Review Article

Transformer Differential Protection Method for Recognition between Power Transformer Internal Defects and Inrush Current: A Comprehensive Review of Detection Techniques

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Abstract
The cornerstone of any electric power system lies in its power transformers, as their seamless operation is crucial for network reliability. Instant disconnection from the grid is imperative upon detecting any faults to prevent cascading issues. However, distinguishing between fault conditions, like inrush current, which necessitates caution rather than immediate action, poses a challenge for effective protection schemes. This dilemma can lead to relay malfunctions, further jeopardizing system integrity. This paper delves into a thorough analysis and comparison of various methods employed in differential protection to discern between internal faults and inrush currents, aiming to enhance system resilience. This comprehensive review explores the efficacy of intelligent techniques, hybrid approaches, and traditional methods in fault detection. By shedding light on the strengths and limitations of each method, researchers in this domain can glean insights to innovate and address the deficiencies of existing strategies in tackling internal faults and inrush currents detection. Ultimately, this endeavor seeks to fortify the reliability and stability of power systems in the face of dynamic operational challenges.

Keywords: Inrush current, Internal defects, Power transformer, Transformer differential protection techniques

1 Introduction

An electric power system operates as a cohesive network of multiple components, collaborating to deliver electrical energy to consumers. Among these components, the transformer stands out as a pivotal and substantial investment, demanding a robust protection system characterized by both reliability and swift response times. This system must swiftly and decisively isolate the transformer from the rest of the network upon detecting a fault. Transformers, among the system's most critical assets, warrant protection primarily against overloads and faults. Ensuring their uninterrupted functionality is paramount, given their significance and the potential repercussions of any operational deviations. Thus, the protection measures must be carefully designed and executed to uphold system integrity and prevent costly downtime [1]. Over the years, the evolution of protection relays has followed a discernible timeline, progressing through various stages of technological advancement. It commenced with the era of electromechanical relays typified by CDG (current induction disc generator) relays. Subsequent strides in manufacturing led to the emergence of static relays, marking a significant departure from their predecessors. This evolution culminated in the advent of digital relays, representing a pivotal shift towards more sophisticated and adaptable protection mechanisms. Today, the pinnacle of this evolution is embodied in modern numerical relays equipped with microprocessors capable of intricate data processing. These relays exhibit unparalleled capability to discern between normal and abnormal system conditions, ensuring swift and accurate decision-making. The latest iteration of protection relays, known as Intelligent Electronic Devices (IEDs), epitomizes the convergence of technology and innovation to address the challenges inherent in electrical protection systems.

IEDs stand as a testament to the relentless pursuit of technological solutions to enhance the efficacy and resilience of electrical protection infrastructure. Their integration signifies a paradigm shift towards more intelligent, more responsive systems capable of safeguarding critical assets with unparalleled precision and reliability [2]. To streamline future repair efforts, the protection system must minimize the downtime associated with transformer malfunction while mitigating the risk of catastrophic failure. This entails maintaining robust protection capable of swiftly isolating the transformer in response to abnormal conditions. Prolonged operation of the transformer amidst abnormal circumstances compromises its immediate functionality and accelerates wear and tear, diminishing its overall lifespan. Therefore, an efficient protection mechanism is vital, as it not only safeguards against immediate disruptions but also extends the longevity of the transformer by preventing prolonged exposure to adverse operating conditions. By promptly initiating shutdown procedures during abnormal events, the protection system plays a pivotal role in preserving the integrity and reliability of the transformer, thus ensuring the sustained performance of the electrical system as a whole [3]. Instabilities in conventional differential protection can arise from myriad factors, each presenting unique challenges to the system's reliability. Tap changer errors, for instance, introduce fluctuations that disrupt the normal operating parameters, potentially compromising the effectiveness of the protection scheme. Similarly, transformer switching maneuvers, especially those exacerbating inrush currents, pose significant challenges by distorting the expected current profiles, thereby complicating accurate fault detection. Furthermore, the emergence of the zero-sequence current component further exacerbates the complexity of differential protection, as it deviates from the typical differential current patterns, leading to false alarms or missed detections. These factors collectively underscore the inherent vulnerabilities of traditional protection methods in addressing modern operational exigencies. Navigating these challenges necessitates innovative solutions capable of adapting to dynamic operational environments. By leveraging advanced technologies and methodologies, such as intelligent algorithms and hybrid protection schemes, it becomes possible to enhance the resilience and efficacy of protection systems, ensuring robust performance even amidst evolving system dynamics [4].

Protection remains paramount as long as there exists any probability of failure within the electrical system. Consequently, it becomes imperative to swiftly isolate a faulty transformer upon the occurrence of an internal fault. This proactive measure serves multiple critical purposes: it prevents the escalation of damage, preserves the overall stability of the electricity grid, and ultimately safeguards the quality of electricity supplied to consumers. The risk of exacerbating the fault and causing additional damage to the system is mitigated by promptly disconnecting the faulty transformer. This protects the integrity of the transformer itself and prevents potential cascading failures that could disrupt the entire electricity network. Moreover, by ensuring the timely isolation of faulty equipment, the protection system maintains the desired quality standards of electricity delivery, thereby upholding reliability and meeting consumer expectations. In essence, the swift response of protection mechanisms in isolating faulty transformers serves as a cornerstone in maintaining the integrity, stability, and quality of the electricity system. The objectives of the protection system for the transformer are to ensure that the transformer operates within normal load parameters, to handle any difficulties arising from secondary overload to prevent damage to the transformer, to isolate the transformer before it completely loses control, and to maintain the overall functionality of the power system. Any faulty transformers should be promptly removed from the system [5].

Ensuring the efficacy of a protection system hinges on its ability to detect and respond to specific variations within the power grid that could potentially lead to equipment damage or prolonged outages. Protective strategies within the power grid are meticulously crafted per the specifications and design of system components, aiming to mitigate common risks stemming from line-switching activities and load fluctuations. During the design phase of a protection approach, numerous factors must be carefully weighed against cost considerations. Key design elements must strike a delicate balance to achieve optimal performance. Reliability, selectivity, speed, and sensitivity are paramount considerations. Reliability stands as a cornerstone, ensuring that the protection system consistently operates as intended, instilling confidence in its ability to safeguard critical assets. Selectivity is equally crucial, enabling the system to precisely identify and isolate faults while minimizing the impact on unaffected areas. Speed is of the essence, as swift response times are imperative to mitigate potential damages and reduce downtime. Additionally, sensitivity plays a pivotal role, allowing the system to discern subtle variations and trigger appropriate responses, even in challenging operating conditions. By prioritizing these features in the design of protective systems, engineers can cultivate a robust framework capable of effectively addressing diverse threats and ensuring the power grid's resilience against potential disruptions [5], [6].

