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# Simulation Model and Practical Testing of Operating Characteristic of Differential Protection for Optimization of Fault Discrimination of Power Transformer

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## Abstract

Differential protection is a key technique used to safeguard power transformers from internal faults while ensuring stable operation during inrush currents and external faults. The objective of this study is to evaluate the operating characteristic curve of differential protection by the simulation model enabled various fault scenarios, including magnetizing inrush currents, external faults, and internal faults. A differential protection model for a three-phase transformer was simulated using MATLAB/Simulink to simulate various fault conditions and also present a practical test was conducted using an Omicron CMC 356 tester tuned to the proposed curve to validate the relay's performance under controlled experimental conditions, which addresses the lack of experimental validation for differential protection under combined fault scenarios. The same fault types and parameters were used in both Simulink and Omicron CMC 356 tests, producing identical detection results with a 30 ms trip time. The experimental results closely align with those obtained from the simulation, confirming that the proposed differential protection operating characteristic curve is more stable when distinguishing external faults and inrush currents, and performs more efficiently when distinguishing internal faults. Combining real-time MATLAB/Simulink and CMC 356 experiments provides an effective methodology for validating the proposed differential protection technology for power transformers.

Keywords:- Differential Protection, Inrush Current, Internal Fault Detection, CMC 356 Test Set, Fault Discrimination.

## 1. Introduction

Power transformers are important elements in the electrical power grid, tasked with the crucial role of voltage transformation and providing the effective transmission of electrical power from generation to load. Their active operation is vital for ensuring a continuous power supply and keeping grid stability. However, transformers are prone to different types of faults such as phase-to-ground faults, winding failures, short circuits, and insulation breakdowns. These faults, if left improperly managed or unidentified, can lead to prolonged outages, catastrophic equipment damage, and serious safety hazards. Differential relays are considered essential for detecting and isolating internal transformer faults. The differential device operates by comparing currents flowing into and out of the transformer; these currents are balanced under normal operating conditions. When this balance is disturbed, an internal fault occurs, causing the relay to issue a trip signal and isolate the transformer before significant damage ensues [1], [2].

The underlying principle of differential protection relies on Kirchhoff's Current Law, which states that the algebraic sum of currents entering and leaving a node is zero. This principle is used by installing current transformers (CTs) on all transformer terminals. These CTs measure currents that, when compared, provide the differential current used by the relay to determine if an internal fault exists. The current entering and exiting the transformer differs significantly during internal faults, such as a winding short circuit. The relay identifies this difference as the differential current and starts protection activity for isolating faults. During external faults and under normal operation, the differential current remains close to zero because the CTs accurately reflect the same current magnitude and phase on both sides of the transformer, considering proper compensation for transformer vector groups and CT ratios. [3], [4]. However, although being highly reliable, differential protection of transformers has to face several natural dynamics in operation, also counting the existence of magnetizing inrush currents. If a transformer is powered when there is no load, it will pull a burst of current called inrush current. This inrush current can be several times the rated current of the transformer, occasionally exceeding 6 to 12 times the nameplate value, and it is of short duration. The inrush current is primarily a result of the core of the transformer being saturated and due to the residual magnetization in the core. Since the current is not a fault current, there should be no tripping of the relay. However, since inrush currents produce differential currents of a similar magnitude to those produced by internal faults, protecting the differential protection becomes quite complex. To address this, recent differential protection has adopted harmonic blocking or harmonic restraint schemes. They analyze the harmonics of the present waveform, particularly the second harmonic, which is typically low for fault current and high for inrush current. The relay is prevented from energizing by blocking. It operates, preventing a nuisance tripping as per the setting, if the distortion factor (percentage content of the second harmonic) is higher than a defined level (typically 10 -15%) [5]. Through transient conditions and high fault currents, CTs may saturate because of their magnetic core limitation led to distorts the secondary current signals provided to the relay. This saturation leads to inaccurate current measurements, potentially causing false differential currents. To migrate this, researchers have developed compensation methods and CT saturation identification algorithms to maintain relay stability and prevent unselectively disconnected operation. These techniques are incorporated into relay logic to adaptively adjust operation thresholds or apply correction factors during suspected saturation events [6].

To improve the security and reliability of differential protection, recent approaches use modern deep learning and signal processing techniques. Adaptive filtering technique analyzes multiple harmonic components beyond the second harmonic, including higher-order harmonics, to achieve more accurate inrush detection. Wavelet transform-based technique provides time-frequency localization of harmonic components, which is highly effective in distinguishing transient inrush currents from fault currents with non-stationary characteristics [7]. Furthermore, fuzzy logic and pattern recognition techniques employ heuristic knowledge and statistical characteristics of current signals to classify events as faults or inrush with improved detection efficiency [8]. Machine learning models, especially deep learning techniques such as convolutional and recurrent neural networks, have been proposed to automate and enhance differential relay decision-making. These techniques are trained on extensive datasets consisting of both inrush and fault scenarios, learning complex temporal and spectral patterns that differentiate between the two phenomena more reliably than traditional techniques [9]. Such intelligent protection systems provide a significant development in power transformer protection, proving faster and more accurate fault recognition capabilities. Due to instruments, safety, and expense limitations, actual testing of differential relays under different fault and transient conditions is sometimes impracticable because of the complexities of transformer work and protection logic. These programs give detailed analysis of protection performance, including sensitivity, response time, and stability under both non-fault and fault conditions [10]. Transformer models in these programs incorporate dynamic magnetic behavior, residual flux, nonlinear core saturation effects, and enable realistic simulation of fault transients and inrush currents. Protection algorithms can be implemented in MATLAB scripts or Simulink function blocks, providing seamless integration and experimentation of differential protection logic with transformer models.

In this study, transformer differential protection is explored through a combination of simulation and practical testing to better understand its performance under real-world conditions. The first part of the work focuses on creating two simulation models using MATLAB and Simulink. In the first model, transformer inrush conditions — such as core saturation and residual magnetism — are recreated using custom MATLAB functions. This model connects to relay logic built inside the Simulink environment, helping evaluate how well the relay can tell the difference between harmless inrush currents and dangerous internal faults. The simulation is enhanced using Simscape Electrical tools to find a more detailed, realistic model of the transformer and the electrical grid around it. This design makes it possible to perform a wide range of real-life conditions, from internal faults inside the transformer to external faults in the connected grid, furthermore normal operating conditions.

The protection relay is built into this simulation environment to see how the protection relay interface works in each operational condition. But the simulation alone cannot fully reflect grid behavior. This study also includes hands-on experimental testing using the OMICRON CMC 356 device. This device provides controlled current and voltage signals that simulate the most fault conditions, inrush events, and normal load scenarios. We can verify whether the system functions as intended in practice by seeing how the real relay reacts during these tests. This study provides a comprehensive understanding of transformer differential protection's operation by comparing simulation with actual results. The results of the analysis proved valuable new insights into how relay parameters might be perfectly configured to balance reliability and safety. It shows that the protection capability is influenced by harmonic constraint thresholds, CT precision, and saturation effects. Ultimately, this research contributes to the development of differential protection techniques, which are critical for the modern power system.

This paper's remaining sections are arranged as follows: In Section 2, the latest developments in transformer differential protection are reviewed, including both traditional and modern discriminating approaches. Section 3 describes the detailed modeling approaches for transformers and relay logic within MATLAB and Simulink environments, and a practical model, which is a 7UT SIEMENS differential protection relay that is tested by Omicron CMC 356. Section 4 presents simulation results and practical results under various operating scenarios, with a discussion of the implications of these results for relay design and setting. Finally, Section 6 concludes the paper, summarizing the contributions and suggesting future research directions.

## 2. Literature Review

Transformer differential protection has long been a critical area in power system protection, particularly due to challenges in distinguishing internal faults from inrush and other non-fault conditions. Sheryar et al. [11] presented a stability-oriented analysis for differential protection and emphasized the need for dynamic performance evaluation under varying loading and system conditions. Their case study underlines the importance of adaptive settings to improve security and dependability.

Hamilton [12] analyzed transformer inrush currents and evaluated various harmonic restraint techniques, concluding that the 2nd harmonic component remains a reliable inrush discriminator, though its accuracy can degrade under certain energization profiles.

Azizan et al. [13] contributed with a Simulink-based simulation of transformer differential relays, validating the model's sensitivity to fault currents while maintaining security during external disturbances, laying groundwork for relay algorithm development in MATLAB environments.

In the context of hardware and prototyping, Simatupang and Mungkin [14] designed a low-cost SCR-based differential relay prototype for single-phase transformers. Their work emphasizes the accessibility and educational value of hardware-level development. Meanwhile, Deng et al. [15] introduced an advanced optimization method for differential protection of converter transformers, incorporating magnetic flux restraints to mitigate false tripping during high inrush events. This approach enhances selectivity during transformer energization. Furthermore, Key, Son, and Nam [16] proposed a deep learning-based internal fault detection algorithm for power transformers, which significantly improves classification accuracy during overlapping inrush and fault conditions. Their study highlights the shift toward intelligent, data-driven protection solutions capable of adapting to the growing complexity of modern power networks.

Collectively, these works reveal a progressive trend in transformer protection—starting from basic simulation and hardware relay logic toward sophisticated. They affirm that combining analytical techniques, simulation tools like MATLAB/Simulink, and hardware test platforms such as CMC 356 is essential to achieving reliable and practical protection schemes for today's power systems.

## 3. Methodology

This study uses a dual method to evaluate the operation of differential protection using both simulation and practical testing. The methodology consists of two main parts: the first considers a MATLAB/Simulink model to simulate the differential protection technique, and the second focuses on the evaluation of the simulation results through practical testing using an Omicron CMC 356 and 7UT relay. The outcomes are compared to determine the performance and efficiency of the proposed study of differential protection. MATLAB/Simulink output results, like differential and current computation, are compared with real measured values based on the tests of the CMC 356. The comparison of the simulation results with actual tests proves a comprehensive knowledge of protection operation. All discrepancies between simulated and practical results were analyzed to refine relay and CT settings, harmonic restraint limits, and CT settings must be developed. This approach provides disciplined testing for transformer differential protection while verifying the functioning of the protection system in the majority of operating conditions through the integration of theoretical simulation with actual testing.

