INTERNATIONAL JOURNAL OF RESEARCH IN MECHANICAL, MECHATRONICS AND AUTOMOBILE ENGINEERING (IJRMMAE)
ISSN: 2454-1435 (Print) | 2454-1443 (online)
Volume 6 Issue 1, July – Sep. 2020 - www.ijrmmae.in – Pages 31-41

CHALLENGES AND SOLUTIONS ON CURRENT-ONLY DIRECTIONAL OVERCURRENT PROTECTION FOR DISTRIBUTION AUTOMATION

P.M.Kumarasan[1], R.Udhayakumar[2], Manimegalai[3], Indhumathi[4]
[1,2,3,4]Assistant Professor
Department Of Electrical & Electronics Engineering, A.R Engineering College,Villupuram
E-mail:udayalanayaeee@gmail.com

Abstract—Overcurrent relays are widely utilized for power system protection. While directional relays are prevalent on the transmission side, distribution systems often employ nondirectional types. These relays discern fault direction, which can be forward (between relay and grid) or reverse (between relay and source), considering the typical power flow from source to grid. Traditional directional overcurrent relays necessitate both current and voltage measurements, making them more costly than nondirectional ones. This paper introduces a novel current-only directional detection method, addressing its theoretical underpinnings, test signal analysis, challenges, and solutions. Additionally, potential applications of current-only directional relays in distribution-side protection, crucial for smart grid implementation, are outlined.

Index Terms—Distance protection, fault direction, fault isolation, fault location, medium voltage, MV, phase angle, radial network, relay, ring-main unit, smart grid, subtransmission, voltage-less direction.

I. INTRODUCTION

Numerical feeder protection relays commonly employ nondirectional time overcurrent techniques, where overcurrent monitoring occurs over a set time to trigger protection mechanisms [1], [2]. This monitoring, typically lasting 40–100 ms, distinguishes between faults and load changes and is governed by standards like IEC 60255 [3], specifying various overcurrent magnitude and duration thresholds for nondirectional relays. Time relaying introduces delays to allow closer relays and breakers to clear remote faults effectively, necessitating complex coordination settings for distance protection [2]. On the other hand, directional overcurrent relays [4] utilize a reference voltage phasor, also known as "voltage polarization," to discern fault direction.

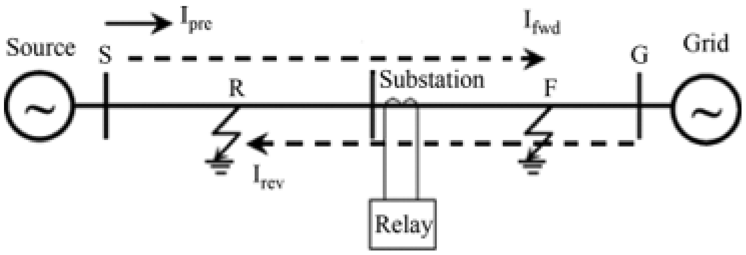


Fig. 1. Overcurrent relay: Forward (F) and reverse (R) fault.

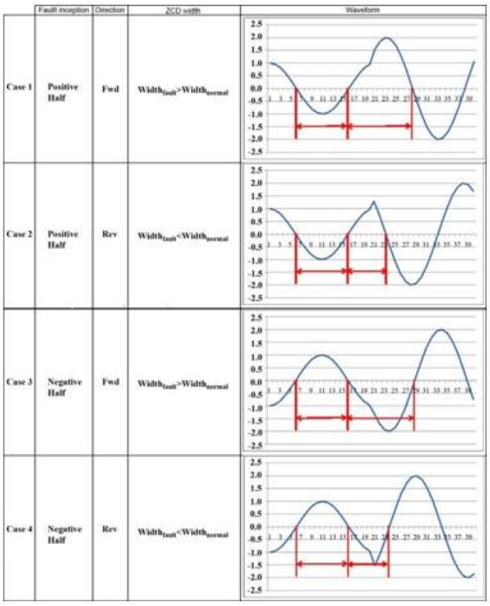
II. CURRENT-ONLY DIRECTIONAL DETECTION

A. Principle

The current-only detection principle, initially proposed by Ukil et al. [7], is briefly summarized here. As depicted in Fig. 1, a power line connects an upstream power source (S) to a downstream power distribution system (grid, G), with the normal power flow direction from the upstream source to the downstream grid. A forward fault (F) occurs between the relay and the line, while a backward or reverse fault (R) occurs between the source and the relay. Due to Kirchoff's current law, the fault current in the reverse case () is directed in the opposite direction to the prefault current () compared to the forward fault current (). This results in a phase angle difference in the post-fault current [7]. Phasor diagrams illustrating this phenomenon can be referenced in [7]-[8].