Various methods have been proposed to enhance the recognition of inrush current from internal faults. However, many of these methods may still not be able to satisfy this distinction in all situations.

The contributions of this paper are highlighted as follows. A review of transformer protection schemes against internal and external faults and transient phenomena is presented. All techniques used in power transformer differential protection to address issues related to internal defect recognition are discussed. The advantages and disadvantages of each technique are comprehensively reviewed, including modeling techniques, estimations, and concepts. This review represents the latest advancements in the field and serves as a valuable resource for researchers. It provides insights into improving transformer differential relays' performance by addressing the limitations of existing techniques. Also, it thoroughly compares two main differential protection techniques, conventional and intelligent. The latest advancements in these techniques are also presented in detail.

2 Transformer Protection Schemes

Various protection schemes are employed to safeguard transformers against both internal and external faults. Table 1 showcases common faults encountered in power transformers and corresponding electrical and mechanical protection measures. The array of protection schemes aimed at safeguarding transformers from internal and external disturbances can be summarized as follows.

Table 1: Transformer fault types and recommended protection [5]–[7]

Transformer Faults Type	Recommended Protections
Transformer winding	Differential and overcurrent relays
Inter-turn faults	Differential and Buchholz relays
Transformer core	Differential and Buchholz relays
Transformer tank	Differential, Buchholz and oil level gauge
Over flux	Volts-Hertz relay
Transformer overload	Overcurrent relay
Transformer tap changer	Differential and gas receive relays
Transformer temperature rise	Winding temperature and oil temperature levels

2.1 *Overcurrent protection*

This protective measure serves as a secondary defense for transformers, shielding them from short circuits and overloads. Activated when the current on either side of the transformer surpasses a predefined threshold, it acts as a fail-safe mechanism. Crucially, it distinguishes currents arising from internal faults from those associated with external defects or regular load operations, much like other protection systems employing overcurrent relays. External faults or prolonged excessive loads can lead to overheating of the transformer windings, resulting in insulation degradation. This degradation heightens the risk of internal flashovers within the transformer, underscoring the critical importance of this protective measure in averting potential damage and ensuring the transformer's sustained functionality [7]. Time-delay overcurrent relays represent a viable option for safeguarding transformers against internal faults. These relays are specifically designed to provide a delayed response to overcurrent conditions, allowing for differentiation between temporary surges and sustained fault currents. By incorporating a time delay, these relays ensure that the protection system does not unnecessarily trip during transient events, thereby enhancing the reliability of the transformer's operation. In the context of transformer protection, time-delay overcurrent relays play a crucial role in detecting internal defects such as winding faults or insulation failures. By providing a time delay before initiating protective actions, these relays allow for identifying and isolating internal faults while minimizing the risk of false tripping due to temporary disturbances. This targeted approach enhances the overall effectiveness of the protection scheme, ensuring prompt and accurate response to internal faults while maintaining system stability [6].

2.2 *Earth Fault and Restricted Earth Fault Protection (REF)*

The grounding of transformer windings can be achieved through direct solid grounding or the use of either resistance or reactors, depending on the specific requirements of the protection scheme in place. This particular protection system is meticulously engineered to address earth-winding faults effectively. In this design, the overcurrent units may be exclusively connected in the neutral phase, predominantly in the residual phase, or incorporated into a differential connection encompassing both the earth and all phases. Due to the cancellation effect of load currents, these overcurrent units necessitate significantly lower settings compared to phase overcurrent units. In cases where non-differential connections are utilized, the incorporation of harmonic restraint may be necessary. While these configurations typically offer lower settings, they are tailored to protect solely the earthed winding [7].

Traditional earth fault protection methods employing overcurrent devices may not provide adequate protection for transformer windings, especially in cases where a star-connected winding has an impedance-earthed neutral. To address this limitation, the implementation of restricted earth fault protection, commonly referred to as REF protection, substantially enhances the level of protection. REF protection offers a notable advantage by significantly increasing its effectiveness, particularly for star-connected windings with impedance-earthed neutrals. This method allows for the application of restricted earth fault protection on both windings of a two-winding transformer, providing comprehensive and high-speed protection against earth faults with minimal additional equipment requirements. A high-impedance relay is typically selected for REF protection configurations for optimal performance in terms of rapid operation and phase fault stability. This choice ensures a swift and reliable response to fault conditions while maintaining system stability [8], [9].

2.3 *Over-flux protection*

Transformers operate within specific flux parameters, and exceeding these levels can increase core temperature, resulting in overheating throughout the transformer. It is crucial to implement protective measures to prevent damage from this occurrence. The flux in a transformer is directly related to the voltage-to-frequency ratio (V/f). As such, over-flux protection functions by monitoring and responding to variations in this ratio [7], [10].

2.4 *Over voltage protection*

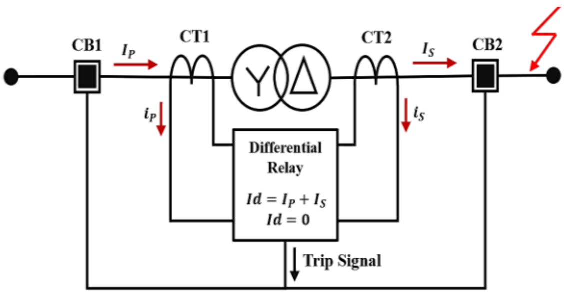
Any increase in system voltage can accelerate the aging process of transformers by causing insulation failure. Therefore, voltage protection is essential to shield transformers from voltage fluctuations [10]. It is imperative to assess whether the current overvoltage protection systems are adequate or if there are design flaws contributing to transformer damage [11]. High overvoltage at transformer terminals can stem from switching events or lightning strikes. Overvoltage may also manifest at the secondary terminals of an unloaded transformer, especially when protective auto transformers are activated through a feeder of considerable length [12].

2.5 *Differential protection*

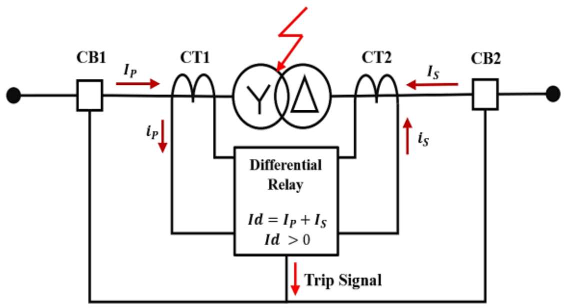
These scenarios were using overcurrent protection exclusively for power transformers poses challenges due to coordination issues and prolonged fault clearance times, the application of differential protection becomes imperative. As per established protection policies and philosophies, the predominant technique employed for preventing internal short circuits in transformers rated at 10 MVA [7], [13] and above is the implementation of differential protection. Differential relays function by calculating the disparity between currents measured by current transformers (CTs) situated on the primary and secondary windings of the transformer. This calculated difference, known as the "differential current," serves as a key indicator of internal faults. When the magnitude of the differential current exceeds a predetermined threshold, the differential protection system interprets it as indicative of an internal defect. Consequently, a trip signal is issued to the circuit breaker, prompting the disconnection of the transformer from the electrical grid. This swift response mechanism ensures timely isolation of the transformer to prevent further damage and maintain the integrity of the power system.