### 3.1 Transformer Modeling

The transformer used in this study is a three-phase as in Table 1, two-winding power transformer with a rated voltage of 132/33 kV, as indicated on the nameplate provided by CG, manufactured by IEC 60076 standards. The transformer follows a YND1 vector group configuration, meaning the primary side is star-connected with a grounded neutral, while the secondary side is also connected, ensuring compatibility for protection schemes, particularly differential protection, as modelled in this study.

**Table 1 model specifications of three-phase, two-winding power transformer.**

| Parameter | Specification |
|---|---|
| Manufacturer | CG |
| Standard | IEC 60076 |
| Transformer Type | Three-Phase, Two-Winding Power Transformer |
| Rated Power | 63 MVA |
| Rated Voltage (Primary) | 132,000 V |
| Rated Voltage (Secondary) | 33,000 V |
| Vector Group | YND1 |
| Tap Changer Range | ±10% in 17 steps (1.25% per step) |
| Rated Frequency | 50 Hz |
| Cooling Type | ONAN/ONAF (Oil Natural Air Natural / Oil Natural Air Forced) |
| Impedance Voltage (at 75°C) | 12.75% |
| Insulation Level (Primary) | 550 kV |
| Insulation Level (Secondary) | 170 kV |
| Rated Current (Primary side) | 275.15 A |
| Rated Current (Secondary side) | 1102.26 A |
| Maximum Oil Temperature Rise | 55°C |
| Maximum Winding Temperature Rise | 60°C |
| Core Connection | Star with grounded neutral (YN) |
| Secondary Connection | Delta (D1) |
| Weight (approximate) | 17,655 kg (total) |

The rated power of the transformer is 63 MVA, with cooling modes of ONAN/ONAF, which provide both natural oil-air cooling and forced air cooling for increased capacity. The impedance voltage is specified at 12.75% at 75°C, ensuring adequate fault current limitation and proper coordination with protective relays. The transformer features tap-changing capabilities on the high-voltage side, with 17 tap positions ranging from -10% to +10% in 1.25% increments, allowing for voltage regulation under varying load conditions.

The primary voltage is rated at 132,000 V, while the secondary voltage is 33,000 V, with tertiary windings present, typically for station services or auxiliary loads, though specific tertiary voltage ratings are not detailed in this view. The transformer is equipped with Class A insulation and is designed to operate with a maximum oil temperature rise of 55°C and a maximum winding temperature rise of 60°C under nominal loading conditions.

For simulation and relay setting purposes, the rated currents are derived as follows: on the high-voltage side, 275.15 A, and the low-voltage side, 1102.26 A, matching the CT configurations applied in both MATLAB/Simulink modeling and hardware testing using the CMC 356. The base insulation levels are 550 kV for the primary and 170 kV for the secondary, consistent with system protection requirements for a 132/33 kV network.

This transformer model provides a realistic and industry-standard basis for analyzing the differential protection scheme, as it represents typical equipment used in transmission substations for voltage step-down applications. The inclusion of detailed nameplate information ensures accuracy in simulations and parameter settings, enhancing the reliability and relevance of both computational and practical testing results in the context of this research.

### 3.2 Differential Relay Modeling

A differential protection relay is central to evaluating the activity of transformer protection techniques. Differential protection is based on the principle of the difference between the currents entering and leaving a protected zone—in this case, the transformer—to detect internal faults as shown in Figure 1. Accurate simulation of these relays requires implementing algorithms that mimic their fundamental operating principles, including current measurement, compensation for transformer characteristics, and fault discrimination logic.

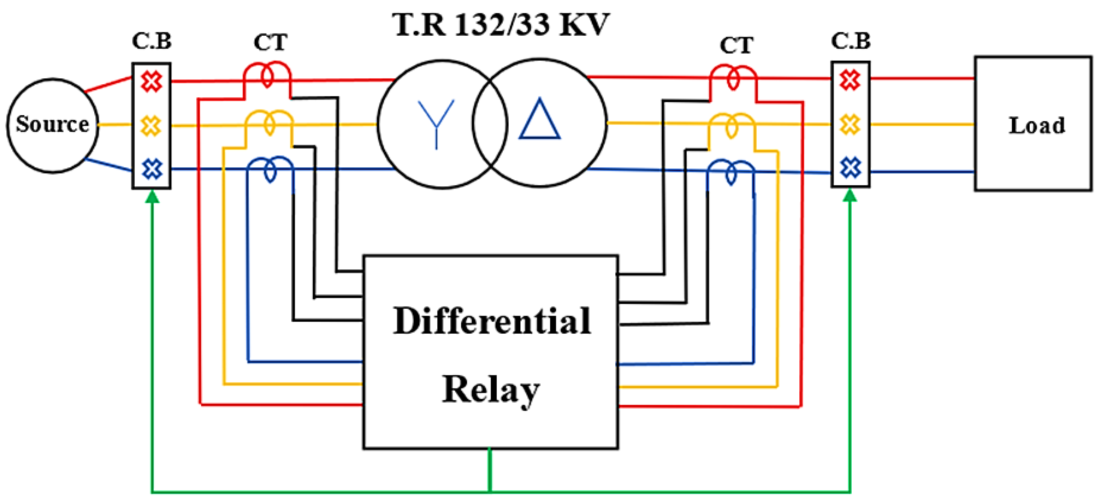


**Figure 1. General Block Diagram of Differential Protection.**

At the core of differential operation is the determination of the differential current, Idiff, which is the difference between the sum of primary currents in the transformer and the sum of secondary currents, after accounting for the transformer turns ratio and current transformer (CT) specifications [17]. This compensation ensures that, during external faults or under normal load conditions, differential protection estimates minimal differential current, thereby maintaining stability. Furthermore, to the percentage characteristic, differential protection incorporates blocking elements or harmonic restraint to develop security through transformer energization. Magnetizing inrush currents are rich in the second harmonic component, while internal faults generally have negligible second harmonic content [18], [19]. The relay algorithm extracts the second harmonic magnitude of the differential current using digital signal processing techniques, such as the discrete Fourier transform or bandpass filtering. To prevent false operations caused by inrush currents, the differential protection limits tripping when the second harmonic content exceeds a threshold, which is typically set between 10% and 15% of the fundamental component [20].

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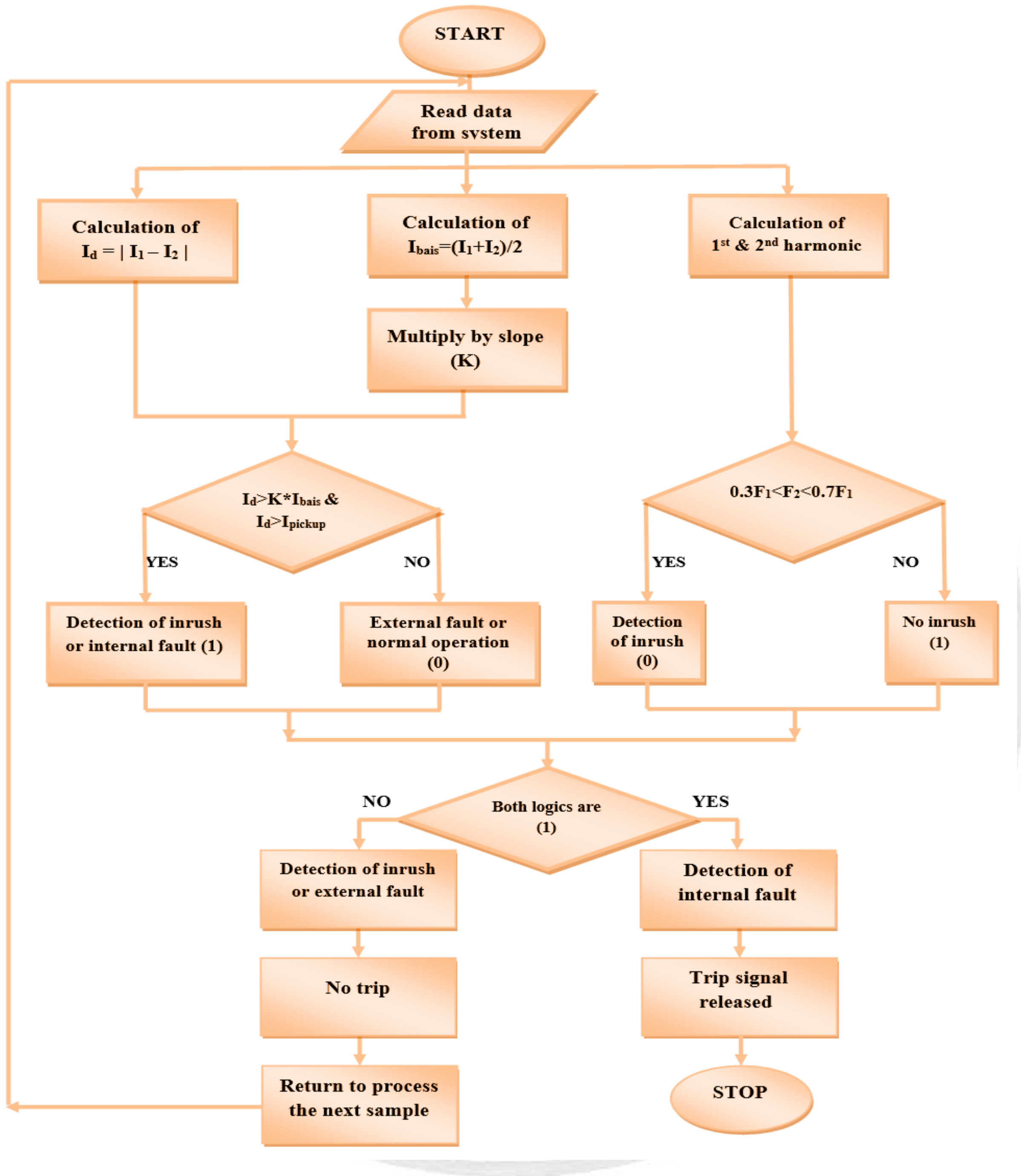


**Figure 2. Flow chart of the proposed Differential Relay Scheme.**

The flowchart as shown in Figure 2 illustrates the differential protection strategy's step algorithm with inrush current detection and restraint, which maintains reliable performance in the event of internal faults and prevents unselective tripping from external fault scenarios or inrush current. The process begins with collecting data from the power system, particularly primary and secondary current readings from the transformer. The system calculates the bias current. $I_{bais,}$, and the differential $I_d$ ,Where k is the transformer turns ratio and compensation factor for CT configurations.

