Review on Different Techniques for Differential Protection of Power Transformer

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Abstract - *Significant work has been put into developing digital relaying algorithms because of the many advantages of digital relaying in terms of economy, performance, dependability, flexibility, and system interaction. In this study, numerous methods established for the differential protection of three-phase transformers are surveyed and compared. The algorithms introduced for digital relaying are described after a brief examination of the concept, the issues with differential protection of transformers, and the existing solutions as implemented with conventional (electromagnetic) relays.*

The article discusses both the most contemporary technologies for transformer protection, such as artificial neural networks (ANN) and fuzzy logic, as well as more traditional ways. The use of ANN and fuzzy approaches for the safety of power transformers is stressed more than the use of conventional methods, which are just briefly mentioned.

Key Words: *Differential Protection, Power Transformer*

1. INTRODUCTION

Being one of the most expensive parts of the electrical power system, the power transformer needs to be well secured from internal problems. Transformers frequently incur transient faults, which can overwhelm the differential protection's winding current transformers (CTs). Through-faults with a saturated CT might cause the transformer breakers to trip and the differential protection to operate improperly.

About 11.62% of power transformer failures are due to winding defects, according to a CIGRE technical paper [2]. Due to its ease of use and speedy functioning, the differential relay is the main piece of protective equipment in big power transformers [3]. Inrush current, which is a transient current with an 8–10 times bigger magnitude than the full load current, can flow in the transformer windings when a transformer is first powered or encounters a rapid shift [4].

Inrush current and internal faults cannot always be distinguished by differential relay [3, 5]. Various approaches and strategies, which may be categorised into three groups, have been presented to differentiate the inrush current from internal defects. The first category consists of signal processing techniques that extract the spectral and wave shape characteristics of data using feature extractors like the wavelet transform (WT) and fast Fourier transform (FFT) [6]–[9]. These approaches' drawbacks include a heavy computing cost, susceptibility to noise, and a particular tendency to be affected by threshold settings.

Trial and error should be used to determine the threshold values since otherwise the protection system's generality and dependability would suffer, especially in the face of outside influences. The second set of techniques are model-based techniques that aim to determine an exact estimation of the primary winding current by utilizing estimation techniques like the Kalman filter (KF) to find the magnetizing inrush currents [9].

2. DIFFERENT TOPOLOGY OF DIFFERENTIAL PROTECTION OF POWER TRANSFORMER

Finding a quick and effective differential relay method that separates the transformer from the system inflicting the least harm is the key problem in transformer protection. As the algorithm distinguishes between the operating situations, it should also avoid performing improperly. An enhanced differential protection system for power transformers is presented in article one. The suggested plan is based on a ratio of the primary and secondary currents of each phase's absolute difference and absolute sum, plus the primary and secondary terminal voltages of each phase's absolute difference and absolute sum. The proposed algorithm aims to prevent improper operation that could result from transient phenomena like magnetic inrush current, simultaneous inrush with internal fault, and faults with current transformer saturation. This mal-operation could occur with the conventional three-phase transformers differential protection scheme. The suggested differential protection technique has been investigated utilizing current and voltage ratios, and the results indicate that it can deliver a quick, precise, safe, and reliable relay for power transformers.

It is possible to distinguish between inrush and fault circumstances using the current ratio. However, transformer energization due to an internal problem is identified using voltage ratio. Additionally, the suggested relay is restrained using the current direction criterion during external faults and heavy energization. Numerous fault- and non-fault-related situations have been simulated. The suggested method successfully distinguishes between magnetising inrush and fault circumstances in less than a half power frequency cycle, as shown in article [1]. In many circumstances, it is also analyzed if fault resistance and ct saturation exist.

The findings demonstrate that, depending on the fault case, the suggested approach may quickly identify and categorize fault situations from neutral ends with 3% of windings and higher. This method is determined to be straightforward, trustworthy, secure, and reliable for differentiating between inrush currents and fault currents.

A well-known method for protecting transformers, motors, generators, buses, and other types of power equipment having input and output current measurements is the current differential principle. The concept is also utilized to create percent differential protection that may be tuned to a certain sensitivity for detecting in-zone faults and security during external faults. The typical method for achieving this protective reliability is to simulate a differential-restraining feature with two regions—one working and the other not—while monitoring the actual differential restraint ratio during faults. The installed current transformers (CTs) would quickly get saturated by some external faults with large dc offset and high X/R system time constant, which would then result in high differential/restraint ratios over the set characteristic in the working zone. The differential protection would activate in these circumstances, resulting in an unintended transformer trip.