3 Principles of Differential Protection

Differential protection serves as the primary safeguard for transformers, as depicted in the basic strategy outlined in Figure 1 [3]. In this configuration, I_P and I_S, denote the primary and secondary currents of the system, respectively. Under normal operating conditions, the secondary current passing through the CTs remains constant, resulting in no current flow through the differential protection circuit. As illustrated in Figure 1(a), when a fault occurs outside the transformer zone, the fault current traverses both CTs. Since the fault current passing through both CTs is identical, the differential relay configuration prevents any current flow through the protection relay, even in instances of high fault current [3]. Conversely, in the differential protection configuration shown in Figure 1(b), an internal fault triggers the current flow in opposite directions into both CTs. Consequently, the differential relay discerns the current disparity and issues a command signal to the circuit breaker in response to the internal fault [14], [15].



(a)



(b)

Figure 1: Differential relay configuration (a) External fault case (b) Internal fault case.

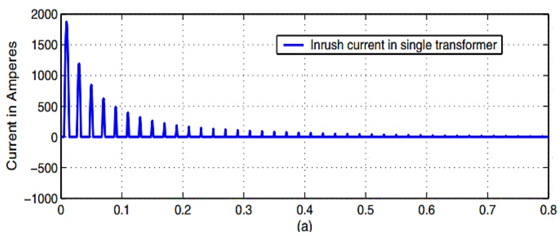


Figure 2: Typical inrush current for a power transformer.

Despite the ability of a differential relay, under ideal circumstances, to differentiate between internal and external faults, various phenomena can lead to the failure of the differential protection system. These phenomena often stem from the nonlinear characteristics inherent in the transformer core and CTs. During the startup of a power transformer, a substantial inrush current surges into the high-voltage side of the protective autotransformer. The magnitude of this inrush current is influenced by several factors, including the transformer's capacity, primary winding resistance, grid voltage, and residual flux at the moment of switching [1]. This influx of current has the potential to disrupt the proper functioning of the differential protection system, resulting in the issuance of a false trip signal. Figure 2 depicts a typical inrush current waveform. The primary challenge associated with differential protection revolves around effectively managing the impact of inrush current.

The magnitude of the current might exceed its specified rating significantly, and it may take several milliseconds for its decaying time constant to decrease to a few cycles. A high-current flow with a significant harmonic component can lead to abnormal operation of protective equipment. This abnormal operation has repercussions on the entire system because the amplitude of the inrush current surpasses the capacity of circuit breakers, isolators, and fuses. This results in noise and distortion entering the power system, affecting its quality. Moreover, it subjects the transformer core and windings to mechanical stress, ultimately impacting the lifespan of the transformer [16], [17]. In certain instances, significant differential currents have been noted to flow unexpectedly, even in the absence of faults. This occurrence is attributed to second harmonics under specific operational circumstances. Such incidents typically arise when a nonlinear load, such as a furnace, is introduced into the power system associated with the transformer. This form of malfunction differs from the commonly encountered issue caused by energizing an unloaded transformer. Unlike the immediate malfunction observed during transformer energization, this type of malfunction occurs after a considerable delay following the switching-in of the load [18], [19]. In order to trigger the differential relay and subsequently isolate the transformer, a substantial magnitude of the differential current is required to induce malfunctions. These occurrences encompass various phenomena, such as sympathetic inrush current, magnetizing inrush current during the energization process, and CT saturation. These phenomena are intricately linked with the nonlinear characteristics inherent in power transformers and CT cores [20].

4 Transformer Differential Protection Techniques

Numerous methods have been proposed in the literature to differentiate between inrush current and internal faults for application in the differential relays of power transformers. These methods can be broadly categorized into two main groups: conventional and intelligent differential protection techniques. Below, we delve into the fundamentals of each approach.

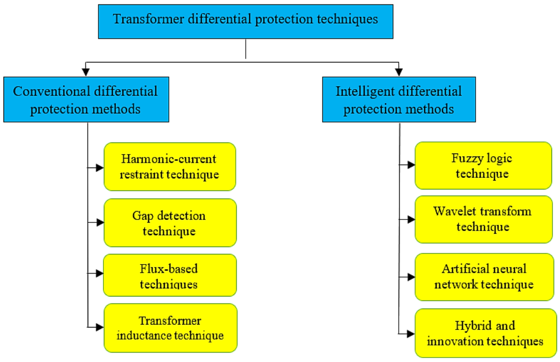


Figure 3: Transformer Differential Protection Techniques.

Table 2: Ratio of harmonics components in ideal IC [6]

Components of Harmonics in Magnetizing IC	Amplitudes (% of Fundamental)
D.C	55
Second	63
Third	26.8
Fourth	5.1
Fifth	4.1
Sixth	3.7
Seventh	2.4

4.1 *Conventional differential protection methods*

Figure 3 illustrates the primary methods within this category, including the harmonic-current restraint technique, gap detection technique, flux-based techniques, and transformer inductance technique. These methods play pivotal roles in enhancing the effectiveness of differential protection for power transformers.

4.1.1 Harmonic-Current Restraint Technique

The harmonic-current restraint method is a well-established technique utilized to differentiate between inrush current and internal faults. Typically, the presence of the 2nd harmonic within the inrush current ranges between 30% and 60% of the fundamental component, as outlined in Table 2 [6]. In this approach, detecting harmonic components plays a crucial role in distinguishing inrush current from faults and ensuring the correct operation of the differential protection system [21]. Harmonics are evaluated in relation to the fundamental frequency, where the second harmonic falls within the range of 30% to 60%, the third harmonic between 10% and 30%, and subsequent harmonics decrease progressively. Therefore, the presence of inrush current is identified by observing the percentage value of the second harmonic, which falls within the range of 0.3 to 0.6 times the amplitude of the fundamental frequency. Any deviation from this range indicates the detection of an external or internal fault [15].