Following this, the algorithm calculates the first and second harmonic components of the differential current and employs a signal processing method such as Fast Fourier Transform (FFT). The appearance of the second harmonic is a key factor in magnetizing inrush conditions through transformer energization. The flowchart incorporates a critical check on the harmonic content, where the second harmonic ratio F2/F1 is compared against a predefined threshold, typically between 0.3 and 0.7. If the second harmonic content is over the threshold, the algorithm classifies the event as inrush current, inhibiting the relay process to keep system stability.

In parallel, the differential protection logic set a percentage restraint characteristic by multiplying the bias current by the slope factor k. If the differential current over both the slope-set bias current and the relay's minimum pickup threshold, and no inrush condition is detected, the system recognizes an internal fault and initiates a trip signal to deenergize the transformer, avoiding damage [21].

If neither an internal fault nor an inrush condition is detected, the system determines the presence of either external faults or normal operating conditions, during which relay operation is restrained, and no trip signal is issued. The process then loops continuously, analyzing subsequent data samples to ensure real-time, dynamic protection of the transformer [22].

Differential protection integration in simulation programs such as MATLAB/Simulink considers various phases. To begin, currents measured from both transformer ends are sampled and normalized using CT ratios and transformer turns ratios. After that, the differential between the two currents is estimated. Subsequently, taking harmonic restraint conditions into account, the relay compares the differential current to its percentage characteristic curve. Once the differential current above the specified thresholds without harmonic restriction, the output becomes a trip signal [23].

Modern differential relay models may also integrate adaptive settings and artificial intelligence algorithms to improve discrimination between faults and transient phenomena. Recent studies have looked into ways to improve relay reliability and lower misoperations, including neural networks, fuzzy logic, and wavelet transforms [24]. The differential relay model entails simulating the basic working, such as differential current computation, percentage restraint, and harmonic blocking. This makes it possible to thoroughly verify relay operation under actual transformer process conditions, which serves as the foundation for protection scheme optimization [25].

A typical operating characteristic curve, as shown in Figure 3, used by the transformer differential protection technique, is depicted in the graph. This graphic shows a continuous current ($I_{bais}$) on the horizontal axis and the differential current ($I_{diff}$) on the vertical axis versus the bias. It helps differentiate between internal faults and external disturbances, like inrush currents or CT errors, by a differential protection will operate or restrain.

**Explanation of the Operating Characteristic:**

***A. Horizontal Axis – Bias Current ($I_{bais}$)***

The bias current is a measure of the current flowing through the transformer under normal operation or during external faults. It typically represents the average of the magnitudes of the primary and secondary currents, adjusted for the turns ratio. Bias current proves stability to the relay by accounting for transformer ratio mismatches, tap changer effects, and CT errors. The equation (1) used for bias current is:

$$I_{bais} = \frac{|I_1|+|I_2|}{2} \quad (1)$$

Where $I_1$ and $I_2$ are the primary and secondary currents, respectively, and k is the turns ratio correction factor that sets the secondary current to the primary side reference frame.

***B. Vertical Axis – Differential Current ($I_{diff}$)***

The differential current presents the imbalance between the incoming and outgoing currents of the transformer. Under normal operation and external faults, this current is ideally near zero. A significant differential current indicates the possibility of an internal fault, such as winding short circuits or insulation failures. The differential current is calculated in (2) as:

$$I_{diff} = |I_1 - k.I_2| \quad (2)$$

This relay is not allowed to operate in the protective device operating zones where the computed. $I_{diff}$ Is under that shown characteristic curve. This prevents false tripping in the event of inrush conditions, CT mismatches, or external failures. The relay trips in the above curve, indicating an internal transformer fault, when $I_{diff}$ Over the threshold set by the curve for a specific $I_{bais}$.

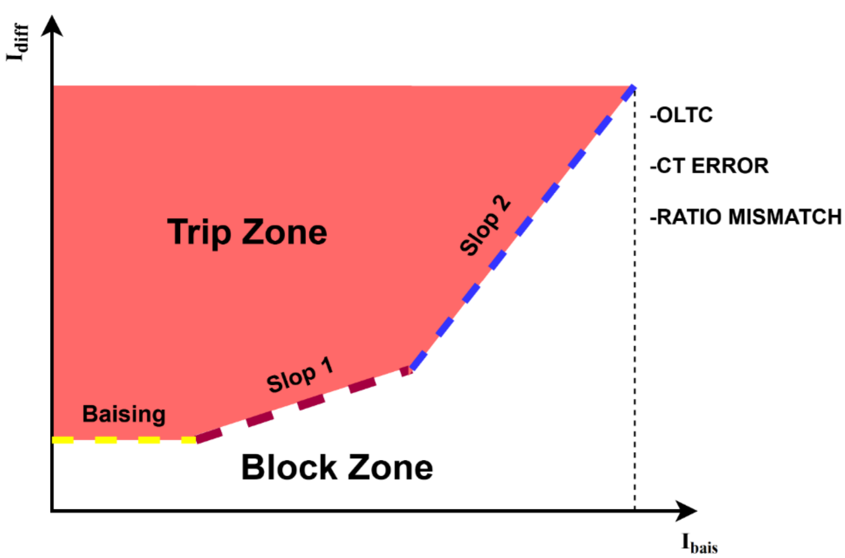


**Figure 3. The operating characteristic slopes.**

### 3.3 Differential Protection Hardware Testing

Siemens' advanced numerical protection system, SIPROTEC 7UT82, is designed to protect power transformers, reactors, and other comparable elements in high-voltage power grids. This SIPROTEC 5 family element provides high-speed and safe protection by using differential algorithms to accurately distinguish between external faults and internal faults and such as transformer inrush or current transformer saturation. Because it illustrates essential features including breaker failure strategies, restricted earth fault prevention, and overcurrent protection, as well as enabling protection for both two- and three-winding transformers, the protection system is suitable for both utility and power grid applications [26].

One of the primary characteristics of the 7UT82 is its integrated compensation for CT ratio changes, vector group shifts, and tap changer position; this provides precise differential current measurement and stable operation. Communication capabilities and IEC 61850 are specifications that allow ton interface simply with modern digital substations and SCADA. Its modular hardware design includes programmable logic operations, a graphical display for real-time monitoring, and comprehensive fault logging for post-event analysis [27]. The SIPROTEC 7UT82 reflects Siemens's approach of combining safety, automation, and communication into a single platform, which enhances operational efficiency and system reliability in today's complex electrical networks [28].


**Figure 4. Siemens numerical protection system, SIPROTEC 5 7UT82**

The Omicron CMC 356, as shown in Figure 5, is a highly modern and versatile protection device test set widely employed for testing different protection techniques, including differential protection in power systems. Differential protection is a critical protection device employed for detecting internal faults within power transformers, generators, and transmission lines by monitoring the current entering and leaving the protected zone. Reliable and Accurate testing of such protection tasks is important to provide the stability and safety of the power grid [29].

The CMC 356 is equipped with six independent current output channels, which makes it ideal for testing differential protection schemes that require simultaneous injection of currents in multiple phases on both sides of the protected equipment. The equipment can simulate internal and external fault statements by providing magnitude-varied and phase-shifted current signals such as. Through an internal fault simulation, the equipment can provide high differential currents with low restraining currents to check the relay's ability to trip. Conversely, for external faults or load flow conditions, the device can produce balanced currents with low differential components to verify that the relay remains stable and does not trip undesirably [30].


**Figure 5. The Omicron CMC 356 protection devices tester.**

Furthermore, the CMC 356 is designed for dynamic experiments, including transient playback, shot tests, and ramp tests, and allows for evaluating the relay's operation under fast-changing fault statements. It also supports advanced software control through Omicron's Test Universe software, which provides user-friendly test templates and automated test sequences for differential protection. The software also gives detailed reporting and documentation of the testing operation [31].

One of the important benefits of employing the CMC 356 for differential protection testing is its ability to test relays using different types of signal inputs, including analog and digital inputs (IEC 61850 GOOSE and Sampled Values), ensuring compatibility with both conventional and modern digital substations. Additionally, the flexibility and precision of the CMC 356 allow protection engineers to conduct thorough relay verification, including bias settings, harmonic restraint features, testing process times, and slope characteristics [32].

The Omicron CMC 356 has an important role in the troubleshooting, commissioning, maintenance, and testing of differential protection devices. Its good features, high accuracy, and support for both analog and digital checking platforms make it an indispensable tool for ensuring the reliable operation of power system protection devices [33].

## 4. Results and Discussions

The Results and Discussion section is one of the most important parts of a research paper. For your study on transformer differential protection using MATLAB/Simulink and CMC 356 practical test, this section should give the results of the simulation and testing parts, interpret those results, and relate them back to the research aims.

### *A. MATLAB/Simulink model*

The MATLAB/Simulink model, as shown in Figure 6, presents an implementation of transformer differential protection employing the 87T relay concept. This program simulates a power grid, including a differential relay, current transformers (CTs), circuit breakers, a power transformer, and a three-phase source.  This technique is designed to protect the transformer from internal faults while maintaining stability during normal operation and external disturbances. A three-phase voltage source supplies power into the transformer toward a load, giving a typical voltage transmission grid operating at 132 kV. This source connects to a circuit breaker that allows for controlled disconnection of the transformer in case of a detected fault or for maintenance purposes. A three-phase voltage and current measurement block is positioned after the breaker to monitor the electrical parameters essential for system observation and relay operation. The protection process begins with the current transformers on the primary side of the transformer. Three CTs that scale down high-line currents to lower, quantifiable values appropriate for input into the protection system are modeled; each has a rating of 300/5 A and 50 VA. For distribution purposes, this transformer reduces the voltage from 132 kV to 33 kV, which is a common configuration in electrical substations. The model accurately reflects both electrical characteristics and the physical winding configuration, which is critical since transformer winding connections affect differential protection calculations.