The article focused [2] on certain improvements made to the primary differential protection's differential concept and provided instructions on how to set up the protection for increased security and sensitivity.

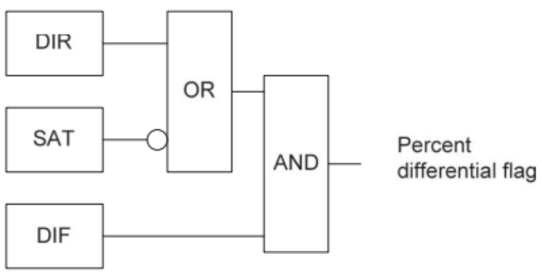

Fig-1: 87T security logic [2]

If the differential/restraint feature is the only factor providing security, the transformer percent differential protection is not sufficiently dependable during an external malfunction. Due to the saturation of CTs caused by external faults, there may be instances in which dangerously high differential/restraint ratios cross the characteristic and cause an undesired trip. It is essential for the protection to give extra security during external faults with the aid of early CT saturation detection and directionality check. To configure the protection for best performance, a thorough investigation of the system, including the power transformer and current transformers, is required.

One of the primary issues with the power transformer differential protection has been the current transformer (CT) saturation phenomena, which results in inaccurate current readings and improper relay functioning. In order to stabilize the relay during external faults and accurately distinguish CT saturation from cross-country internal faults, one of the authors proposed [3] a quick and effective transformer differential protection scheme with additional differential CT saturation and cross-country fault detection modules after the external fault detection. All of these modules were based on the differential wavelet coefficient energy with border distortions.

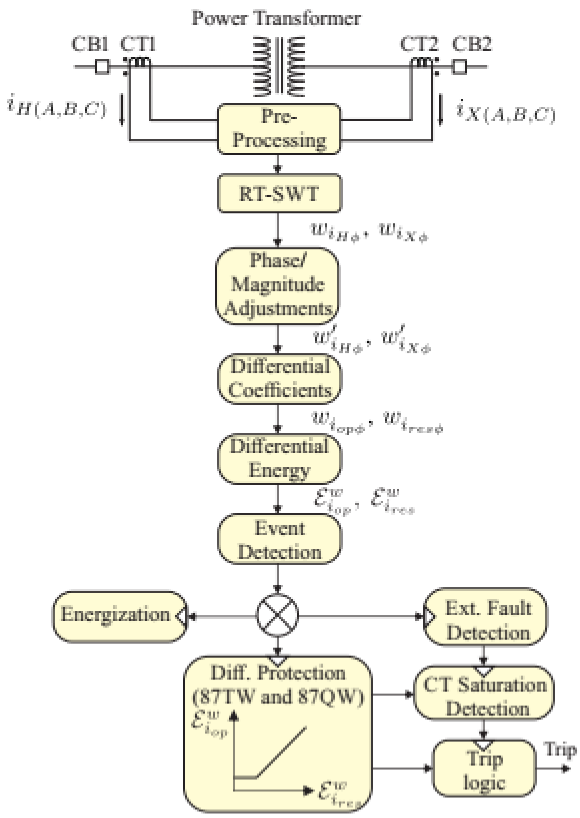

Fig-2: The proposed wavelet-based transformer differential protection [3]

With typical simulations of internal faults, transformer energizations, and external faults with CT saturations followed by cross-country internal faults, the performance of the proposed technique was evaluated. While a phasorbased conventional protection scheme only guaranteed 92.60% of success rate with an average relay operating time of 19 ms, the proposed wavelet-based differential protection with only 87TW and 87QW units presented a success rate of 100%for detecting internal faults with an expressive average relay operating time of 214 s. The suggested approach was the most straightforward, efficient, and precise one.