To enhance the reliability of the differential protection relay, researchers have explored utilizing the sum of the 2nd and 5th harmonics [22]. Various methods are employed to determine harmonic components, including passive filters, Fourier transform, sine-rectangular transform, Haar function, Walsh function, extended Kalman filter, least squares algorithm, and Debauches function [4]. However, advancements in power transformer manufacturing, particularly in magnetic materials such as amorphous transformer cores with low power dissipation, have limited the effectiveness of this technique [23], [24]. In modern transformers, the amplitude of the 2nd harmonic in inrush current during startup is typically around 7% of the fundamental component, leading to differential relay malfunctions [24]. Simply reducing the threshold values for the second harmonic is not an optimal solution, as excessively low thresholds may cause the differential protection to malfunction in the presence of internal defects if they fall below 15% of the fundamental component [21]. In Wang *et al.* [25], an adaptive identification technique based on the 2nd harmonic is proposed to enhance the detection of transformer inrush current. This technique utilizes a floating threshold value that adjusts dynamically based on fluctuations in the 2nd harmonic and fundamental components over time, enabling the differential relay to restrain itself effectively during instances of inrush current. Sutherland 1996 [26] introduces the concept of utilizing Prony analysis to assess the energy of first and second harmonics. This ratio is subsequently determined by analyzing the damping specifications of the fundamental and second harmonics. A notable discrepancy between inrush current and internal defects is observed when comparing the fundamental and second harmonic energies. In Krishnamurthy and Baningobera 2019 [27], transformer differential relays with harmonic constraints can be tested using either single-frequency or multiple-frequency harmonic sources, yielding comparable results with slight variations. Relay manufacturers typically mandate tests utilizing several harmonic sources, often employing a diode half-wave rectifier. When testing relays using single-frequency harmonic sources in accordance with manufacturer standards, users may opt to compare multiple relays simultaneously. The principal outcome of Sutherland

1996 [26] is the development of a harmonic blocking scheme for transformers aimed at preventing the overcurrent relay (SEL751A) from tripping under transformer inrush current conditions. This is achieved by employing component 87HB of the transformer differential type (SEL487E) to transmit a harmonic blocking signal via an IEC61850 GOOSE protocol.

A drawback of this technique is its susceptibility to interference from long transmission lines, where the presence of inductance and capacitance can negatively affect the performance of differential protection. Specifically, capacitors can induce resonance and amplify the harmonic components within the line, potentially undermining the reliability of the protection system [16]. However, this method offers enhanced safety in scenarios where the harmonic content of one or both phases is insufficient to prevent relay operation, thus proving valuable in certain applications [23], [28].

4.1.2 Gap detection technique

Gap detection involves identifying time intervals during which the differential current approaches zero. Typically, this gap duration exceeds 1/4 cycle for inrush currents and is less than 1/4 cycle for internal faults. Thus, by analyzing this gap, it becomes possible to differentiate between inrush currents and internal defects [29], [30]. However, the performance of the gap detection algorithm can be impacted by CT saturation, particularly due to the significant DC component present in inrush currents [31]. Notably, certain transformer protection relays, such as those manufactured by SIEMENS and AREVA, utilize this technique to discern between inrush currents and internal defects [9], [10]. A simple yet effective technique for enhancing the functionality of a differential relay is discussed [29]. The proposed method employs the most advanced technique for differential relays available in the current generation, following the classification of the relay's input signal using a classification algorithm. The method circumvents the drawbacks associated with gap-and-harmonic-based detection techniques by opting for this direct approach. A test setup featuring a resistive solid-state fault current limiter (FCL) is employed, subjecting it to various scenarios to validate the reliability of the suggested technique. The results confirm the accuracy and consistency of the modified technique, demonstrating its efficacy both with and without the presence of the FCL, as well as in scenarios involving CT saturation.

4.1.3 Flux-based techniques

Flux-based techniques rely on changes in magnetizing flux (linkage flux) and leakage flux as indicators of internal faults in power transformers. These techniques exploit the disparity in flux levels between normal operation and fault conditions, particularly when inrush current passes through the primary winding. A flux-based method is proposed, utilizing the computation of the relationship between the rate of change of linkage flux (dλ/di) and the current rate of change as a restraining factor [32]. This restraint function is derived from the measured voltage and current data. It's worth noting that the computation does not directly use linkage flux due to challenges in accurately quantifying remnant flux. While it was demonstrates the effectiveness of this method in distinguishing between internal defects and inrush current, its precision relies on the accurate measurement of leakage inductance and appropriate selection of threshold values for the derivative dλ/di [21]. One implementation of this technique involves measuring leakage flux using optical fiber sensors positioned at various points near the transformer yoke. Notably, the leakage flux observed when the no-load transformer is energized differs significantly from that during normal operation, allowing for identifying inrush current [33]. However, a primary disadvantage of this technique is the necessity of installing a flux sensor.

A notable drawback of this approach is the requirement for experimental measurements of transformer parameters. Additionally, errors in current and flux measurements can lead to false operations of transformer differential protection [34]. These limitations underscore the need for careful calibration and precise measurement techniques when implementing flux-based protection methods.

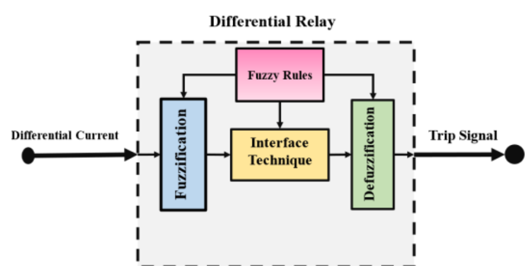


Figure 4: Fuzzy logic architecture.

4.1.4 Transformer inductance technique

During both internal faults and normal operation, the linear section of a power transformer core's magnetic characteristic maintains a consistent magnetizing inductance. This stability arises from the core remaining unsaturated and experiencing minimal magnetizing current. However, transformer core saturation, which occurs during inrush current, represents a significant deviation from this behavior. Furthermore, during inrush current events, the iron core undergoes fluctuations between saturation and non-saturation states, leading to abrupt changes in magnetizing inductance [35].

Based on this technique, the instantaneous inductance of the transformer is determined by measuring the current and voltage on both sides of the transformer. Subsequently, the calculated instantaneous inductance is compared to a predefined threshold value. If the calculated value exceeds the threshold, it indicates the presence of an inrush current; conversely, if it falls below the threshold, the scenario is classified as an internal fault. The algorithm's execution time is less than a quarter cycle, making it highly efficient. Moreover, the algorithm is well-suited for CT saturation situations [35]. Experiments were conducted at Tsinghua University's laboratory to validate the proposed techniques using a three-phase transformer bank supplied by a 50 Hz power system grid. Nevertheless, a limitation of the Transformer Inductance Technique lies in its reliance on specific transformer specifications. Additionally, to yield accurate and dependable results, this technique necessitates the availability of current and voltage transformers [36].

4.2 *Intelligent differential protection methods*

Figure 3 highlights the key methods within this category, including the fuzzy logic (FL) technique, wavelet transform (WT) technique, artificial neural network (ANN) technique, as well as hybrid and innovative techniques.