On the secondary side of the transformer, another group of CTs for measuring the output currents and parameters used in simulation is shown in Table 2. These CTs have a1200/5 A, to accommodate the higher currents represented on the low-voltage side of the transformer because of using the stepped-down voltage and higher current flow. The output from these CTs is connected to the differential protection system, providing that the currents input and output of the transformer can be precisely compared. The differential system known as “87T” receives the current inputs from both the primary and secondary sides with applies compensation for the transformer turns ratio, and calculates the difference current by subtracting the scaled two-side current. The protection uses a differential curve characteristic, which means the capability differential current increases proportionally with the transformer load current (bias current), giving stability through high load state and external faults. A fixed low pickup setting ensures that minor errors from CT mismatches or tap changer operations do not cause unintended trips. One critical feature included within this differential protection model is harmonic restraint content. Through transformer energization, flow through the windings, magnetizing inrush currents, rich in second harmonic content. The relay distinguishes these inrush events from genuine internal faults by detecting the presence of significant second harmonic components in the differential current. If the second harmonic exceeds a preset threshold, the relay refrains from tripping, ensuring system stability during transformer startup.

**Table 2: Parameters of the Transformer used for simulation.**

| Specification | Value |
|---|---|
| Slope of percentage differential | 20% |
| Pick up of differential | 0.25 ×In =0.25 × 5=1.25A |
| Windings resistance R1, R2 | 0.00348 p.u/ 2 = 0.00174 p.u |
| Winding reactance X1, X2 | 0.12733 p.u/ 2= 0.063665 p.u |
| Core resistance Rm | 1715 p.u. |
| Core reactance Xm | 1729 p.u. |
| Zero-sequence reactance Xo | 0.108 p.u. |

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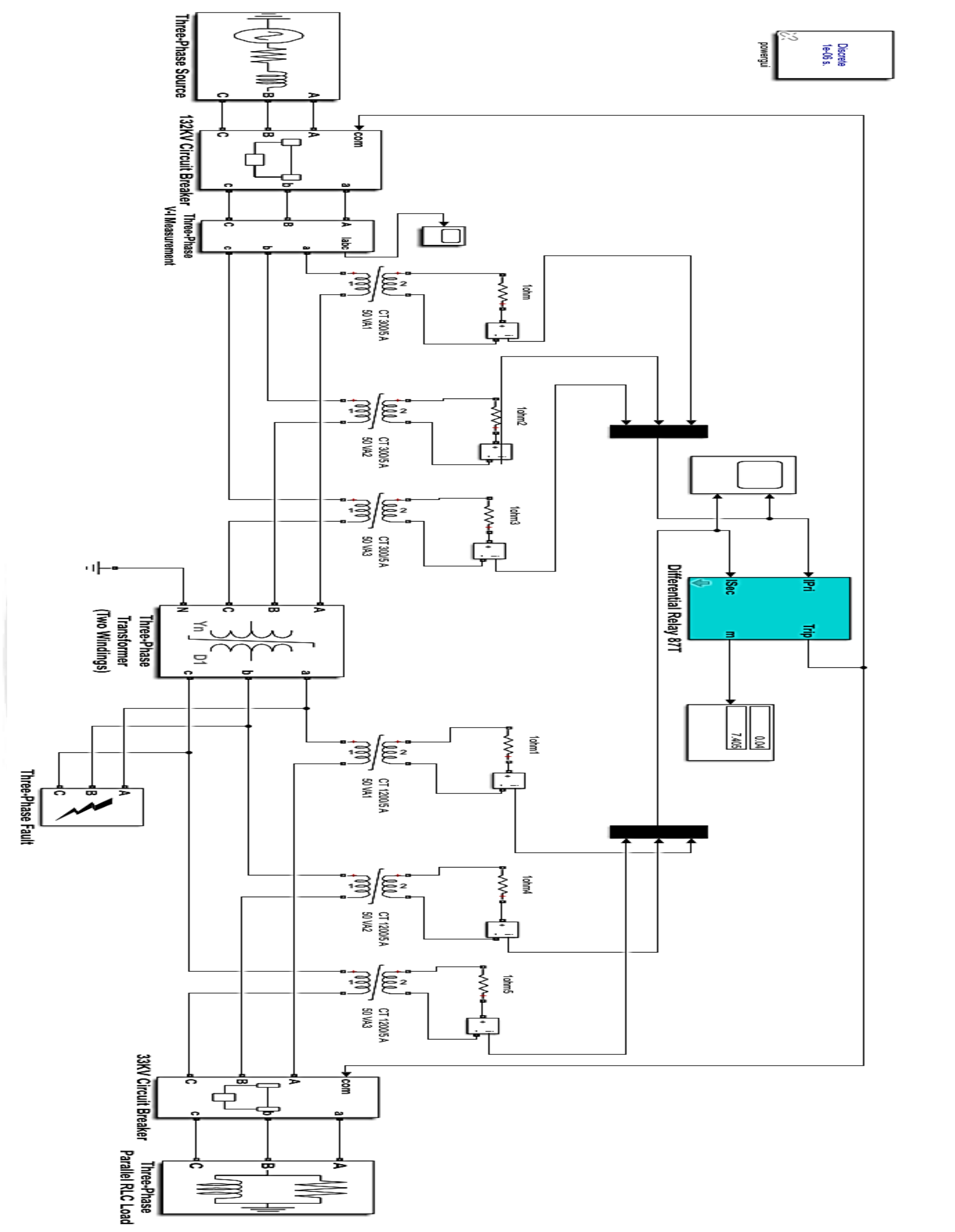


**Figure 6. The MATLAB/Simulink model of the Differential Protection System.**

Overall, this MATLAB/Simulink model provides a complete, realistic platform for testing and validating transformer differential protection schemes. It allows engineers and researchers to observe relay behavior under different operating conditions, fine-tune relay settings, and ensure that the protection system provides both sensitivity to internal faults and security against false trips caused by inrush currents or external disturbances.

The first waveform, as in Figure 7, represents the operating characteristic slope of the transformer differential protection relay. The graph plots the differential current (Idiff) against the bias current (Ibias), which helps determine whether a fault exists within the protected zone of the transformer. The characteristic is typically divided into multiple zones to ensure stable and secure operation. In the first zone (blue line), the relay remains stable and does not trip for low differential currents, allowing it to tolerate minor measurement errors or CT mismatches under normal operating conditions. The second zone (orange/red slope) introduces a bias-dependent tripping threshold to prevent false tripping during external faults with CT saturation. In the third zone (yellow steep slope), a much higher differential current is needed to trip the relay under high bias conditions, protecting against external disturbances while maintaining selectivity during heavy through-faults. This multi-slope characteristic ensures sensitivity to internal faults while maintaining stability during external disturbances and load changes.

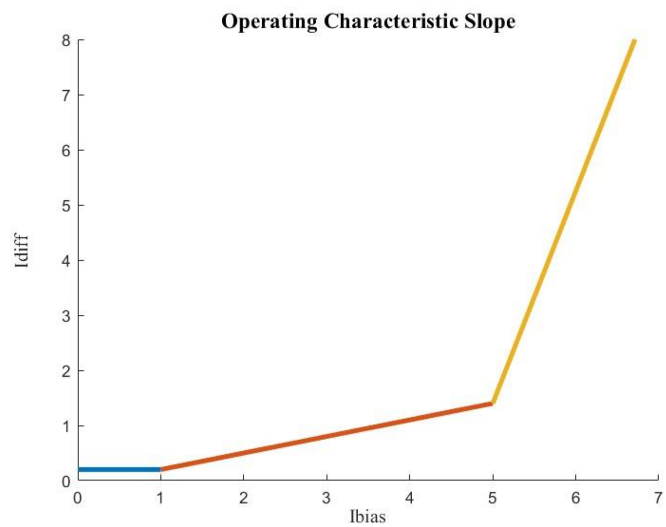


**Figure 7. The operating characteristic slope of the transformer differential protection.**

The second waveforms in Figure 8 show the three-phase inrush current characteristics of a power transformer over a time span of 0.5 seconds. The horizontal axis presents time in seconds, while the vertical axis shows current amplitude in arbitrary units labeled as “Iabc.” The three colored waveforms—typically representing phases A (red), B (blue), and C (yellow)—exhibit a transient response that is most prominent at the beginning of energization. Phase A shows an important higher peak inrush current, reaching values down to -15 units, showing a strong unidirectional magnetizing current commonly seen because of core saturation. Over time, the inrush currents in all three phases gradually settle into a more symmetrical, sinusoidal form as the magnetic flux stabilizes. This waveform pattern is typical during transformer energization

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and is critical for understanding transient behavior and designing protection schemes to differentiate between inrush and fault currents.

The third waveform, as presented in Figure 9, the differential current (Idiff) varied with time both before and after an internal fault occurred. From the testing, the differential current is still extremely low from the start to about 0.2 seconds, demonstrating stable, normal operation. When a failure inside the transformer windings starts to happen, the differential current starts to rise dramatically at about 0.2 seconds. The differential current maintains rising as the fault worsens and eventually passes the thresholds of the characteristic curve of the protection system, and the trip signal is changed from 0 to 1, as in Figure 10.