B. Previous Works

Eissa [9] explored current-only directional detection, focusing on the difference in fault current directions. However, the approach in [9] relied on a time-domain method, which may be susceptible to influences from inherent noise, harmonics, and frequency deviations. Consequently, achieving a robust implementation for power systems protection could be challenging. Pradhan et al. [10] proposed a phase angle-based detection method, which represents a more promising approach. However, their implementation involved using symmetrical components for three-phase operation and Kalman filtering for phase angle computation. It will be demonstrated later that symmetrical components pose challenges when dealing with real-life current signals characterized by inherent unbalances and frequency deviations. Additionally, Kalman filters may not be optimal for addressing issues related to harmonics, computational speed, and complexity. Pradhan and Jena [11] also investigated the utilization of current-only directional protection algorithms to enhance the detection of "close-in" faults, where the fault is in close proximity to the relay.



	Fault inception	Direction	ZCD width	Waveform
Case 1	Positive Half	Fwd	$Width_{fault} > Width_{normal}$	
Case 2	Positive Half	Rev	$Width_{fault} < Width_{normal}$	
Case 3	Negative Half	Fwd	$Width_{fault} > Width_{normal}$	
Case 4	Negative Half	Rev	$Width_{fault} < Width_{normal}$	

III. FREQUENCY DOMAIN ALGORITHM

A. Detection Method

The directional device receives input solely from current sensors such as current transformers (CTs) or Rogowski coils. Our proposed approach involves utilizing the discrete Fourier transform (DFT) to compute phase angles. Under normal operating conditions, minimal changes occur in the current phase angle, while fault occurrences induce significant variations. By continuously estimating the current phase angle using DFT at each cycle, denoted as , and calculating the difference , one can detect fault occurrences. Forward or reverse faults exhibit substantial angle changes, with negative and positive polarities, respectively. DFT is particularly advantageous for handling total harmonic distortions (THD) [6]. Non-DFT-based methods, such as those employing Kalman filters [10] or recursive least squares [6], may be too slow for online protection, typically operating within the 20–100 ms range [2]. Additionally, black-box approaches like neural networks (NN) [13] as decision logic may not be preferred over deterministic methods like DFT. Ensemble decision-making is also feasible [7].

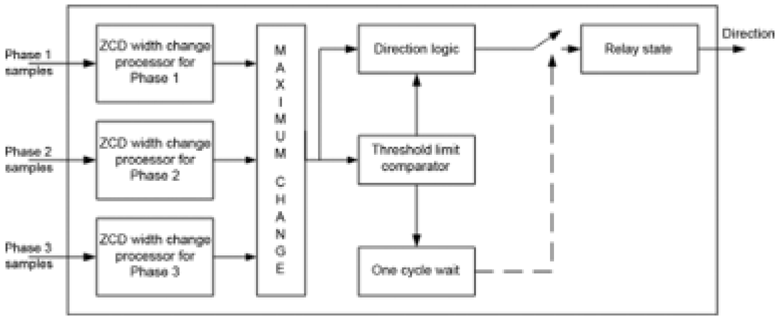


Fig. 3. Signal processing view of ZCD-based time-domain approach.

B. Fault Signal Analysis

Utilizing the DFT-based algorithm, the analysis of forward and reverse faults is detailed in [8], employing signals from fault recorders with a sampling frequency of 2.5 kHz in a 50 Hz system, resulting in 50 samples per cycle, with a sampling angle of .

