Journal of Information Systems Engineering and Management
2025, 10(38s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/

Research Article

Differentiation Between Inrush and Fault Currents in Transformers to Avoid Malfunctioning of Protection Scheme

[1*]Nitin Mahadeo Khandare, [2]Prashant J. Gaidhane

[1]Research Scholar, Department of Electrical Engineering, Government College of Engineering-Jalgaon (An Autonomous Institute), Kavayitri Bahinabai Chaudhari North Maharashtra University, Jalgaon*

[2]Associate Professor, Department of Instrumentation Engineering, Government College of Engineering-Jalgaon (An Autonomous Institute), Kavayitri Bahinabai Chaudhari North Maharashtra University, Jalgaon

[1]Corresponding Author Email: khandareniting3@gmail.com*

ARTICLE INFO

Received: 31 Dec 2024

Revised: 20 Feb 2025

Accepted: 28 Feb 2025

ABSTRACT

The power transformers are key components of the today's power systems. To ensure smooth operation, it modifies the supply's voltages and current levels at different power system stages. Differentiating between fault currents and inrush currents is the most crucial component of transformer protection. The most vital part of a protection strategy for transformer is the ability to differentiate between inrush current and internal fault currents. Therefore, safeguarding it is crucial to ensuring the power system operates steadily and consistently. Inrush current is the primary cause of protective system breakdowns. Thus, timely and precise fault current and inrush current discrimination is essential for reliable and satisfying power system operation.

Keywords: Fault Currents and Inrush Current, Protection of Transformer, Electrical Machines, Discrimination.

1.INTRODUCTION

The power transformer is key component of power system and is essential to the security and continuousness of the electric supply. The precise operation rate isn't the best, though. Conversely, transmission lines operate at an accuracy rate of nearly 100%. Therefore, the transformer's protection performance needs to be enhanced.

The primary protection for power transformers has traditionally been differential protection. It has been frequently used in power systems owing to its high degree of sensitivity and quick response time. Kirchhoff law serves as the basis for the differential protection concept. However, the power transformer can't strictly comply with Kirchhoff's law due to the presence of a magnetizing branch. Since the excitation current is low under typical circumstances, the transformer can be protected from its effects by the setting value. However, when transformer is switched on at no load condition, inrush current is likely to happen. The inrush current can be as much as 6–8 times the full load current because it is so large. Due to this high current, the differential protection may malfunction.

The inrush current that enters the transformer when it is powered can be up to ten times the current of the entire load. A long-standing issue with the design and operation of differential protection relays utilizing power transmission and distribution networks is the phenomena of inrush current in a transformer during energisation. Therefore, there is a chance that magnetizing inrush current will induce erroneous tripping during energisation. Only fault conditions (not inrush conditions) must cause the relay to function. Distinguishing between fault current and inrush current is crucial for dependable protection. It is well known that separating fault current from magnetizing inrush is a challenging problem for transformer protection.

The protection systems for transformer are made to detect a second harmonic and restrain during inrush transient phenomena because a magnetizing current often comprises a larger second harmonic current than an internal fault. However, transformer defects can also result in the generation of second harmonic components. This could be the result of saturation of current transformer or the existence of distributive or shunt capacitors in the EHV transmission line that the transformer is linked to. On occasion, the fault current's second harmonic may have a magnitude that is equal to or larger than magnetizing inrush current.

Journal of Information Systems Engineering and Management
2025, 10(38s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/
Research Article

2.LITERATURE REVIEW

In their paper, the authors describe how they use an Extended Kalman Filter (EKF) algorithm to differentiate between magnetic inrush currents and internal fault currents of transformer. The current carried by primary winding of transformer was estimated using EKF algorithm with the two step predictive corrective mechanism. The current carried by primary winding of transformer was estimated using the EKF for various faults and switching angles. The more serious the internal issue, the shorter the detection time. As a result, this plan offers prompt transformer protection against serious faults. [1]