Both the suggested and the traditional procedures were resistant to the CT saturation with regard to the many events to the power transformer. However, compared to the usual method, the suggested CT saturation detection module is simpler, needing simply the incorporation of a wavelet coefficient energy increment/decrement counter as opposed to the standard harmonic-based functions. Additionally, the suggested approach guaranteed a 100% success rate in identifying cross-country internal problems from the database 4, as opposed to the standard approach's 89% success rate employing both independent and cross-blocking modes. In comparison to the conventional technique using the independent and cross-blocking modes, which had success rates of 100% and 87.05%, respectively, the suggested method for databases 5 and 6 ensured a detection success rate of 99.11% for cross-country internal problems. As a result, the suggested technique demonstrated high reliability in identifying cross-country internal defects and was immune to CT saturation.

For the protection of a three-phase transformer, author [4] offers a differential algorithm to distinguish between transient events such inrush currents and external faults from solid and turn-to-turn faults. To determine the type of event, the algorithm is based on the behavior of the second central moment (SCM). Instantaneous differential currents are filtered and normalized before being used as input signals by the algorithm. To successfully identify the event, the system compares the SCM's magnitude with a predetermined threshold based on the binomial distribution. The algorithm recognizes the occurrence as a fault situation if the SCM magnitude exceeds the limit. If not, the event is classified as a steady-state situation or a transitory event. If the transformer's settings are altered or the harmonic makeup of the differential current changes, the threshold is setting-free. If the power system is changed, the threshold does not need to be recalculated. When current transformers undergo saturation, the D index was developed to speed up fault diagnosis. This index compares the SCM's magnitude to a certain limit in order to identify the fault current. Both indices operate simultaneously, and if any of them crosses either of their thresholds, a fault situation is identified. The technique is built in MATLAB and evaluated using a real-time digital simulator (RTDS).

The magnitude of the SCM and the D index for each phase were determined using the suggested technique using the differential current. To distinguish between distinct types of events, both indices were compared to their corresponding thresholds. Detection of an inrush current or an incident that does not necessitate urgent protective action was made if the SCM or D index did not meet the set requirements. If not, it was seen as an internal problem. Compared to the 89.95% accuracy of the traditional technique, the algorithm's accuracy was 99.63%. A typical defect detection time smaller than a cycle of 60 Hz was also revealed by the suggested approach. These findings demonstrated that a novel differential protection for three-phase power transformers may be built using the algorithm.

Author was tasked with [5] creating a differential protection strategy to distinguish between internal faults and power transformer magnetizing current in order to reduce the likelihood of false tripping. A method based on an accelerated convolution neural network (CNN) is developed to distinguish between internal defects and inrush current. The proposed algorithm's primary competitive advantage is its ability to combine the fault detection and feature extraction blocks into a single deep neural network (DNN) block by allowing the network to automatically identify key features.

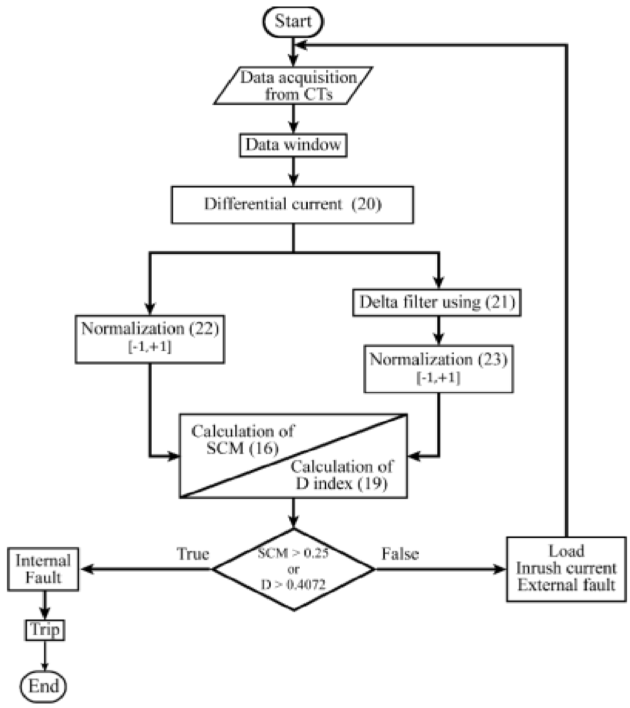

Fig-3: Flow diagram of second central moment-based transformer differential protection [4]

This leads to the algorithm being faster, more hardware-friendly, and more accurate as a consequence. The proposed method is applied to a simulated 230kV network and an experimental prototype. Different cases with various external factors are simulated to calculate reliability indexes.