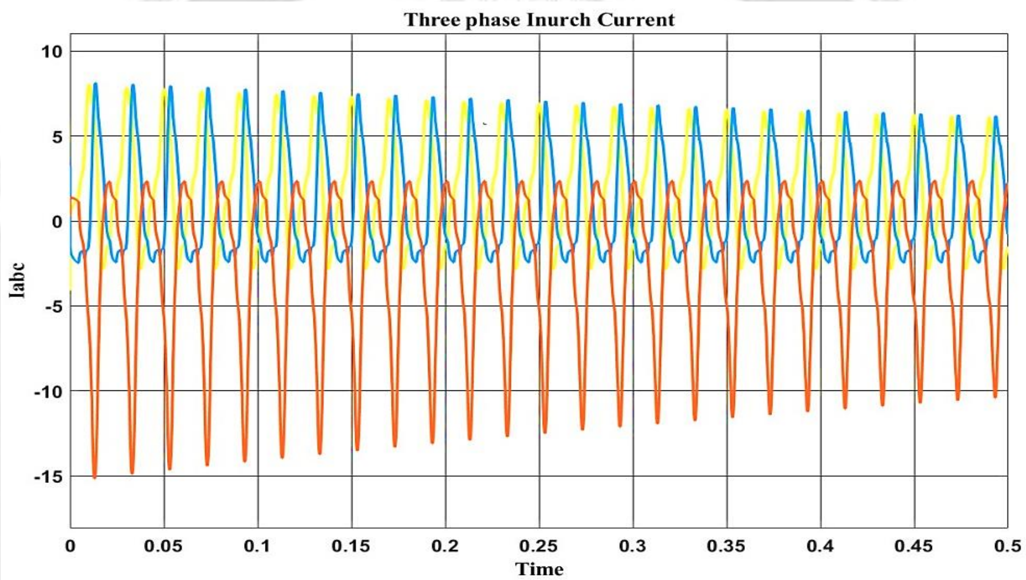


**Figure 8. Three-phase inrush current characteristics of a power transformer.**

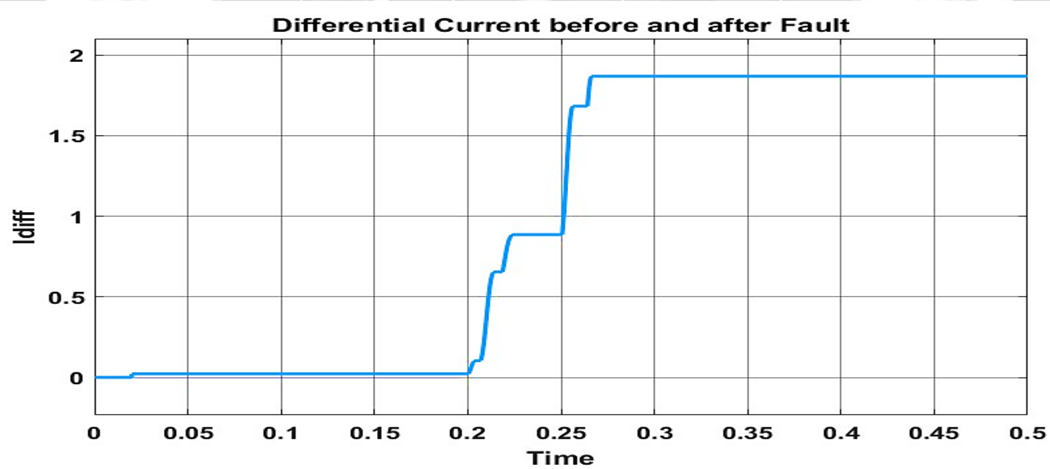


**Figure 9. The differential current varied with time both before and after an internal fault occurred.**

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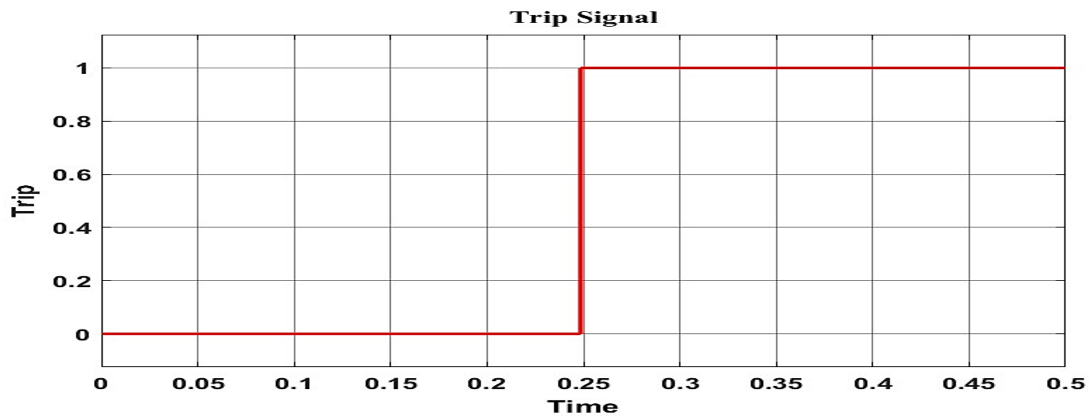


**Figure 10. The trip signal both before and after an internal fault happens.**

The waveforms in Figures 10 and 11 present the 132kV and 33kV sides of the transformer consist of three-phase current (Iabc) through the fault that happens. Before the fault, the three-phase currents show as balanced sinusoidal waveforms, presenting a normal load state. At approximately 0.2 seconds, the phase currents start to present signs of disturbance as the internal fault occurs. At 0.25 seconds, the phase current falls sharply toward zero, indicating that the differential protection is active and sends a trip command to the circuit breaker to disconnect the transformer from the grid. This rapid reduction in current confirms the proper functioning of the protection scheme, which prevented further damage by quickly disconnecting the faulted transformer section.

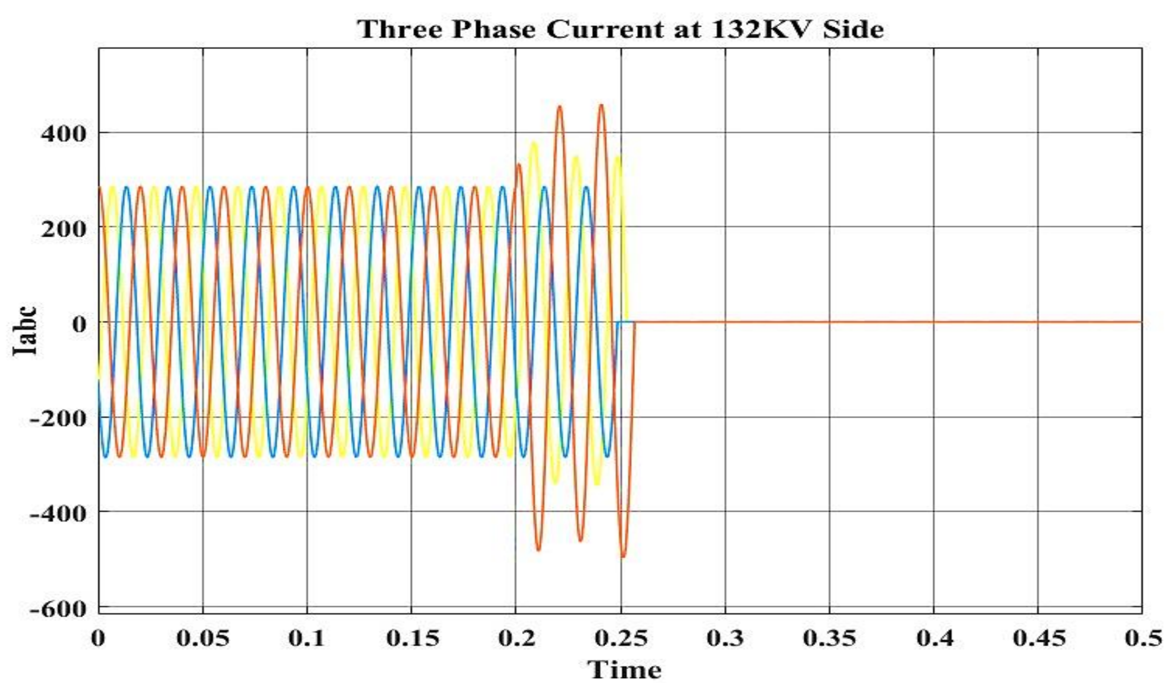


**Figure 11. Three-phase current (Iabc) of the 132kV side through the fault happens.**

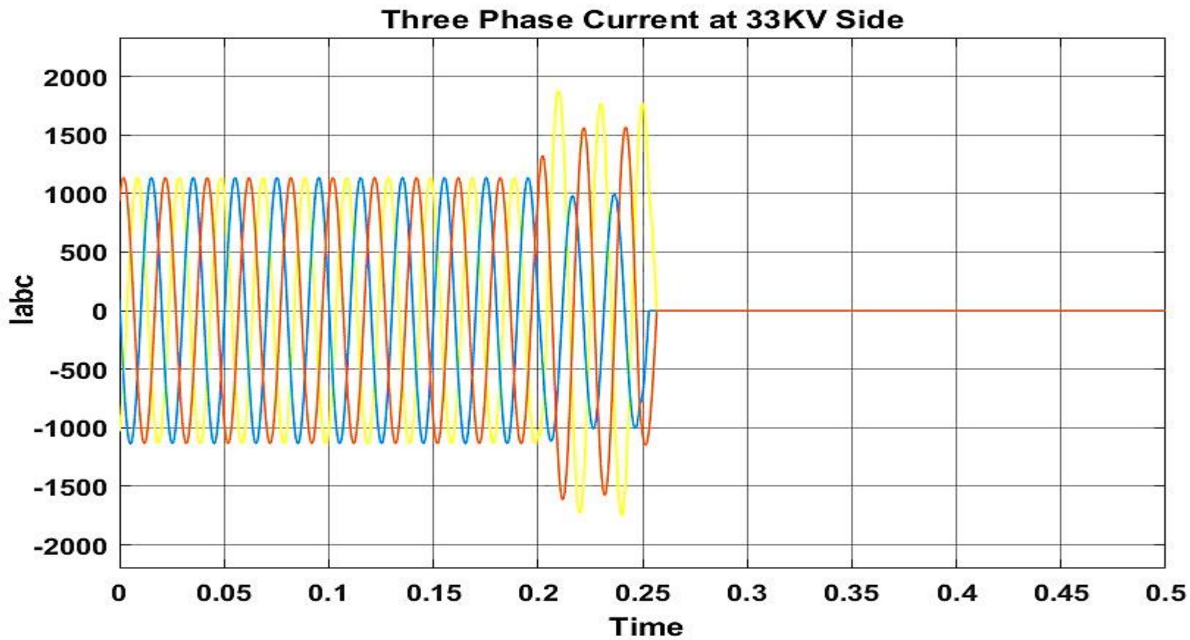


**Figure 12. Three-phase current (Iabc) of the 33kV side through the fault happens.**

These simulation results highlight the important role of transformer differential protection in recognizing internal faults and operating stably under different load and external fault states. The coordination between the operating characteristic curve, differential current monitoring, and fast breaker operation provides the protection system provide the necessary security and reliability for a 132/33 kV transformer.