4.2.1 Fuzzy Logic Technique

Fuzzy logic emulates human-like reasoning in processing tasks, comprising three primary stages: Fuzzification, Inference, and Defuzzification, as depicted in Figure 4 [37]. In the first stage, crisp quantities are transformed into fuzzy sets using membership functions. Various types of membership functions, including bell-shaped, Gauss, sigmoid, triangular, and S-curve waveforms, can be utilized. Subsequently, fuzzy inference processes the fuzzy sets using IF-THEN rules to determine the appropriate sequence of actions or outputs [38]. The final stage, known as defuzzification, converts the fuzzified outputs back into crisp values. Since 1993, fuzzy logic-based techniques have been proposed to enhance the functionality of differential protection in distinguishing inrush current from internal defects. Various criteria for differential protection approaches based on fuzzy logic have been introduced [38], outlining the formulation of fuzzy settings and protection criteria. These criteria are combined with two supporting conditions to issue a more reliable tripping signal, ensuring a robust decision-making process.

A multi-criterion stabilization algorithm is proposed to enhance discrimination through fuzzy reasoning [39]. This algorithm is tested using real-world data and signals generated by EMTP-ATP. The suggested protection algorithm demonstrates reliability and significantly higher sensitivity compared to conventional algorithms. The investigation encompasses various operating conditions of power transformers and the behavior of different criterion signals. An EMTP model of a power transformer with a power system was developed to facilitate this. Over 80,000 different scenarios, including internal defects, external faults, and transformer energization, were generated using this model. The simulations also considered turn-to-turn shorts, particularly those involving only a few turns, for internal failure scenarios. Different configurations of transformer operation (loaded, unloaded, and supplied from both sides) were examined for energization scenarios. The determination of criterion signals, combinations, and threshold values was based on this extensive dataset [39].

Fuzzy logic emerges as a potent mathematical tool, forming the basis of a protection approach centered on ruling out non-internal failure phenomena [40]. Simulation results underscore the effectiveness of this fuzzy protection technique, which can swiftly identify internal faults in less than half a cycle, thereby significantly enhancing the overall protection system. Meanwhile, a method leveraging fuzzy reasoning techniques was proposed to enhance the discrimination between inrush current and internal faults [18]. Through advanced stabilization techniques evaluated using signals generated by EMTP-ATP, the study demonstrates superior reliability and sensitivity compared to traditional stabilization approaches with crisp settings. An algorithm based on adaptive fuzzy logic was introduced to optimize slopes for the stability characteristics of differential relays under varying conditions [36]. Utilizing PSCAD/EMTDC, the algorithm's performance is thoroughly scrutinized and compared with conventional methods. Simulation results highlight the algorithm's robustness to CT saturation during external faults. Lastly, a research introduces a fuzzy-based algorithm incorporating various elements, including a percentage of the differential feature curve, a flux-differential current derivatives curve, and harmonic restraint to enhance transformer protection [19].

The research explores the application of fuzzy logic in power transformer differential protection [41]. The protection scheme incorporates both differential and overcurrent relay principles. The overcurrent relay is proposed to serve as a backup protection mechanism, while the differential relay provides the primary protection. A fuzzy logic controller is developed to orchestrate the coordinated operation of the main and backup protection systems and identify any abnormal operation. Numerical results indicate that the proposed model offers the transformer swift, comprehensive, and robust protection. One drawback of the fuzzy logic technique is its relatively longer decision-making time in transformer protection applications.

4.2.2 Wavelet transform technique

WT offers significant advantages in processing data within the time-frequency domain, addressing the limitations of the fast Fourier transform (FFT) when analyzing nonstationary signals. The discrete WT (DWT) proves particularly useful in extracting signal contents by segregating them into approximation and detailed signals, indicating various signal features. Through DWT, the signal undergoes decomposition into low and high-frequency components via the application of high-pass and low-pass filters [42], followed by a down sampling process to generate approximation and detail coefficients for specific frequency bands. This process, illustrated in Figure 5, iterates until reaching a predetermined level. Selecting an appropriate mother wavelet is paramount for diagnosing and analyzing transient events in power transformers. The Daubechies wavelet emerges as a suitable choice for investigating high-frequency current signals characterized by short periods, fast decay, and abrupt swings [43]. The choice of mother wavelet significantly influences the accuracy of signal feature identification. Selecting an appropriate mother wavelet relies on the Pearson correlation coefficient (denoted as γ) calculation, which is computed and compared for all types of Daubechies wavelets according to Equation (1). This calculation aims to identify the optimal wavelet from a predefined set of wavelets (db1, db2, ..., db6) that can best approximate the original signal. The ideal wavelet is determined based on which wavelet's approximation exhibits the highest Pearson correlation coefficient with the original current signal during an internal fault scenario.

$$\gamma = \frac{\sum (M - \bar{M})(N - \bar{N})}{\sqrt{\sum (M - \bar{M})^2 \sum (N - \bar{N})^2}} \quad (1)$$

Where M is the original current signal, N is the wavelet signal, and the mean values of M and N, are denoted by $\bar{M}$ and $\bar{N}$, respectively [44]. WT offers the inherent advantage of prioritizing transient conditions and enabling the selection of shorter analysis intervals. This focus on transient phenomena allows for the reliable identification of transient current signals through effective current characterization [43].

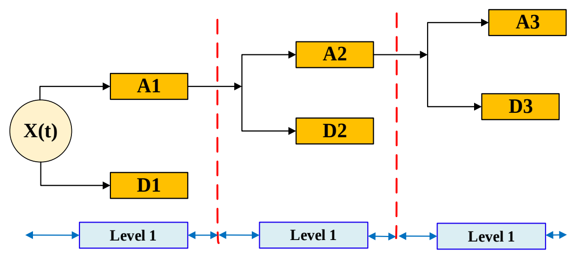


Figure 5: Multi-resolution for approximation and details.

The differential protection of power transformers utilizing WT is introduced [45]. Since the accuracy of any classifier method hinges on the input parameters, data derived from various coefficients can be employed as inputs to classifier algorithms to discern between fault and non-fault conditions. Fault identification algorithms are constructed by comparing the detail coefficients generated using DWT with a predefined threshold value [23], [24]. EMTP-ATP is utilized to simulate various internal faults and switching conditions to evaluate the performance of the proposed approach. The suggested REF protection system enhances phase-to-ground fault detection by utilizing high-frequency components instead of phasor estimates [46]. This wavelet-based

REF protection system is tested against comparable conventional restricted earth-fault units using simulated phase-to-ground faults for a few winding turns. The discrimination criterion is based on synchronizing the maximum and minimum points between the transformer flux and the differential current wavelet coefficient [47]. An innovative algorithm [48] employs wavelet packet transform (WPT) to distinguish inrush currents from internal defects. By utilizing a wavelet-based processor step, high-frequency components of disturbances are collected and organized, leading to the development of a suitable criterion within an appropriate frequency range. The presented method [49] describes a decision-making method that utilizes a wavelet transform-based feature extraction approach to differentiate between inrush current and internal defects in power transformers. This highlights WT's superior time and frequency localization properties compared to FFT, resulting in more unique feature extraction. An efficient wavelet transform-based technique for indirect symmetrical phase shift transformers (ISPST) is proposed [50]. Differential current wavelet energy is calculated using conventional Parseval's theorem, and an appropriate threshold is selected to distinguish between inrush current and internal defects. The approach proposed in [51] entails minimal computational burden and has been specifically designed for real-time applications. It was implemented on a digital signal processor to enable real-time analysis. The suggested wavelet-based protection strategy represents a promising alternative to traditional differential protection relays, offering potential for integration alongside conventional differential protection methods in future applications.