Comparison between the accelerated CNN, conventional CNN, and nine widely used methods demonstrates the faster and more reliable performance of the proposed algorithm.

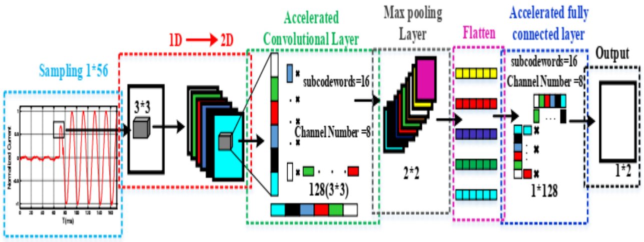

Fig-4: Procedure of the proposed differential protection scheme of the power transformers [5]

The computational cost, dependence on the model, and preset threshold of existing approaches in differential protection to differentiate internal defects from the inrush current in power transformers reduce the dependability and generality of this critical operation. With the help of the enormous quantity of data captured by contemporary data gathering systems, the suggested solution represents a significant advancement in the practical intelligent automation of power transformer protection. By employing the product quantization approach to accelerate the convolution and FCN layers, we created an accelerated CNN. The accelerated CNN runs four times quicker than the basic CNN, improving accuracy by around 1% while maintaining accuracy. Furthermore, once the CNN structure is established, the suggested machine learning-based security mechanism may be used with many systems independent of the system characteristics. Both simulated and actual scenarios of applying the suggested strategy to a system were used. Ten additional approaches, including eight data-driven and two signal processing methods, were compared to the outcomes of the accelerated CNN method.

When an internal defect develops during DC bias or inrush current, the converter transformer's current differential protection stops working. In order to create a new differential protection system, a new criteria is therefore provided in [6]. The new criterion is determined by the wavelet energy entropy (RWEE) of the primary fault component to the secondary fault component. Once an internal fault occurs, the energy entropy (WEE) of the primary side is much larger than that on the secondary side, and then a large RWEE can be obtained. Otherwise, WEE of both sides are similar, and RWEE is around one. The simulation results show that the proposed criterion can perform well under inrush current, CT saturation, and DC bias conditions. It can discriminate the internal fault from external fault. Most importantly, it avoids the refusal of tripping when an internal fault occurs.

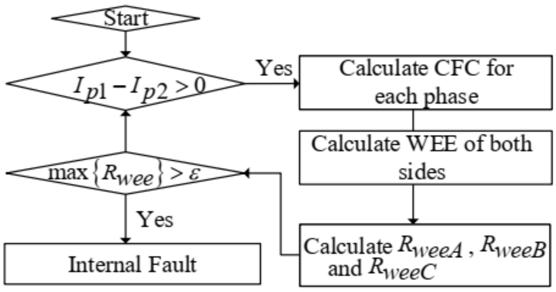

Fig-5: Flow diagram of RWEE based transformer protection [6]

In [6], a brand-new WEE-based criterion for converter transformer differential protection is put forward. On the other hand, because an internal fault only causes a change in the direction of CFC on the primary side, it is used as a major fault characteristic to separate internal fault from other disturbances.

In order to establish criteria, the ratio of WEE on the main side to that on the secondary side is used. The new protection strategy is offered based on the suggested criterion. The effectiveness of the suggested system and its improvement of TDP dependability under various disturbance circumstances have been confirmed by simulation. It demonstrates that the suggested technique performs as intended regardless of internal or external fault and that it is unaffected by noise and fault impedance. Results are unaffected by inrush current, DC bias, or CT saturation. In contrast to the majority of wavelet-based techniques, it resolves the issue of tripping rejecting when internal problems arise.

Energization and internal fault circumstances need to be adequately separated in order to increase the reliability and security of transformer differential protection. For differentiating between the transformer inrush current and internal defects, a novel approach with a low computing overhead and excellent resilience against measurement noises is suggested in article [7]. The recursive extended least-squares (RELS) algorithm is used to fit sine waves to the sample points of the normalized differential currents for various phases in the suggested technique. The approach can efficiently predict the dynamics of the measurement noises thanks to the expanded kernel. As a decision-making factor, three residual signals—defined as the variations between fitted sine wave signals and normalized differential currents—are taken into consideration. In roughly a half-cycle of the power system frequency, the energization state is determined based on the chosen criteria. To show the efficacy of the suggested strategy, several simulation and experimental test scenarios are employed. The findings demonstrate that the suggested method has a 98% accuracy

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rate, operates quickly, and has a comparatively little computing load for embedded implementation.