IV. TIME DOMAIN ALGORITHM

A. Zero-Crossing Detection Method

Zero-crossing time (ZCT) in the time domain could also serve as a basis for current-only directional detection [14]. The principle entails that during normal operation, the ZCT width remains constant, determined by the nominal frequency. For instance, in a 50 Hz supply frequency system, the ZCT width for half a cycle would be 10 ms. As depicted in Fig. 2, a forward fault results in increased ZCT width, whereas a reverse fault typically leads to decreased width. The width between two ZCTs is determined by counting the number of samples with the same polarity lying between them. The zero-crossing detection (ZCD)-based algorithm is depicted in Fig. 3.

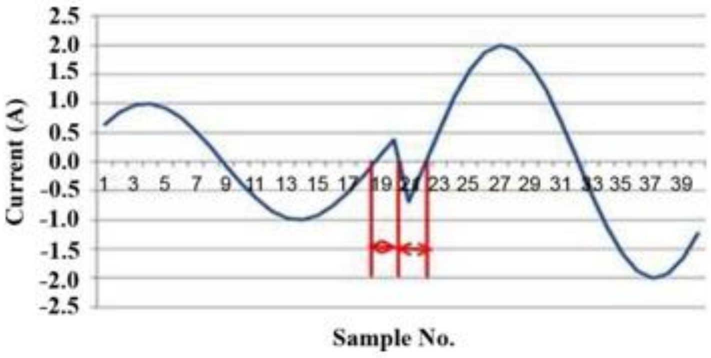


Fig. 4. Example of limitation of ZCD-based method.

B. Issues With ZCD-based Method

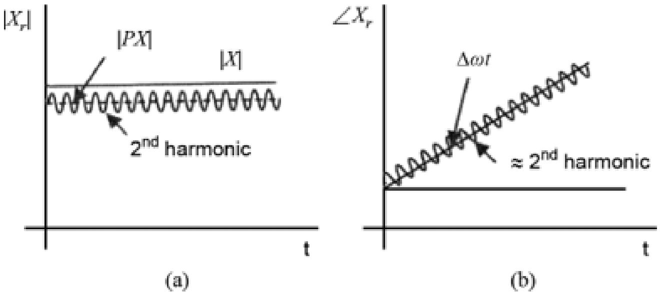
While the ZCD-based time-domain method may be straightforward to implement, it has several critical limitations [14], some of which are highlighted below, also applicable to other time-domain methods like the one reported in [9]: • The signal length between two consecutive zero crossovers heavily depends on the fault inception angle. Therefore, if a fault occurs close to zero crossovers, two consecutive crossovers with small widths may lead to erroneous directional decisions. Corrections to the logic may be necessary to handle such instances, although these are not elaborated further, as the preferred choice is the DFT-based method [8]. • The processing relies on digital samples of the input signal, making it susceptible to false decisions in the presence of harmonics or disturbances. • No digital filtering techniques are employed, leaving the ZCT width vulnerable to the influence of constant DC components.

V. TECHNICAL CHALLENGES

The current-only directional algorithm(s) face several challenges, as described in this section.

A. Three-Phase Operation

In real-world applications, it's essential to incorporate current-only algorithms for three-phase operations. Pradhan et al. [10] proposed using the positive phase sequence (PPS) component through symmetrical component analysis. However, the angle of the PPS is highly sensitive to frequency deviations, inherent phase current imbalances, and noise [6]. Theoretical analysis [6] demonstrates that frequency imbalances (e.g., in the range of) introduce slope and ripple in the PPS phase angle, as illustrated in Fig. 5[6]. Furthermore, inherent imbalances among the three phases are typical in real-world power systems operations. Analysis [6] reveals that these imbalances introduce additional components onto the main phase components, resulting in angle slope (as seen in plot (b) of Fig. 5). As discussed earlier, applying the current-only concept requires the prefault current phase angle to remain almost constant. However, the presence of harmonics and imbalances may already introduce a slope in the prefault angle. This slope can cause the phase angle difference between two cycles to assume a finite value, erroneously indicating a fault. Consequently, the PPS component of the prefault current cannot reliably serve as a stable and robust polarizing quantity.



(a) (b)

Fig. 5. Influence of frequency deviation on the (a) Magnitude and (b) Anglevariation with time of phasor estimate.