**B. Practical Test by OMCIRON CMC 356**

Figure 13 illustrates the test experiment for differential protection of a power transformer employing the Siemens 7UT82 relay, the CMC 356 test set, and associated test software. The 7UT82 differential protection relay is connected to two groups of current transformers (CTs) representing the 132 kV and 33 kV sides of the transformer. These CT inputs (shown in red and blue wiring) are routed through the test terminal block and connected to the CMC 356 device, which simulates current signals. The CMC 356 is also connected to the trip input of the relay to detect when the relay issues a trip signal. A PC with specialized test software is connecting to the CMC 356 for controlling test parameters and recording results. This connection enables the simulation and analysis of various fault conditions to verify the correct operation of the differential protection scheme.

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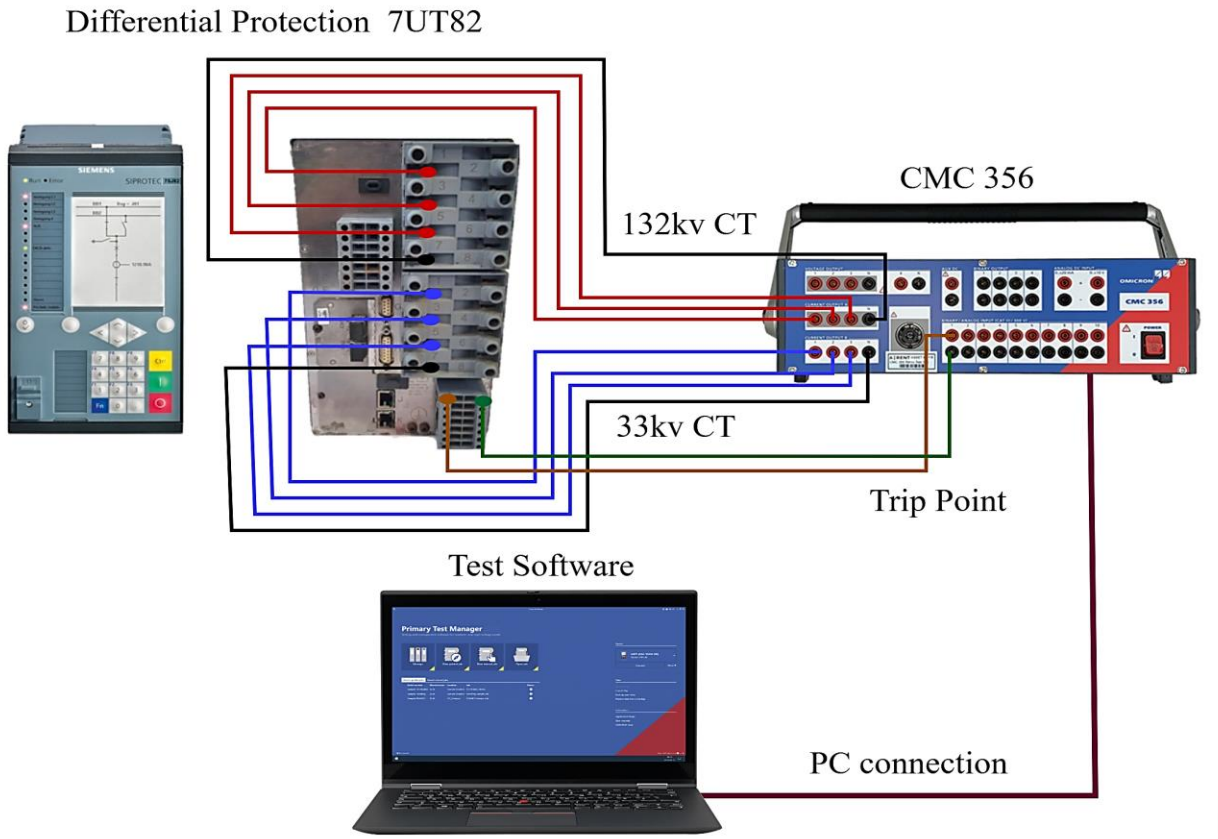


**Figure 13. The test experimental 7UT82 relay and the CMC 356 tester.**

This feature is important for experiment protection system performance, as it is capable the simulation of simulating different fault conditions, including phase-to-phase, phase-to-ground, and three-phase faults, both inside and outside the protected transformer zone. Finally, the low-voltage side feeds power to a three-phase parallel RLC load, representing typical consumer or industrial demand. Another circuit breaker is included on the 33 kV side to isolate the load, when necessary, either during fault clearing or protection system testing. The table outlines important electrical parameters for a transformer differential protection system. These parameters are essential for accurate modeling and reliable relay operation during fault detection.

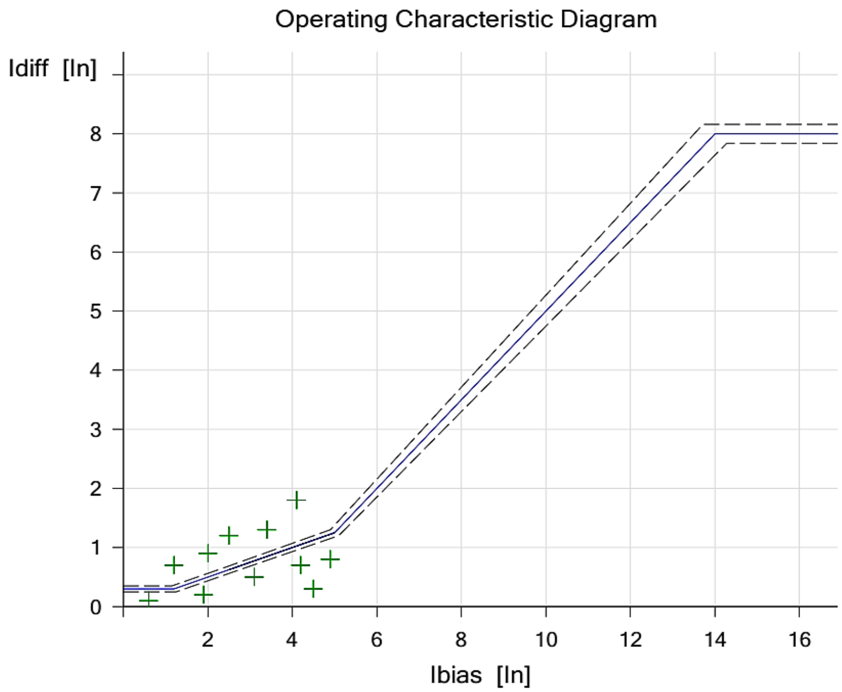


**Figure 14. The operating characteristic curve is set in Omicron tester software.**

The operating characteristic curve, as shown in Figure 14, provides a visual evaluation of the differential protection system process to external and internal fault simulations. The x-axis represents the bias current (Ibias) and the y-axis shows the differential current (Idiff), both normalized to the rated current (In). The blue solid curve shows the differential operating characteristic, knowing the threshold upper that the relay should operate (trip), and below which it should restrain (not trip). The dashed lines surrounding the curve present the tolerance band, indicating acceptable deviations due to measurement or timing tolerances. The green plus signs (+) on the plot show the actual test points set through the test. All the test points lie down or are very close to the differential characteristic curve, demonstrating that the protection system responded appropriately through all tested states. For test points where Idiff was down the operating curve, no trip was indicated, verifying the system stability and security versus external faults and during normal operation. However, points close to or on the curve present a trip case for internal faults, which were correctly performed by the system, with trip times recorded in the associated test table. The efficient configuration and calibration of the differential protection scheme are clearly indicated by the disappearance of any test points above the top tolerance band of test points with the predicted curve. With the time test table, these results confirm the system's dependability, sensitivity, and selectivity; it can accurately discern between external and internal faults. The differential protection scheme for the power transformer was subjected to a series of tests to evaluate its performance under varying load and fault conditions. Table 1 presents the results of these tests, illustrating the behavior of both the differential current (Idiff) and the bias current (Ibias), as well as the corresponding primary and secondary current measurements for each phase.

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In the initial test (Shots 1 to 3) in Table 3, the differential current remains relatively low, from 0.10 to 0.50 times the rated current (In), while the bias current increases from 0.60 to 3.10 In. Through this state, the differential protection system demonstrates appropriate restraint, as the measured differential current remains within acceptable limits, indicating no internal fault condition. The bias current changes from 2.50 to 4.50. In the test (Shots 4 to 6), the differential current rises to values between 1.20 and 0.30 In. The differential current across the device pickup thresholds in Shot 4 may indicate an internal state. With a maintained 180-degree phase difference, the current readings reveal increasing magnitude on both sides of the transformer. The result indicates that the system successfully identifies internal faults that point to an unbalanced situation.