A method is proposed to differentiate between faults and healthy conditions in power transformers using the continuous WT (CWT) [52]. This differentiation relies on the analysis of the differential current waveform since the characteristics of the initial zero crossing of faults and inrush currents differ. However, WT-based techniques exhibit drawbacks such as high sensitivity to noise and the influence of CT saturation on their performance [53].

4.2.3 Artificial Neural Network (ANN) Technique

The fundamental architecture of a neural network encompasses three key components: the input or multiplication stage, the activation or transfer function, and the output [54], [55], depicted in Figure 6. Neural networks are structured with an input, hidden, and output layer. Artificial neurons or nodes are interconnected and endowed with threshold values within these layers. Input signals are directed into the neural input layer, where neurons function as processors, generating outputs through basic nonlinear operations on the input values. Each neuron is assigned a weight, with neural network training adjusting these weights according to the training process [56]. Both feed-forward and back-propagation neural networks are harnessed to differentiate faults from other transient conditions using offline methods [57].

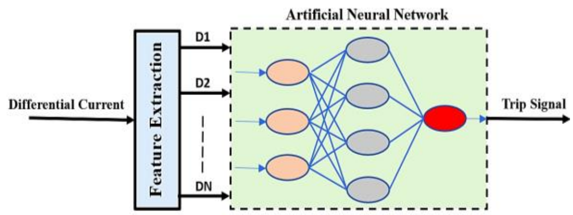


Figure 6: ANN structure.

A novel approach combines two ANNs in a master-slave configuration [58]. These interconnected ANNs employ innovative strategies, including novel concepts for parallel hidden layers, to distinguish between inrush current and internal defects effectively. Similarly, statistical inference techniques was utilized such as mean value, standard deviation, and product-moment correlation coefficient in conjunction with an ANN to discern between inrush current and internal faults [59]. Moreover, a study introduces a denoising-classification neural network that integrates a convolutional neural network (CNN) with a convolutional auto-encoder [60]. This hybrid model reliably safeguards transformers by analyzing the voltage differential current curve.

Differential protection is established by employing ANNs to train on primary and secondary currents using neural network tools. This approach is aimed at safeguarding a Terco-type transformer with a capacity of 2 KVA [61].

A CNN-based technique for rapidly identifying inrush current from fault conditions is introduced [62]. One of the key advantages of this method is its integration of fault detection and feature extraction blocks within a single deep neural network (DNN) block. Meanwhile, the approach proposed in [63] involves a feed-forward ANN functioning as a classifier. Notably, this method incorporates statistical data samples for training the neural network using back-propagation neural networks. Additionally, a DNN-based technique called CLGNN [64], combining CNN with light-gated recurrent units (LGRU) was developed. The algorithm exhibits promising accuracy in distinguishing inrush current from internal defects.

The fast gated recurrent neural network (FGRNN) is designed to swiftly adapt to rapid changes and significantly reduce computation time by eliminating the reset gate in the gated recurrent unit (GRU) [65]. Through comprehensive comparisons involving simulations and experiments encompassing various external factors, including seven established algorithms, it is demonstrated that the suggested FGRNN outperforms both GRU and the aforementioned algorithms in terms of speed and reliability. An experimental prototype is employed to evaluate the proposed approach, utilizing a three-phase transformer with specifications of 380/380 V, 50 Hz, and 1 kVA to gather the experimental data.

The primary limitations of ANN-based techniques include their heavy reliance on transformer parameters, substantial memory storage requirements, challenging experimental setup, high computational expenses during training, and limited generalization to diverse systems.

4.2.4 Hybrid and Innovation Techniques

In general, hybrid techniques consist of two algorithms that overcome the shortcomings of each algorithm and satisfy the full algorithm in terms of accuracy and reliability. An approach built on a Clark-based transform to extract signal characteristics and a modified hyperbolic S-transform for fault classification are proposed [66]. It is proposed for cascaded WTs for differential current decomposition at high band frequencies to use feature extraction as input for empirical mode decomposition to distinguish inrush current from internal defects [67].

The developed approach [68] is constructed in two parts: the first part adopts the S-transform because it is accurate in terms of signal processing and facility feature extraction, and then the features are converted into numerical values. Fuzzy logic is the second part, which is responsible for decision-making in classifying faults and inrush currents. A differential protection [69] is based on Clark and WT in the time domain, with only one differential unit per power transformer and automatic settings available. An efficient CNN and extreme gradient boosting (XGBoost) [70] are combined to improve the accuracy of differential protection. A one-dimensional CNN receives data produced by various test scenarios for high-level feature extraction. After that, XGBoost is employed as an effective classification tool to discriminate transformer internal faults from other abnormalities accurately.

The algorithm introduced in [71] combines DWT and probabilistic neural networks (PNN). The high-frequency components of fault signals are decomposed using DWT. The PNN is divided into two training scenarios to compare the splitting algorithm's maximum ratio with the DWT's maximum coefficient. The simulation system is applied to several case studies based on Thailand's energy transmission and distribution networks.

A differential protection system employing WT and an adaptive neuro-fuzzy inference system (ANFIS) is developed [72]. A probabilistic distance measurement (PDM) method is proposed in [73] to differentiate between inrush currents and internal defects in power transformers. Investigations on the performance of a differential relay for various fault types under geomagnetically induced current (GIC) conditions are conducted in [19]. The results obtained under GIC conditions validate the reliability of the transformer model used in the EMTP-RV software environment for time-domain simulations. A technique based on a rate of change of phase angle (RoCoPA) is introduced to identify inrush currents from internal faults [74]. Another approach [75] is based on the integral principles of transformer differential protection, requiring the direct calculation of standard signals from various stages' operating and restraint currents. Combining DWT with ANNs, an algorithm for fault recognition from normal conditions is proposed [76]. However, this method suffers from the drawback of taking approximately one cycle to issue a final decision. A technique based on PNN and DWT of differential current details [77] is presented to distinguish between inrush currents and internal faults in a single-phase transformer. Notably, this approach lacks details regarding accuracy, execution time, and its suitability for single-phase modules [78].