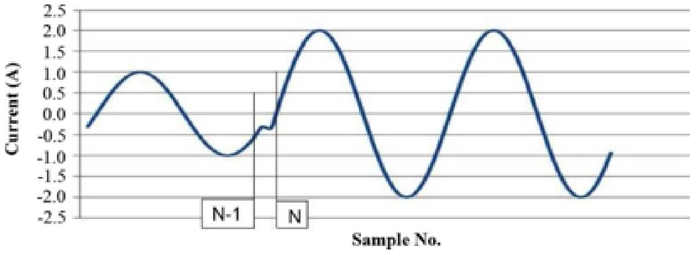


Fig. 6. Sampling frequency limitation.

If the measured phase shift falls below this threshold, it is considered unreliable due to sampling limitations. This solution ensures that only significant phase shifts are considered for fault detection, mitigating the impact of sampling frequency limitations.

C. Frequency Deviation

To address frequency deviations, the DFT-based algorithm should be designed to accommodate variations in system frequency. This can be achieved by incorporating adaptive techniques that adjust the algorithm parameters based on real-time frequency measurements. By dynamically adapting to frequency deviations, the algorithm can maintain its accuracy and reliability under varying operating conditions.

D. Harmonics

Harmonics in the current signal pose a challenge to accurate phase angle estimation. Employing digital filtering techniques tailored to mitigate harmonic effects can enhance the robustness of the algorithm. Adaptive filtering algorithms capable of dynamically adjusting filter parameters based on the harmonic content of the signal can effectively suppress harmonic interference, ensuring accurate fault detection even in the presence of harmonics.

E. Noise

Inherent measurement noise in the current signal requires appropriate noise filtering techniques to ensure reliable operation of the directional detection algorithm. Implementing advanced noise filtering algorithms, such as adaptive noise cancellation or Kalman filtering, can effectively attenuate measurement noise while preserving the integrity of fault signals, thereby improving the robustness of the algorithm.

F. Grounding Systems

Different grounding systems in medium voltage networks influence fault characteristics and must be accounted for in the directional detection algorithm. The algorithm should be designed to adapt to various grounding configurations, incorporating models that accurately represent the impedance characteristics of different grounding systems. By considering the specific characteristics of each grounding system, the algorithm can accurately differentiate fault conditions and improve fault detection performance.

G. Coordination with Fault Inception Detection

Coordination between the current-only directional detection module and fault inception detection modules is essential to ensure effective fault detection and discrimination. Integration of fault inception detection logic into the directional detection algorithm enables seamless coordination between the two modules, facilitating comprehensive fault detection and localization capabilities.

H. Valid Prefault Current

Ensuring the availability of valid prefault current data is crucial for accurate fault detection. Implementing robust prefault current monitoring mechanisms that continuously monitor the integrity of prefault current measurements can ensure that valid prefault data is consistently available for fault detection purposes.

I. Prefault Direction Change

Handling prefault direction changes requires the algorithm to dynamically adapt to changes in prefault current direction. By continuously monitoring prefault current direction and updating directional detection parameters accordingly, the algorithm can effectively accommodate prefault direction changes and maintain accurate fault detection capabilities.

J. Computation Time

Optimizing computation time is essential to ensure real-time operation of the directional detection algorithm. Implementing efficient algorithmic optimizations and leveraging parallel processing techniques can significantly reduce computation time, enabling timely execution of the algorithm within the required time constraints. Additionally, utilizing hardware accelerators and specialized processing units can further enhance computational efficiency and facilitate real-time operation of the algorithm.

As seen in Fig. 9, for a forward fault, the angle difference increases significantly, indicating a clear fault direction determination. Conversely, in Fig. 10, for a reverse fault, the angle difference decreases, again allowing for a distinct fault direction determination. These trends demonstrate the effectiveness of the proposed algorithm in reliably detecting fault directions even for small phase angle differences.

Overall, the alternative solution presented in Fig. 8 offers a cost-effective approach to fault direction determination without the need for higher sampling frequencies. By utilizing post-fault and prefault current values and applying decision logic based on accumulated phase differences, the algorithm provides reliable fault direction determination while minimizing the risk of generating unreliable signals in cases of small phase angle differences. This ensures robust protection of power distribution systems while optimizing resource utilization and cost-effectiveness.