In the suggested procedure, three RSs are identified and taken into consideration as the decision criterion. The suggested technique outperforms the current ones in terms of computing complexity and resilience against measurement disturbances. The algorithm also has an operating time of 0.5 cycles of power system frequency and a 98% accuracy level.

The transformer protection must function dependably in the event of a problem for power systems to run safely. Creating a quick and precise differential protection strategy that restrains the transformer during energizing and external fault circumstances as well as disconnects it during internal fault conditions is difficult. For power transformers with any type of winding connection, star or delta, a general method based on the ratios of primary and secondary voltages and currents, augmented with current direction and wave-shape criteria, is proposed. The ratios are those between the terminal phase voltages and the absolute differences and sums of the primary and secondary line currents. The main goal is to prevent exterior faults under current transformer saturation, energising on an existing internal fault, and improper functioning of the standard differential protection strategy during energization. Performance analyses show that the suggested algorithm can safeguard a power transformer quickly, effectively, and dependably for all kinds of winding topologies.

A power transformer differential protection method that is applicable to all winding designs is provided. It is based on ratios of the difference and sum of the 60 Hz components of the line currents and the phase voltages at the transformer terminals. The voltage ratio is utilized to identify simultaneous energization under internal fault, but it restricts the relay during energization alone. The current ratio is used to differentiate between energization and fault scenarios. Additionally, the signal restraint during external faults associated with ct saturation is provided by the current direction in addition to the wave-shape requirement. The suggested technique may correctly distinguish between energising and fault instances in less than one cycle, according to analysis of a large number of cases of normal and fault conditions. Additionally, the presence of fault resistance and ct saturation is taken into account, and its impact on the performance of the suggested system has been assessed.

The findings show that the suggested approach can quickly identify and differentiate between fault scenarios from 5% of the winding. All winding designs of polyphase transformers may distinguish between energising and fault circumstances with the suggested method with high accuracy and efficiency.

A power transformer differential protection system based on support vector machines (SVM) and high-frequency features retrieved using the real-time boundary stationary wavelet transform was reported by the author [9]. (RTBSWT). With the use of synthetic data, SVM models are created that take into account a wide range of events, including inter-turn faults, external faults during CT saturation, and developing external-to-internal faults. The findings of a comparative performance assessment that took operating time, accuracy, and other reliability indices into account were positive. The provided SVM-based relay's simplicity, built on the traditional differential protection framework with no difficult-to-derive parameters, draws attention to possible implementation issues in the real world.

The SVM-based protection technique had a success rate of 100% in identifying external faults, internal defects, and energization events. Depending on the DSP being utilised, the relay operating period in a hardware implementation ranges from a few hundred seconds to a few milliseconds.

A difficult instance is when an exterior transformer defect evolves into an internal fault, a CT saturation, or both. However, the approach demonstrated a 98.7% accuracy in separating emerging external-to-internal problems from exterior faults with and without CT saturation. With an operation time of up to 2.6 ms, the suggested relay is capable of performing this event differentiation.

When it came to important turn-to-turn internal defects, the suggested SVM-based protection strategy performed better than the traditional one and had the quickest operating time. The NI sbRIO 9637 board has a portion of the given data-driven protection system implemented.