**Table 3 Test Shots 1 to 6 done by CMC 356 secondary injection.**

| Shot | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Idiff: | 0.10ln | 0.20ln | 0.50ln | 1.20ln | 0.70ln | 0.30ln |
| I bias: | 0.60 ln | 1.90 ln | 3.10 In | 2.50 ln | 1.20 ln | 4.50 In |
| I Primary L1: | 1.607 A | 4.822 A | 8.267 A | 8.496 A | 4.363 A | 11.022 A |
| Phase Primary L1: | -180 | -180 | -180 | -180 | -180 | -180 |
| I Primary L2: | 1.607 A | 4.822 A | 8.267 A | 8.496 A | 4.363 A | 11.022 A |
| Phase Primary L2: | 0 | 0 | 0 | 0 | 0 | 0 |
| I Primary L3: | 0 A | 0 A | 0 A | 0 A | 0 A | 0 A |
| Phase Primary L3: | 0 | 0 | 0 | 0 | 0 | 0 |
| I Secondary L1: | 0.634 A | 2.156 A | 3.297 A | 1.649 A | 0.634 A | 5.326 A |
| Phase Secondary L1 | 0 | 0 | 0 | | 0 | 0 |
| I Secondary L2: | 1.268 A | 4.312 A | 6.594 A | 3.297 A | 1.268 A | 10.652 A |
| Phase Secondary L2 | 180 | 180 | 180 | 180 | 180 | 180 |
| I Secondary L3: | 0.634 A | 2.156 A | 3.297 A | 1.649 A | 0.634 A | 5.326 A |
| Phase Secondary L3: | 0 | 0 | 0 | 0 | 0 | 0 |

In the tests (Shots 7 to 12) in Table 4, variations in both differential and bias currents are shown to simulate fault evolution and different loads. Differential currents from 0.40 to 1.80In, while bias currents rise up to 4.90 In. In other where the differential current exceeds the device's set operating characteristic, as in Shots 9 and 10, the system is expected to perform, signaling an internal fault. However, the system prevents trips from high load states or external faults by suitably limiting performance in cases where strong bias currents and low differential currents synchronize as Shots 6 and 11. The system shows reliable sensitivity to internal faults and maintains stability to an external fault or inrush. These results show that the system can consistently safeguard the power transformer and are consistent with the differential device's anticipated behavior.

**Table 4 Test Shots 7 to 12 done by CMC 356 secondary injection.**

| Shot | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|
| Idiff: | 1.3 In | 0.9 In | 1.8 In | 0.8 In | 0.4 In | 0.50 In |
| Ibias: | 3.4 In | 2.00 In | 4.1 In | 4.9 In | 2.2 In | 0.70 In |
| I Primary L1: | 10.793 A | 6.659A | 13.548A | 13.089 A | 5.970 A | 2.756 A |
| Phase Primary L1: | -180 | -180 | -180 | -180 | -180 | -180 |
| I Primary L2: | 10.793 A | 6.659A | 13.548 A | 13.089 A | 5.970 A | 2.756 A |
| Phase Primary L2: | 0 | 0 | 0 | 0 | 0 | 0 |
| I Primary L3: | 0 A | 0 A | 0 A | 0 A | 0 A | 0 A |
| Phase Primary L3: | 0 | 0 | 0 | 0 | 0 | 0 |
| I Secondary L1: | 2.663 A | 1.395 A | 2.917 A | 5.199 A | 2.283 A | 0.254 A |
| Phase Secondary L1: | 0 | 0 | 0 | 0 | 0 | 0 |
| I Secondary L2: | 5.326 A | 2.790 A | 5.833 A | 10.399 A | 4.565 A | 0.507 A |
| Phase Secondary L2: | 180 | 180 | 180 | 180 | 180 | 180 |
| I Secondary L3: | 2.663 A | 1.395 A | 2.917 A | 5.199 A | 2.283 A | 0.254 A |
| Phase Secondary L3: | 0 | 0 | 0 | 0 | 0 | 0 |

The differential protection system for the transformer was checked by employing the CMC 356 secondary injection test set, specifically targeting L1-L2 fault conditions on the reference side primary. The test results in Table 5 included various combinations of differential current (Idiff) and bias current (Ibias) to evaluate the performance of the protection relay across a wide range of operating conditions. At low differential current levels (e.g., 0.10 In, 0.20 In, and 0.50 In) with relatively high bias currents (e.g., 0.60 In to 4.50 In), the protection system did not give a trip signal, as expected. This behavior shows that the Ibias-based restraint mechanism is successful in lower requires less tripping, and validates the relay's stability during normal operation or external fault state.

**Table 5 Test Results for Fault Types**

| Idiff | Ibias | Nominal Trip Time | Actual Trip Time | State | Result |
|---|---|---|---|---|---|
| 0.10 ln | 0.60 ln | N/T | N/T | Tested | Passed |
| 0.20 ln | 1.90 ln | N/T | N/T | Tested | Passed |
| 0.50 ln | 3.10 ln | N/T | N/T | Tested | Passed |
| 1.20 ln | 2.50 ln | 0.0300 s | 0.0291 s | Tested | Passed |
| 0.70 ln | 1.20 ln | 0.0300 s | 0.0301 s | Tested | Passed |
| 0.30 ln | 4.50 ln | N/T | N/T | Tested | Passed |
| 1.30 ln | 3.40 ln | 0.0300 s | 0.0292 s | Tested | Passed |
| 0.90 ln | 2.00 ln | 0.0300 s | 0.0305 s | Tested | Passed |
| 1.80 ln | 4.10 ln | 0.0300 s | 0.0280 s | Tested | Passed |
| 0.80 ln | 4.90 ln | N/T | N/T | Tested | Passed |
| 0.40 ln | 2.20 ln | N/T | N/T | Tested | Passed |
| 0.50 ln | 0.70 ln | 0.0300 s | 0.0297 s | Tested | Passed |

However, the device successfully worked within the anticipated time response for higher Idiff values (≥ 1.20 In), when internal faults are tested. For these fault states, the system's nominal travel time was set at 0.0300 seconds, but the recorded trip times changed between

0.0280 and 0.0305 seconds. These small deviations show high timing accuracy and confirm that the protection function responds quickly and consistently under fault status. All test cases returned a “Passed” result, providing that the protection settings are properly configured and that the differential protection device is correctly in both restraining and operating zones.

Table 6 summarizes various studies on transformer protection and relay testing techniques. It shows mothed ranging from theoretical analysis and simulations to hardware testing employing the CMC 356. The main point of focus is fault classification, inrush current recognition, and validation of protection performance. The results highlight development such as enhanced accuracy through artificial intelligence, effective inrush blocking using harmonic restraint, and reliable results from combined simulation and practical testing, as demonstrated in the current study.

## 5. Conclusion

This study has demonstrated the effectiveness of transformer differential protection through both simulation and experimental validation. Using MATLAB/Simulink, various transformer fault conditions—including inrush, internal, and external faults—were modeled to assess relay performance. The same fault types and parameters used in the Simulink simulation were applied in the experimental test using the Omicron CMC 356. The results from both approaches showed identical detection outcomes, with a consistent trip time of 30 ms. This strong correlation validates the reliability and accuracy of the proposed differential protection scheme. The close agreement between simulation and experimental results confirms that the developed protection model can reliably distinguish between internal faults and non-fault conditions such as inrush or external disturbances. This combined approach strengthens the reliability of transformer protection schemes and highlights the importance of integrating software modeling with practical hardware testing for modern power system protection design.

**Table 6: Comparative Table of Literature.**

| No. | Authors (Year) | Focus Area | Methodology | Key Contributions | Limitations |
|---|---|---|---|---|---|
| 1. | Sheryar et al. (2022), [11] | Stability analysis of differential protection | Case study, simulation-based analysis | Adaptive relay setting methods for improved stability | No hardware validation |
| 2. | Hamilton (2013), [12] | Inrush current and harmonic restraint comparison | Analytical + experimental | Detailed comparison of harmonic restraint techniques | Limited to specific restraint settings |
| 3. | Azizan et al. (2020), [13] | Simulation of differential relay for protection | MATLAB/Simulink | Relay validation for internal vs. external faults | Purely simulation; no hardware involvement |
| 4. | Simatupang & Mungkin (2025), [14] | Hardware prototype of single-phase differential relay | SCR-based hardware prototype | Low-cost educational relay development | Limited to single-phase systems |

| | | | | | |
|---|---|---|---|---|---|
| 5. | Deng et al. (2025), [15] | Inrush discrimination in converter transformers | Magnetic flux restraint modeling | Strategy optimized for converter transformer scenarios | Limited applicability to non-converter transformers |
| 6. | Key, Son & Nam (2024), [16] | AI-based differential protection | Deep Learning, substation data | Accurate fault detection during inrush using neural networks | High computational demand; needs large datasets |
| 7. | This Study | Differential relay testing via simulation and hardware | MATLAB/Simulink + CMC356 hardware test | Combined simulation and real-time testing; validated relay response under inrush, fault, and load conditions | Moderate complexity in model; transformer saturation modeled generally |

## References

[1] Adeniyi Kehinde Onaolapo, "Modeling and recognition of faults in smart distribution grid using maching intelligence technique," Jan. 2018, doi: https://doi.org/10.51415/10321/3250.

[2] A. Y. Hatata, M. A. Essa, and B. E. Sedhom, "Implementation and Design of FREEDM System Differential Protection Method Based on Internet of Things," *Energies*, vol. 15, no. 15, pp. 5754–5754, Aug. 2022, doi: https://doi.org/10.3390/en15155754.

[3] S. A. Hosseini, A. A. Nazari, B. Taheri, F. Razavi, and H. Hashemi-Dezaki, "Proposing a New Approach to Generate the Differential Trajectory of the Differential Relays Using COMTRADE Files," *Sustainability*, vol. 14, no. 21, p. 13953, Oct. 2022, doi: https://doi.org/10.3390/su142113953.

[4] M. Zhang, "Traceable Calibration and Evaluation of Toroidal Current Transformers for High Impedance Fault Detection in Electricity Networks," *INDIGO (University of Illinois at Chicago)*, Jun. 2024, doi: https://doi.org/10.26686/wgtn.26104570.

[5] I. Iliev *et al.*, "Modeling of Measuring Transducers for Relay Protection Systems of Electrical Installations," *Sensors*, vol. 25, no. 2, pp. 344–344, Jan. 2025, doi: https://doi.org/10.3390/s25020344.

[6] K. Solak, W. Rebizant, and A. Klimek, "Fuzzy Adaptive Transmission-Line Differential Relay Immune to CT Saturation," *IEEE Transactions on Power Delivery*, vol. 27, no. 2, pp. 766–772, Apr. 2012, doi: https://doi.org/10.1109/tpwrd.2011.2179815.

[7] Atiyah, Wael Abdulhasan, Shahram Karimi, and Mohamad Moradi. "Real-Time Revolutionizing Internal Defect Detection in Power Transformers by Leveraging Wavelet Transform and Deep Learning LSTM in Cascading Application." *Journal of Electrical Engineering & Technology* 19.8 (2024): 5273-5292.