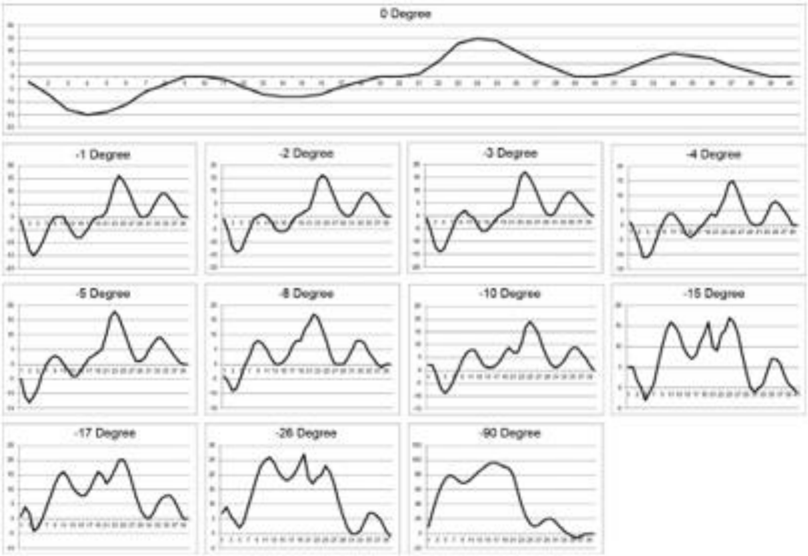


Fig. 9. Angle difference trend for forward fault case.

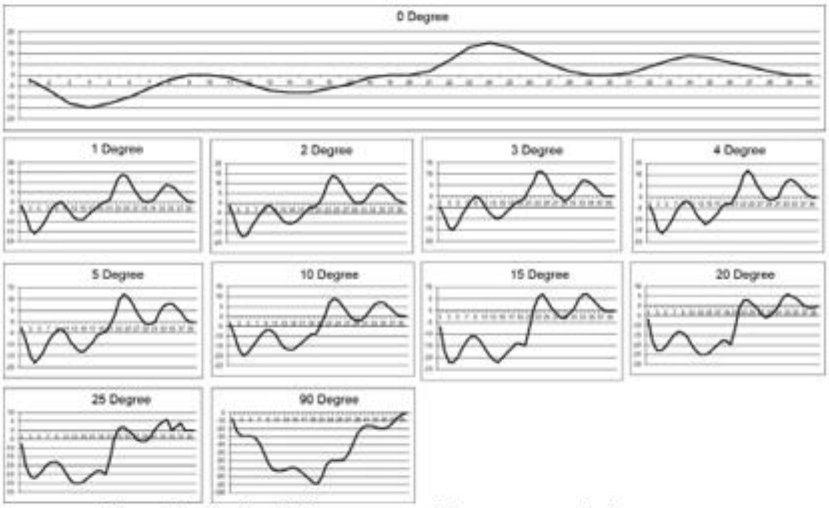


Fig. 10. Angle difference trend for reverse fault case.

These considerations arise from various experiments conducted under different conditions, such as varying time-overcurrent values [3] and fault phase angles for different fault types, all incorporating the embedded implementation of the DFT-based algorithm. It's important to note that positive and negative phase angle changes occur during reverse and forward faults, respectively. In Figs. 9 and 10, the Y-axis represents the angle difference value for each sampling instant (with respect to 2-cycles back) starting from the fault inception point. We monitor for 2 cycles at a rate of 20 samples/cycle (for a 50 Hz system, with a sampling frequency of 1 kHz), hence the X-axis shows 40 sample values. The total sum of all points indicates whether the trend is positive or negative for forward (Fig. 9) or reverse (Fig. 10) cases, respectively. This approach allows us to detect angle change sensitivity from about 0.5∘0.5∘, above which the curves in Figs. 9 and 10 exhibit distinct trends, while below that, there is confusability due to equal oscillations of the trend curve about the X-axis [16].

