay on System

If we divide the system's current into two parts, one before the fault and one after the fault, the pre-fault current (Ipre) can be determined using Equation 1.

$$I_{pre} = \frac{V_S - V_G}{Z} \quad (1)$$

If a fault occurs at point R in front of the relay, the current flowing through the relay can be determined using Equation 2.

$$I_{rev} = \frac{V_G}{Z_{GR}} \quad (2)$$

If a fault occurs at point F, the current flowing through the relay can be determined using Equation 3.

$$I_{fwd} = \frac{V_S}{Z_{SF}} \quad (3)$$

From Equations 2 and 3, the total fault currents in each case can be obtained using Equations 4 and 5.

$$I_F = I_{pre} + I_{fwd} = I_{pre} + \frac{V_S}{Z_{SF}} \quad (4)$$

$$I_R = I_{pre} - I_{rev} = I_{pre} - \frac{V_G}{Z_{GR}} \quad (5)$$

At this point, if we assume the line is inductive, the corresponding currents can be represented in a phasor diagram as shown in Figure 3.

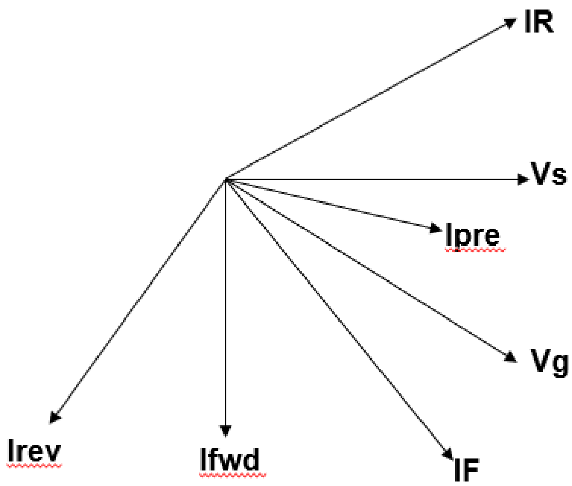

Figure 3. The phasor diagrams for the current-only analysis

If the current before the fault changes in the positive direction, the relay identifies the fault as a reverse fault. If the current changes in the negative direction, the relay understands that the fault is a forward fault. (Ukil, 2016).

7. Proposed current-only directional overcurrent algorithm

The directional overcurrent algorithm we have presented relies on examining the alternation in current between pre-fault and post-fault conditions and makes decisions based on certain operations. It can be seen in Figure 4, this algorithm utilizes a Δi(t) function, where the post-fault current is subtracted from the pre-fault current.

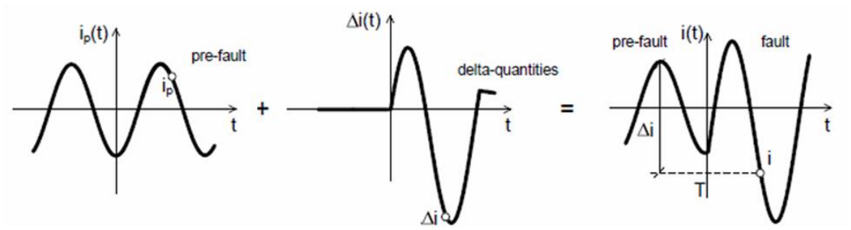

Figure 4. Typical Fault Current

If the fault occurs during a positive alternation and the post-fault current also becomes positive, the delta function will be positive. Since the multiplication of the delta function with the alternation at the time of the fault is positive, indicating a forward fault. Similarly, in the case of a fault occurring during a negative alternation and transitioning to negative alternation post-fault, the multiplication of - with - results in +, again representing a forward fault. On the contrary, if a fault occurs during a positive alternation and the fault increases in the negative direction, the algorithm understands that it is a reverse fault from the multiplication of + with -. These four scenarios are summarized in Table 1 (Alpaslan, 2019)

Table 1. Sign analysis for forward and reverse type faults

Polarity of at Half Cycle at Fault Inception	Initial Polarity of Delta Current	Fault Direction
+	+	Forward
-	-	Forward
+	-	Reverse
-	+	Reverse

8. Simulation of this phenomenon

As previously explained, in traditional overcurrent direction detection, the direction is determined by looking at the average of the product of the fault current and voltage at the moment of the fault. In this context in the Figure 5, a simulation is set up in MATLAB Simulink to model a fault between Phase A and Ground.