In the research that has been done in [79], the differential relay philosophy for power transformers is described, employing ensemble approaches based on decision trees and integrated DWT. This methodology differentiates between a magnetizing inrush condition and an internal defect. A time-frequency analysis-based approach is introduced, employing PSCAD/EMTDC for modeling power transformer operation and internal faults [80]. The method utilizes a hyperbolic S-transformer to process simulation data and extract a determination index. A technique was proposed for distinguishing internal power transformer faults from inrush currents using adaptive sampling and the Hilbert transform [81]. This method demonstrates effectiveness in differentiating internal faults and inrush currents even under noisy signals and with saturated CTs. Testing on a 230/63 kV transformer validates the efficacy of the proposed algorithm. An algorithm presented in [82] utilizes the statistical parameters of detailed d1-level wavelet coefficients as input signals for an ANN. An algorithm employing a sine-wave curve fitting technique is introduced for online discrimination between inrush current and inter-turn faults [83]. Using the least squares approach, this method adjusts a sine wave to the normalized differential current for each phase. A technique for diagnosing internal defects occurring during inrush currents in power transformers was introduced [84]. This method utilizes data windows and stacked denoising autoencoders, eliminating the need for a threshold to differentiate between internal defects and inrush currents. Evaluation of the proposed approach involves simulating internal defects and inrush currents in a typical 154 kV substation in South Korea using PSCAD/EMTDC, considering various parameters affecting inrush currents. A protection-based stability approach is proposed, applying external voltages to the low-voltage side of transformers while maintaining a short circuit on the high-voltage side [85]. This was demonstrated at a Saudi Arabian power plant using a 100 MVA, 380 kV/13.8 kV transformer. A Hardware-in-the-Loop (HIL) test for a transformer differential protection system, verifying the accuracy of the relay's settings configuration was present [86]. The testing phase includes step-by-step construction to validate the principle of differential computations. To safeguard transformers against GIC and geomagnetic disturbances. Authors in [87] propose an improved differential protection approach. This study analyzes the accuracy of current differential protection systems' harmonic blocking under GIC situations. A novel technique for a differential protection relay based on six input currents is introduced, mapping the trajectory onto the relay setup curve [88]. This approach retrieves relay input currents during an incident using COMTRADE files and considers the secondary sides of current transformers. Authors in [89] introduce an instantaneous power-based differential protection (IPDP) for transformers, utilizing instantaneous power to distinguish between various faults and conditions. The suggested approach relies on wave shape parameters of the instantaneous power signal, employing second-order transient-extracting transform (STET) for diagnosis. To enhance protection accuracy, authors in [90] suggest a deep learning protection system based on a CNN, focusing on discriminative features. This network aims to extract distinctive characteristics of the unsaturated part of the differential current, enabling reliable differentiation between internal defects and inrush currents. Authors in [91] propose using the decaying DC component of negative sequence differential current to identify transformer inrush current. Three criteria are considered for setting a threshold to recognize internal faults, validated through simulation results for various internal defects and inrush situations. A new algorithm based on the teager energy operator (TEO) and hidden Markov model (HMM) is presented for transformer differential protection [92]. This research utilizes TEO and HMM to discriminate between internal defects and inrush currents after observing any rise in transformer differential currents. Authors in [93] employ two techniques, the WPT and S-transform, to identify currents in the power transformer. Initially, the minimal description length (MDL) requirements within the WPT method guide the selection of the optimal mother wavelet and resolution level for feature extraction from the WPT tree. Subsequently, the discrete S-transform generates an S-matrix, facilitating the computation of the spectral energy index and standard deviation within the S-transform method. Both methodologies undergo testing using a 1KVA, 220/110V, 50Hz, Δ / Y three-phase transformer to generate a trip signal, ultimately disconnecting the transformer.

Hybrid techniques, while offering high accuracy compared to other methods, do have drawbacks. They typically require a larger amount of data and may involve longer processing times, particularly depending on the selection criteria for the initial and subsequent stages of the hybrid approach. Despite these limitations, their superior accuracy makes them valuable options for effectively distinguishing between different conditions in complex systems like power transformers.

5 Transformer Differential Protection Challenges

Having completely gone through the methods described in this essay and listed in table 3, two main obstacles to the effective operation of transformer differential protection have been identified. The first one is CT saturation; it occurs when the fault current exceeds the dynamic range of CTs. This situation can lead to wrong current measurements and prevent proper protection scheme operation. Handling CT saturation effectively requires a careful selection of CTs with suitable dynamics ranges and saturation characteristics. CT saturation may result in overestimating fault current, which can inadvertently trip transformer protection systems. Similarly, distorted signals due to CT saturation may result in delayed activation of the protective relay in current-biased overcurrent relays by underestimating RMS value for the current signal. Different approaches have been investigated to enable detection and compensation of the problem involving CT saturation, which goes beyond differential protection's behavior towards faults and non-faults because distinguishing between these two becomes more difficult at times, such as: beyond factors influencing the behavior or differential protection during fault condition(s). A Kalman filtering, often called KF algorithm, which is an estimate-based method, is proposed [94] for fast, accurate and effective detection of CT saturation. For non-saturating regions, the technique uses the current sample point and extended KF (EKF) to develop a way to characterize the current wave form. Then, this derived model is used to reconstruct an original current waveform within the saturation region. It applies a criterion based on estimation error of EKF algorithm to detect start and end points of CT saturation interval. Instantaneous magnetic flux is used to identify current transformers to evaluate saturation [95]. Field current estimation is then employed to correct CT saturation. This method employs Jiles-Atherton approach for the assessment of instantaneously magnetic flux density and inrush currents, with saturation evaluation criterion being that at turning point magnetic flux density at the turning point becomes saturated. This experiment involves the use of the support vector regression (SVR) method to compensate for CT saturation induced secondary harmonic current distortion [96]. Despite other alternatives such as MLP, ANFIS, it is not a giveaway that the SVR method aims at minimizing model error only but operational risk error taken as an objective function. This approach uses kernel tricks to optimize all operations, resulting in an intelligent radial basis function (RBF) neural network. Furthermore, a hardware implementation of CT saturation is discussed [97], demonstrating real-time execution on a loop environment using analog-to-digital convertor.

Precisely determining the parameters of the transformers is a considerable challenge in making protection schemes work, including parameters listed as follows.

A) Impedance: Transformers impedance determines the voltage drop across the transformer under load conditions influencing current flow and voltage regulation. Accurate values for this parameter are mandatory to determine fault currents and evaluate protective relay performance. In [98], three voltages and three currents measured at each side of the transformer create the basis of the algorithm. An impedance scheme is fed data via an edge detection technique that uses the fast Fourier transform (FFT) to identify and isolate faults within the transformer protection zone accurately.

B) Saturation characteristics: Transformers, when subjected to high magnetic flux densities, can become saturated, making the voltage-current relationship nonlinear. The knowledge of saturation characteristics helps predict how transformers will respond to different loads and faults. The initial idea of the method [99] is to identify the saturation characteristics by using collected inrush voltage and current waveforms. Studying the effects of transformer Energizing and related inrush currents requires accurately describing a transformer's "deep" saturation area. The close match between recorded inrush waveforms and simulation results has confirmed the proposed method's accuracy and performance.