With this approach, we can achieve an angle change sensitivity of 0.5∘0.5∘ with a 1 kHz sampling frequency, theoretically requiring only 2020 samples per cycle. In other words, without this post-fault period monitoring approach [16], one would require, for instance, a sampling frequency of 3.6 kHz to achieve the same angle change sensitivity.

C. Frequency Deviation: Any frequency deviation is critical for the DFT because assuming a nominal frequency incorrectly affects phase angle computation accuracy. Relays [15] are typically certified for operations with a tolerance of ±0.2%±0.2%. Frequency tracking methods [18]–[21] can estimate the actual line frequency, and the sampling frequency can be adjusted accordingly to maintain a constant samples/cycle ratio, thereby compensating for frequency deviations.

D. Harmonics: DFT-based computation effectively addresses the harmonics problem by isolating the fundamental frequency and disregarding higher harmonics.

E. Noise: Noise mitigation involves employing low-noise, high-accuracy sensors, EMI-free electronics design, and appropriate filters for offset, noise, or jitter corrections.

F. Grounding Systems: In the proposed algorithm (see Fig. 8), which operates on a maximum phase angle basis for three-phase operation, the influence of different grounding schemes on directional detection sensitivity is minimized, as the maximum operation is utilized instead of summation. Thus, variations in grounding schemes would not explicitly impact angle change sensitivity for directional detection.

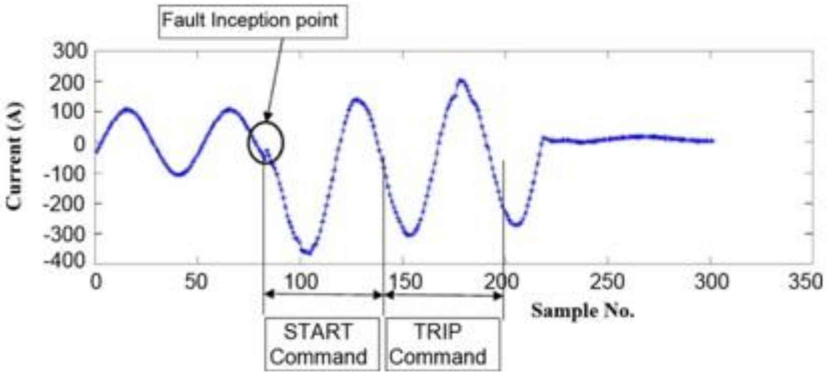


Fig. 11. Typical fault signal with fault inception point.

VI. Solutions to Technical Challenges

G. Coordination With Fault Inception Detection: In a typical overcurrent fault scenario, fault inception occurs around a certain sample, as illustrated in Fig. 11. The fault identification module, employing DMT or IDMT type protection, monitors overcurrent for a specific duration, typically one cycle as shown in Fig. 11. Depending on the chosen stages (lowset, highset, very highset) [3], the fault inception module triggers a trip in case of a persistent fault or does not trip for cleared faults or transient events. The current-only directional module operates independently, starting its computation from fault inception. Coordination with the fault inception module involves checking whether a trip trigger has been issued. If so, directional information is provided; otherwise, it is reset. This coordination ensures that directional information is provided only for persistent faults, not for transient events like load changes, where phase angle changes occur but no trip trigger is issued.

H. Valid Prefault Current: In the proposed algorithm, phase angles from real and imaginary values of DFT samples are considered (see Fig. 8). However, the validity of prefault values must be ensured. For example, two imaginary numbers with vastly different magnitudes can yield the same phase angle, illustrating that phase angle computation alone is insufficient to determine validity. Therefore, prefault current validity is determined by considering the magnitude of complex values. Typically, about 10% of nominal values are considered valid prefault current.

I. Prefault Direction Change: To address potential prefault current direction changes, the algorithm requires valid prefault current for a certain duration, typically about 2 cycles. If direction changes persist in prefault current, they must be addressed at a logical level, possibly through consensus among contiguous relays.

J. Computation Time: The proposed algorithm requires three times more computation for three-phase operation due to the need for separate phase angle computations. For example, in typical protection relays [1], [15], where the sampling frequency is about 2–3 kHz, all protection function computations must be completed before the next sample arrives. Recursive DFT computation ensures optimized performance, while a lookup table-based approach for arctangent function computation is recommended for fast phase angle computation [22].