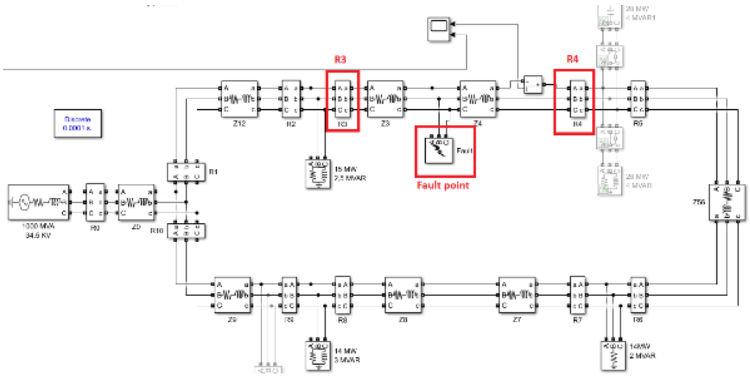

Figure 5. Simulation model of directional protection

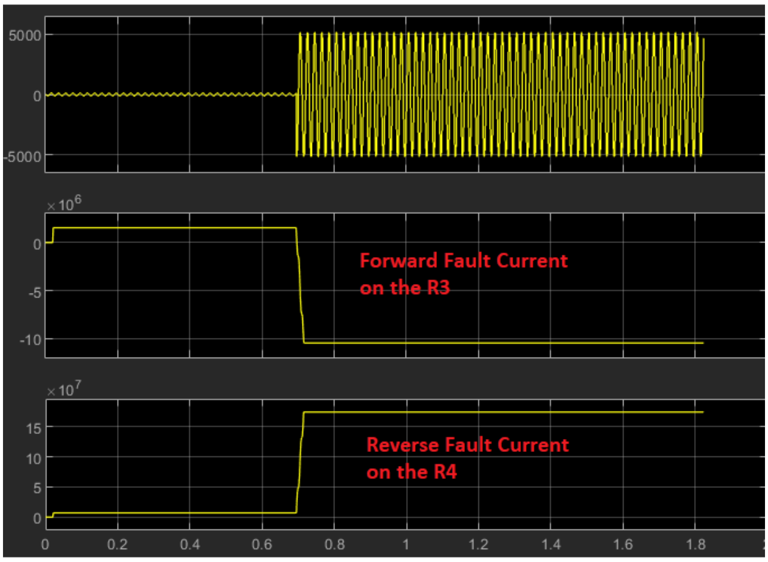

Figure 6. Traditional directional protection algorithm

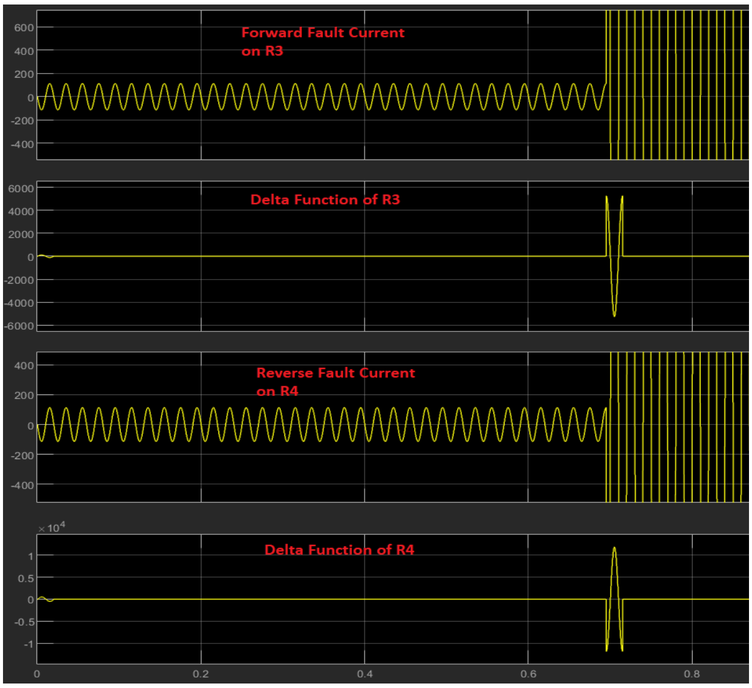

Figure 7. Proposed directional protection algorithm

The fault is detected in both forward and reverse directions using relays R3 and R4. As shown in the Figure 6, at the moment of the fault, R3 detects the fault in the forward direction, causing the average product of current and voltage to decrease in the forward direction. Conversely, R4 detects the fault in the reverse direction, and according to this algorithm, the average product of current and voltage increases. In the current-based algorithm we proposed, the direction of the fault is determined by examining the delta functions derived from the post-fault and pre-fault currents. The results obtained for fault direction determination are as shown in the Figure 7. As seen here, for a forward fault, relay R3 detects that the current is in the positive alternation, so the delta remains positive. The product of the delta and the initial alternation (both positive) results in a positive value, indicating that R3 detects the fault direction as forward. Conversely, relay R4 transitions from positive to negative alternation, and the product of a positive and a negative value indicates a reverse fault direction.