C) Configuration of windings: The magnitude, or phase, relationship between the input and output voltages, as well as winding connections like delta or wye (star), all affect the capability of voltage transformation. In order to correctly analyze transformer behavior in protection schemes, it is crucial to accurately identify winding configurations. This study [100] investigates the mechanical faults in power transformer windings, such as axial displacement and radial deformation. Modeling these mechanical defects with the use of the comprehensive model in the EMTP software will allow researchers to examine how these imperfections affect the transformer's differential protection performance. Investigations are conducted into internal electrical issues such as turn-to-turn short circuits, terminal faults, and the inrush current phenomenon.

In order to identify their features as precisely as possible, engineers and utilities have developed a number of techniques, including complex computational models and real-world testing conducted in lab settings. A few potential fixes and useful ideas are listed below:

1) Testing in a lab: In these tests, transformers with known values of impedance or saturation are subjected to controlled studies. However, this method is rarely appropriate for transformers that are already in operation, and it can also be highly costly and time-consuming. It is critical to precisely align the test circumstances with the current working environment to guarantee reliable results. This work [101] proposes a simple and reliable method for estimating the characteristics that describe an electrical machine using load data obtained through experimentation under operating conditions. The equivalent circuit parameters of the single-phase transformer have been determined based on load data collected from the experiments. Particle swarm optimization and an H-G diagram-based resistance estimation technique were used for analyzing the data.

2) Field measurements: Direct measurements of transformer winding configuration and impedance on installed transformers provide real-world data but require specific tools and knowledge. Logistical limitations or safety issues, which frequently require precise preparation, coordination, and adherence to safety regulations, can restrict the ability to access transformers in the field. This research [102] provides an effective method for determining electrical transformers' unknown parameters. The artificial hummingbird optimizer (AHO) is the basis of the proposed approach, which is designed to produce the optimal values for the unknown transformer parameters.

3) Diagnosis monitoring: Transformers equipped with monitoring systems are able to track their own operation and identify irregularities. This is accomplished through the use of sensors and data collection tools that keep an eye on things like temperature, quality of oil, and winding vibrations. The data is then analyzed using advanced analytics and machine learning techniques to look for abnormalities. In work [103], a fiber optic sensor (FOS) is proposed to measure the vibration and temperature of power transformer windings. The FOS is composed of a Fabry-Perot cavity with two identical fiber Bragg gratings (FBGs).

4) Modeling and simulations: Transformer behavior can be simulated under different conditions using any computational simulation and modeling software. These models incorporate comprehensive descriptions of the geometry, materials, and operational features of the transformers that are employed. Validating model accuracy will require them to be calibrated against either laboratory tests or field measurements, though they must be validated through calibration against field measurements or lab testing practices themselves. In [104], we collect and provide an overview of the proposed, implemented, and verified power transformer models in a set of digital real-time simulation projects.

5) Evidence from the manufacturer and specifications: in the determination of transformer parameters and data given by the manufacturers serve as a point of reference. Sometimes there may be details about resistance, winding pattern, or core saturation levels. This study's analysis of the transformer line of production is its main goal [105]. The first, second, and third manufacturing areas were all thoroughly studied in this study, respectively. The results showed that the manufacturing industry must improve how its employees are assigned. By implementing multi-scenario assessment and adjustment, the simulation approach ensures optimal resource usage in the upgraded manufacturing line. Nevertheless, verifying these figures via field measurement or other validation methods is crucial because their practical performance can vary. These methods are utilized either alone or in combination to accurately fix transformer parameters that ensure the efficiency of protection schemes and the reliability of power systems. For each method, some pros and cons have to be taken into account in accordance with the concrete situation and objectives at hand.

6 Conclusions

The modern functionality of power systems relies heavily on the integrity of power transformers, underscoring the importance of their maintenance to uphold system stability, reliability, and overall operational security. In this study, we meticulously examine and analyze various techniques employed in differential protection to effectively discern between fault currents and inrush currents. Our investigation delves into the diverse types, underlying principles, distinctive features, and the respective advantages and drawbacks of these techniques. Key factors such as accuracy, complexity, and detection speed significantly influence the choice of differential protection techniques. As outlined in table 3, each method presents its own set of strengths and limitations, underscoring the importance of a thorough understanding and careful consideration in their selection. Exploring new techniques to overcome current drawbacks and bolster the reliability of transformer differential protection is crucial for future research.

Table 3: Comparison of various transformer differential protection techniques.

Technique	Principles	Features A	Features C	Features S	Advantage	Disadvantage
Harmonic-current restraint	Calculating the second harmonic	M	M	M	- Simple Principles - No need for transformer parameters - Fast in implementation	- Significant risk of malfunction - Dependent on threshold value - For long transmission lines, the inductance and capacitor have a negative impact on the action of differential protection -This technique has become limited due to improvements in magnetic materials (amorphous transformer cores with low power dissipation
Gap detection	Detecting the zero-crossing interval	M	M	F	- Simple principle - No need for transformer parameters - Fast detecting	- Affected by CT saturation -Not active for external faults -With high ground resistance
Flux-based	Calculating the dλ/di	M	M	F	- Low computational burden - Fast detecting	- Need for transformer parameters and leakage measurement - High dependence on the defined threshold -Implementation required large data - Require complexes techniques in order to perform the necessary calculations
Transformer inductance	Calculating the magnetizing inductance	M	L	F	- Simple in principle - Fast detecting	- Need for transformer parameters and extra measurements -Required current and voltage transformers for measurement. - A large computational burden
Fuzzy logic	Based on fuzzy rules	H	M	M	- Robust to CT saturation - Relatively high accuracy	- Spending more time to issue a decision - It is limited by distorted or loud inputs and by any modifications made to the power system configuration.
WT	Based on CWT or DWT	H	H	F	- Fast detecting - Relatively high accuracy	- High computational burden - High sensitivity to noise - Affected by CT saturation - A lengthy data window is necessary
ANN	Based on ANN	H	H	F	- Fast detecting - High accuracy	- Dependence on transformer parameters - Huge memory storage requirements - High computational expenses during training - Complicated experimental configuration
Hybrid	Based on two algorithms	H	H	F	- Relatively Fast detecting - High accuracy - more reliability and activity	- High computational burden - High complexity-More reliability

A: Accuracy, C: Complexity, S: Speed, L: Low, M: Medium, H: High

Author Contributions

W.A.A.: conceptualization, investigation, reviewing and editing; S.K.: investigation, methodology, writing an original draft; M.M.: conceptualization, data curation, writing—reviewing and editing, funding acquisition, project administration. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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