VII. Discussions:

1. The proposed current-only approach, along with its solutions, is intended for nondirectional relays, which lack voltage sensors. Prototype development using ABB relays [15] is underway.

2. The current-only directional information is relative and requires coordination among relays for system-wide power flow analysis.

3. The current-only approach is not a competitive alternative to traditional voltage-based directional relays but a cost-effective solution for distribution-side protection.

4. Traditional directional relays utilize voltage for various purposes beyond directional detection.

5. The current-only algorithm can complement traditional directional relays and improve fault detection, especially for close-in faults.

6. The algorithm includes provisions for issuing neutral outputs when sensitivity thresholds are not met.
7. Achieving high accuracy, especially above specific sensitivity thresholds, is crucial for safe power system operation.
8. The directional detection module operates independently of fault inception detection but coordinates to provide accurate directional information.
9. Post-fault monitoring ensures reliable directional decisions, although some protection classes may require additional prefault current observations.
10. Cost-effectiveness is a key consideration for distribution-side protection, necessitating efficient solutions over hardware upgrades.
11. Current-only directional relays offer potential benefits for distribution-side protection, including fault localization and close-in fault solutions.

VIII. Conclusion

This paper introduces a novel concept of current-only directional relays, eliminating the need for reference voltage as in traditional directional relays. Prefault current serves as the polarizing quantity, with minimal phase angle variation under normal conditions and significant changes during faults. Analysis of fault signals validates the feasibility of the proposed technique.Various challenges to the current-only approach, such as those related to three-phase operation, angle change sensitivity limitations, frequency deviation, noise, and harmonics, are discussed. Cost-effective solutions to these challenges are detailed to ensure robust implementation. The current-only directional relay offers intelligent directional protection and facilitates fault section localization in distribution systems [8].

References

[1]. Elmore, W. A. (2003). Protective Relaying Theory and Applications (2nd ed.). Marcel Dekker.
[2]. Anderson, P. M. (1999). Power System Protection. McGraw-Hill.
[3]. International Electrotechnical Commission (IEC). (2008). Standard for Measuring Relays and Protection Equipment, 60255.
[4]. Horak, J. (2006). "Directional overcurrent relaying (67) concepts." In Proc. 59th IEEE Conf. Protective Relay Eng.
[5]. Gan, Z., Elangovan, S., & Liew, A. C. (1996). Microcontroller-based overcurrent relay and direction overcurrent relay with ground fault protection. Elect. Power Syst. Res., 38, 11–17.
[6]. Phadke, A. G., & Thorp, J. S. (2008). Synchronized Phasor Measurements and Their Applications. Springer.
[7]. Ukil, A., Deck, B., & Shah, V. H. (2011). "Current-only directional overcurrent relay." IEEE Sensors J., 11(6), 1403–1404.

[8]. Ukil, A., Deck, B., & Shah, V. H. (2010). "Smart distribution protection using current-only directional overcurrent relay." In Proc. IEEE PES Conf. Innov. Smart Grid Technol. (ISGT’10), Gothenburg, Sweden.
[9]. Eissa, M. M. (2005). "Evaluation of a new current directional protection technique using field data." IEEE Trans. Power Del., 20(2), 566–572.
[10]. Pradhan, A. K., Routray, A., & Gudipalli, S. M. (2007). "Fault direction estimation in radial distribution system using phase change in sequence current." IEEE Trans. Power Del., 22(4), 2065–2071.
[11]. Pradhan, A. K., & Jena, P. (2008). "Solution to close-in fault problem in directional relaying." IEEE Trans. Power Del., 23(3), 1690–1692.
[12]. Ukil, A., & Zivanovic, R. (2007). "Application of abrupt change detection in power systems disturbance analysis and relay performance monitoring." IEEE Trans. Power Del., 22(1), 59–66.
[13]. Ukil, A. (2007). Intelligent Systems and Signal Processing in Power Engineering. Springer.
[14]. Ukil, A., Deck, B., & Shah, V. H. (2010). "Fault direction parameter indicator device using only current and related methods." Patent Appl. WO2012049294(A1).