[8] M. M. Marei, M. H. Nawir, and A. A. R. Altahir, "An improved technique for power transformer protection using fuzzy logic protective relaying," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 22, no. 3, p. 1754, Jun. 2021, doi: https://doi.org/10.11591/ijeecs.v22.i3.pp1754-1760.

[9] A. Aljohani and I. Habiballah, "High-Impedance Fault Diagnosis: A Review," *Energies*, vol. 13, no. 23, p. 6447, Dec. 2020, doi: https://doi.org/10.3390/en13236447.

[10] Saeed Jazebi, Behrooz Vahidi, and M. Jannati, "A novel application of wavelet based SVM to transient phenomena identification of power transformers," vol. 52, no. 2, pp. 1354–1363, Feb. 2011, doi: https://doi.org/10.1016/j.enconman.2010.09.033.

[11] M. Sheryar *et al.*, "An Approach to Performing Stability Analysis for Power Transformer Differential Protection: A Case Study," *Energies*, vol. 15, no. 24, p. 9603, Dec. 2022, doi: https://doi.org/10.3390/en15249603.

[12] R. Hamilton, "Analysis of Transformer Inrush Current and Comparison of Harmonic Restraint Methods in Transformer Protection," *IEEE Transactions on Industry Applications*, vol. 49, no. 4, pp. 1890–1899, Jul. 2013, doi: https://doi.org/10.1109/tia.2013.2257155.

[13] N. S. Azizan *et al.*, "Simulation of differential relay for transformer protection," *IOP Conference Series: Materials Science and Engineering*, vol. 767, p. 012004, Mar. 2020, doi: https://doi.org/10.1088/1757-899x/767/1/012004.

[14] Hendri Parulian Simatupang and Moranain Mungkin, "Design And Development Of A Differential Relay Prototype Using SCR For Single-Phase Transformers," *International Journal of Economic, Technology and Social Sciences (Injects)*, vol. 6, no. 1, pp. 22–36, 2025, doi: https://doi.org/10.53695/injects.v6i1.1269.

[15] R. Deng, H. Kong, L. Li, C. Lu, A. Xu, and C. Wang, "Research on optimization strategy of differential protection for inrush current in converter transformer considering magnetic flux restraint," *AIP Advances*, vol. 15, no. 7, Jul. 2025, doi: https://doi.org/10.1063/5.0282628.

[16] S. Key, G.-W. Son, and S.-R. Nam, "Deep Learning-Based Algorithm for Internal Fault Detection of Power Transformers during Inrush Current at Distribution Substations," *Energies*, vol. 17, no. 4, p. 963, Feb. 2024, doi: https://doi.org/10.3390/en17040963.

[17] Wael Abdulhasan Atiyah, S. Karimi, and M. Moradi, "Transformer Differential Protection Method for Recognition between Power Transformer Internal Defects and Inrush Current: A Comprehensive Review of Detection Techniques," *Applied Science and Engineering Progress*, Jul. 2024, doi: https://doi.org/10.14416/j.asep.2024.07.008.

[18] E. Stano, "The Method to Determine the Turns Ratio Correction of the Inductive Current Transformer," *Energies*, vol. 14, no. 24, p. 8602, Dec. 2021, doi: https://doi.org/10.3390/en142486.

[19] Lubomir Sevov and M. Valdes, "Differential Protection in Low-Voltage Buses: An Exploration of Principles and Models," *IEEE industry applications magazine*, vol. 23, no. 5, pp. 28–39, Sep. 2017, doi: https://doi.org/10.1109/mias.2016.2600688.

[20] Waad Noori Taboor, A. A. Obed, and A. Nabi, "Application of Wavelet Packet and S Transforms for Differential Protection of Power Transformer," *Journal of Engineering*, vol. 19, no. 2, pp. 264–279, May 2023, doi: https://doi.org/10.31026/j.eng.2013.02.08.

[21] M. Thompson, R. Folkers, and A. Sinclair, "Secure application of transformer differential relays for bus protection," pp. 158–168, Jan. 2005, doi: https://doi.org/10.1109/cpre.2005.1430430.

[22] B. Ahmadzadeh-Shooshtari and A. Rezaei-Zare, "Transformer Differential Protection During Geomagnetic Disturbances: A Hybrid Protection Scheme and Real-Time Validation Tests," *IEEE Transactions on Power Delivery*, vol. 39, no. 1, pp. 13–28, Feb. 2024, doi: https://doi.org/10.1109/tpwrd.2023.3333807.

[23] J. P. Desai, "Microgrid Harmonic-Restrained Dual Slope Differential Protection," *Journal of The Institution of Engineers (India) Series B*, vol. 105, no. 2, pp. 297–308, Jan. 2024, doi: https://doi.org/10.1007/s40031-023-00976-y.

[24] J. Klomjit and A. Ngaopitakkul, "Comparison of Artificial Intelligence Methods for Fault Classification of the 115-kV Hybrid Transmission System," *Applied Sciences*, vol. 10, no. 11, p. 3967, Jun. 2020, doi: https://doi.org/10.3390/app10113967.

[25] Wael Abdulhassan Atiyah, "A Novel Approach for Diagnosing Transformer Internal Defects and Inrush Current Based on 1DCNN and LSTM Deep Learning," *Journal of Electrical Systems*, vol. 20, no. 4s, pp. 2557–2572, Apr. 2024, doi: https://doi.org/10.52783/jes.3163.

[26] Fouzia Ammou, Younes Ziat, and Ousama Ifguis, "Investigation and simulation on the stability of transformer differential protection against external faults," *Life Cycle Reliability and Safety Engineering*, Jun. 2025, doi: https://doi.org/10.1007/s41872-025-00328-3.

[27] A. S. Sayed, E. M. Nabil, A. Y. Abdelaziz, M. Bajaj, and I. Zaitsev, "An enhanced protection scheme for power transformers integrating alpha plane analysis," *Scientific Reports*, vol. 15, no. 1, Mar. 2025, doi: https://doi.org/10.1038/s41598-025-92595-4.

[28] Y. Li, P. Guo, Q. Xu, and J. M. Guerrero, "A novel FRT strategy for transformerless MMC to improve current differential protection performance under single-phase grounding faults," *International Journal of Electrical Power & Energy Systems*, vol. 168, pp. 110729–110729, May 2025, doi: https://doi.org/10.1016/j.ijepes.2025.110729.

[29] Daksh Vyawhare, J. Chaudhari, C. Parekh, M. Chaturvedi, and K. Shah, "Differential Protection of Power Transformers Using Discrete Wavelet Transform and Convolutional Neural Network," pp. 1–6, Feb. 2025, doi: https://doi.org/10.1109/tpec63981.2025.10906891.

[30] C.-W. Huang, C.-C. Fang, W.-T. Hsu, C.-C. Yang, and L.-T. Zhou, "Improving the Protection of Step-Down Transformers by Utilizing Percentage Differential Protection and Scale-Dependent Intrinsic Entropy," *Entropy*, vol. 27, no. 4, p. 444, Apr. 2025, doi: https://doi.org/10.3390/e27040444.

[31] U. Ehsan *et al.*, "A Detailed Testing Procedure of Numerical Differential Protection Relay for EHV Auto Transformer," *Energies*, vol. 14, no. 24, p. 8447, Dec. 2021, doi: https://doi.org/10.3390/en14248447.

[32] E. Casagrande, W. L. Woon, H. H. Zeineldin, and D. Svetinovic, "A Differential Sequence Component Protection Scheme for Microgrids With Inverter-Based Distributed Generators," *IEEE Transactions on Smart Grid*, vol. 5, no. 1, pp. 29–37, Jan. 2014, doi: https://doi.org/10.1109/tsg.2013.2251017.

[33] S. Kar, S. R. Samantaray, and M. D. Zadeh, "Data-Mining Model Based Intelligent Differential Microgrid Protection Scheme," *IEEE Systems Journal*, vol. 11, no. 2, pp. 1161–1169, Jun. 2017, doi: https://doi.org/10.1109/jsyst.2014.2380432.

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# نموذج محاكاة واختبار عملي لخصائص التشغيل للحماية التفاضلية لتحسين التمييز بين الأعطال في محولات القدرة.

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**الخلاصة:**

الحماية التفاضلية تقنية أساسية تُستخدم لحماية محولات الطاقة من الأعطال الداخلية مع ضمان استقرار التشغيل أثناء تيارات الاندفاع والأعطال الخارجية. تهدف هذه الدراسة إلى تقييم خصائص منحني التشغيل للحماية التفاضلية من خلال نموذج المحاكاة المُمكّن لسيناريوهات الأعطال المختلفة، بما في ذلك تيارات الاندفاع المغناطيسية والأعطال الخارجية والأعطال الداخلية. تمت محاكاة نموذج حماية تفاضلية لمحول ثلاثي الطور باستخدام MATLAB/Simulink لمحاكاة ظروف الأعطال المختلفة، كما تم تقديم اختبار عملي أُجري باستخدام جهاز اختبار Omicron CMC 356 مضبوط على المنحنى المقترح للتحقق من صحة أداء المُرحّل في ظل ظروف تجريبية مُتحكم فيها، مما يُعالج نقص التحقق التجريبي للحماية التفاضلية في سيناريوهات الأعطال المُدمجة. تم استخدام نفس أنواع الأعطال والمعلمات في كل من اختبارات Simulink وOmicron CMC 356، مما أدى إلى نتائج كشف متطابقة بوقت رحلة قدره 30 مللي ثانية. تتوافق النتائج التجريبية بشكل وثيق مع تلك التي تم الحصول عليها من المحاكاة، مما يؤكد أن منحنى خصائص التشغيل المقترحة للحماية التفاضلية أكثر استقرارًا عند التمييز بين الأعطال الخارجية وتيارات الاندفاع، ويؤدي أداءً أكثر كفاءة عند التمييز بين الأعطال الداخلية. يوفر الجمع بين تجارب MATLAB/Simulink وCMC 356 في الوقت الفعلي منهجية فعالة للتحقق من صحة تقنية الحماية التفاضلية المقترحة لمحولات الطاقة.

**الكلمات الدالة:** الحماية التفاضلية، تيار الاندفاع، اكتشاف الخطأ الداخلي، مجموعة اختبار CMC 356، التمييز بين الأخطاء.