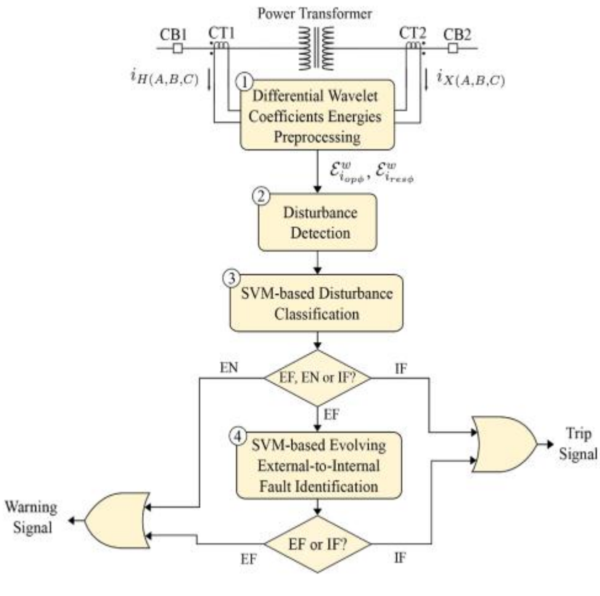

Fig-6: Proposed SVM-based power transformer differential protection [9]

This board was able to run the necessary preprocessing and SVM 1, issuing a trip signal in about 3 ms, which is faster than conventional protection and other existing data-driven power transformers protection schemes. This is despite the fact that the board was not intended to run highly time-consuming digital signal processing and machine learning algorithms.

A thorough analysis of around 7500 motors revealed that stator problems were to blame. Draft received on May 20; updated on October 28. TEC00126-2003, paper number. A. Siddique and G. S. Yadava work at the Indian Institute of Technology's Industrial Tribology, Machine Dynamics and Maintenance Engineering Centre in New Delhi, India (110016). B. Singh works at the Indian Institute of Technology's Department of Electrical Engineering in New Delhi, India (e-mail: bsingh@ee.iitd.ernet.in). Identity of the Digital Object 10.1109/TEC.2004.837304 responsible for 37% of the failures. As a result, diagnostic tests sensitive to the state of the stator winding are needed when conducting predictive maintenance on motors for stator defects.

3. CONCLUSION

This article does a literature review on transformer protection. It has been discovered that many methods and techniques have been proposed and put into practise since the development of digital relays up to this point, but when it comes to full security and the development of techniques to meet modern requirements, the recent mathematical tool of ANN and fuzzy logic concept seems to be dependable, quick, and robust. But in some common real-world scenarios, even these solutions can fall short, and digital relays can malfunction. Therefore, it appears that there is a huge area for research into quick and more dependable power transformer protection techniques.

REFERENCES

[1] Ali, E., Helal, A., Desouki, H., Shebl, K., Abdelkader, S., & Malik, O. P. (2018). Power transformer differential protection using current and voltage ratios. *Electric Power Systems Research*, *154*, 140-150.

[2] Sevov, L., Khan, U., & Zhang, Z. (2017). Enhancing power transformer differential protection to improve security and dependability. *IEEE Transactions on Industry Applications*, *53*(3), 2642-2649.

[3] Medeiros, R. P., & Costa, F. B. (2017). A wavelet-based transformer differential protection with differential current transformer saturation and cross-country fault detection. *IEEE Transactions on Power Delivery*, *33*(2), 789-799.

[4] Esponda, H., Vázquez, E., Andrade, M. A., & Johnson, B. K. (2019). A setting-free differential protection for power transformers based on second central moment. *IEEE Transactions on Power Delivery*, *34*(2), 750-759.

[5] Afrasiabi, S., Afrasiabi, M., Parang, B., & Mohammadi, M. (2019). Integration of accelerated deep neural network into power transformer differential protection. *IEEE Transactions on Industrial Informatics*, *16*(2), 865-876.

[6] Deng, Y., Lin, S., Fu, L., Liao, K., Liu, L., He, Z., ... & Liu, Y. (2019). New criterion of converter transformer differential protection based on wavelet energy entropy. *IEEE Transactions on Power Delivery*, *34*(3), 980-990.

[7] Naseri, F., Samet, H., Ghanbari, T., &Farjah, E. (2019). Power transformer differential protection based on least squares algorithm with extended kernel. *IET Science, Measurement & Technology*, *13*(8), 1102-1110.

[8] Ali, E., Malik, O. P., Knight, A., Abdelkader, S., Helal, A., &Desouki, H. (2020). Ratios-based universal differential protection algorithm for power transformer. *Electric Power Systems Research*, *186*, 106383.

[9] Simões, L. D., Costa, H. J., Aires, M. N., Medeiros, R. P., Costa, F. B., &Bretas, A. S. (2021). A power transformer differential protection based on support vector machine and wavelet transform. *Electric Power Systems Research*, *197*, 107297.