9. Verification of this Phenomenon in Real System

In this study, a test scheme is depicted in Figure 8 was employed. In the test system Figure 9, there are four directional overcurrent relays available, capable of tripping in both directions of power flow. Faults can be induced at Point A such that the current flows in the same direction before and after the fault occurrence. The waveforms recorded by the same directional overcurrent relay in the box are as follows. As can be seen from these Figure 10 and Figure 11.

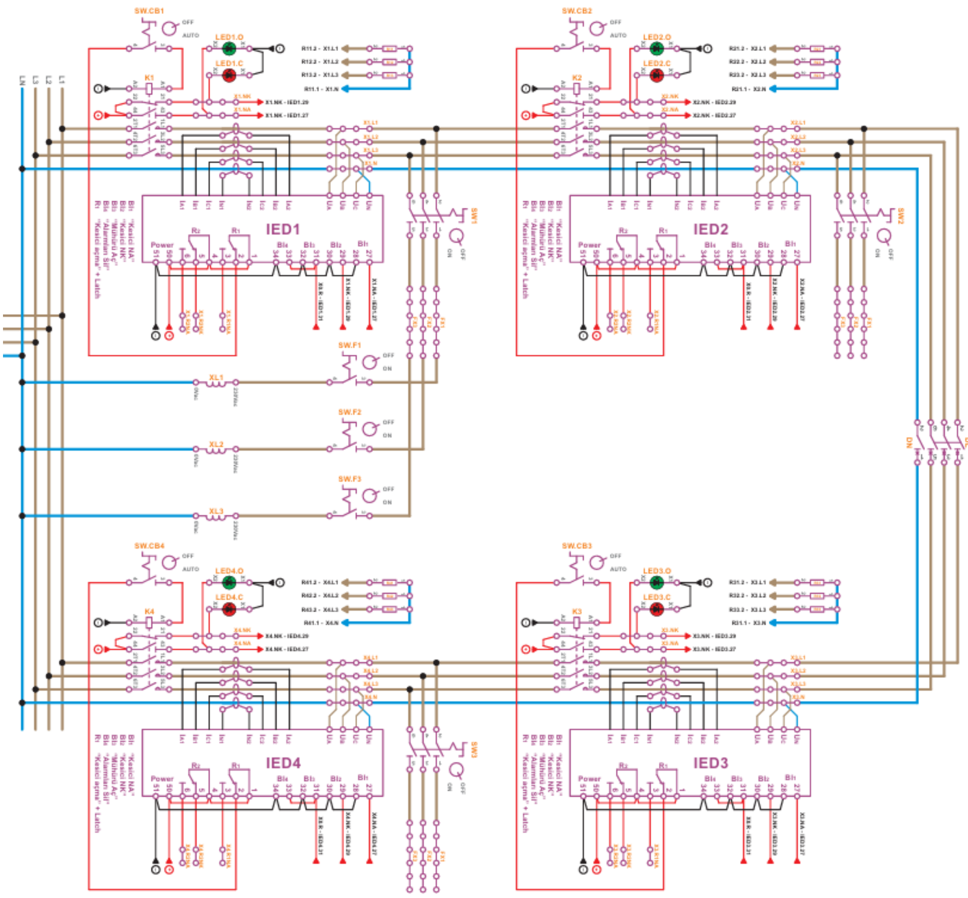

Figure 8. Test scheme of directional protection

Figure 9. Directional relays in test system

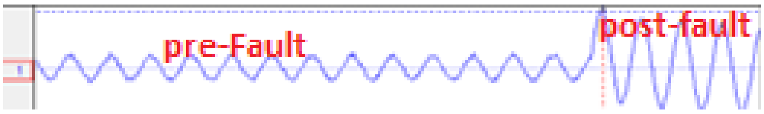

Figure 10. Forward fault in positive alternance

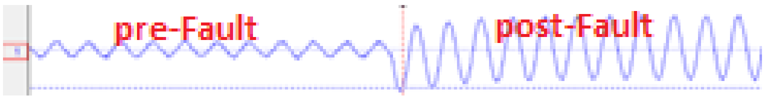

Figure 11. Forward fault in negative alternance

As can be observed from these figures, the fault occurring during the positive alternance, being in the same direction as the current, did not cause any alternation change. Similarly, the fault during the negative alternance, also aligned with the current direction, did not induce any alternation change.

10. Conclusion

As a result of the conducted studies, it has been observed that the real-world tests align with the simulation results. At this point, through the development of advanced algorithms, software revisions can be made to the directional overcurrent relays without altering the switchgear panels. This would enhance system selectivity through directional overcurrent protection, even in rural areas, thereby increasing reliability. Consequently, significant profits can be attained without substantial investment. The software and hardware designs for the relay that will execute the proposed algorithm are currently ongoing.

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