In their study, the authors present a novel method for quickly and accurately differentiating inrush current from fault current. The asymmetry of the inrush current waveform serves as the basis for the development of an exclusive discriminating criterion. For the analysis, a transformer is modelled using MATLAB code. By changing the residual flux in the magnetic core from 0º to 360º at regular intervals of 90º, several switching instants on the supply voltage waveform have been examined. For the first few cycles, inrush current amplitude is always smaller than the magnetizing current peak value (0.452 A) in one or both sides. For the first few cycles, the through fault current's magnitude will always be higher than the magnetizing current peak value in either half. It takes three to four cycles for the magnetizing current to surpass in both cycles in the event of an internal defect. [2]

They looked at how to discriminate between short circuit and inrush currents in power transformer differential current protection. Using the Correlation Method, authors propose a novel approach for applying the DWT to distinguish between internal fault currents and inrush currents using the Wavelet Transform. A power system model is used to test their suggested algorithm. Several examples of inrush currents, internal faults, and simultaneous fault and inrush currents are simulated. Their simulation findings demonstrate the suggested algorithm's quick and accurate ability to distinguish between the various current types flowing in a power transformer under varied circumstances. [3]

This paper introduces a new, simple, yet effective power transformer protection method. Prony analysis is the foundation of this technique for identifying internal fault states and magnetizing inrush in power transformers. It is also able to discriminate between failures in primary and secondary windings. Using Prony analysis as a method to match the waveform of current, it discovers that the aperiodic component of symmetrical inrush current has zero attenuation factor, the aperiodic component of fault current has single attenuation factor, while the asymmetrical inrush current has two. It is noteworthy that there is a large variation in the values of the both attenuation factors of asymmetrical inrush current. Therefore, the attenuation factor of the number of aperiodic components can be used to determine the inrush current. The strategy has been verified by numerous MATLAB simulation results. The suggested approach can escape the limitations of second harmonic restraint since it is unrelated to the second harmonic. Simultaneously, it can distinguish between symmetrical inrush currents, which are not detectable by dead angle constraint. The new standard is straightforward and unambiguous. Additionally, it operates quickly because it just takes one cycle to suit the present waveform. [4]

In their paper, the authors present a novel online detection method that uses artificial neural networks (ANNs) and discrete wavelet transform to distinguish between inter-turn fault and magnetizing inrush current, as well as the fault's position, i.e., whether the primary winding or the secondary winding has an inter-turn fault. Through staging of these events on the specially constructed transformer, the algorithm has been successfully tested online. Less than a cycle after they begin, these occurrences are recognized. Situations where the fault resistance, inception angle and other parameters deviate significantly from which the ANN's learning process may give rise to this categorization. Retraining the ANN and adding the wrongly assigned fault record to the learning database are required if this is the case. [5]

In their study, the authors provide a novel method of distinguishing the power transformers' internal faults and inrush current through the use of a pattern recognition technique that employs the HS transform. According to their findings, the HS transform clearly displays the normalized frequency outlines for internal faults and inrush current, with the second harmonic being more noticeable in the former case than in the latter. To differentiate the inrush current from internal defects, fuzzy C-means grouping is employed, along with the calculation of the spectrum energy

Journal of Information Systems Engineering and Management
2025, 10(38s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/

Research Article

and standard deviation. Large power transformers are effectively protected by HS-transform since it is less susceptible to noise than Wavelet transform. [6]

In order to improve the efficiency of the electrical power system, a paper discusses a structured method for separating internal faults from switching conditions in power transformers. The most common causes of discrimination algorithm failure are C.T. saturation and high magnitudes of inrush current. [7]

2.1:Transformer Internal Fault Currents And Inrush Currents

Before achieving steady state values, the flux through core and the associated current experience a transient when the transformer is turned on. The moment of switching has an impact on how severe the switching transient is. When the applied voltage is sinusoidal under steady state conditions, the instantaneous value of common flux in the core (without any residual flux) changes from $-\varphi_{maximum}$ to $+\varphi_{maximum}$ in half a cycle in order to balance the applied voltage and lag its voltage by 90^o. At the switching instant, if voltage applied is at its negative peak, the flux will rise from zero and the transformer will be turned on with a normal magnetizing current. Similarly, if the transformer is turned on at its positive peak, the flux will rise from zero. However, for a flux-less core, the flux must change from zero to double the $\varphi_{maximum}$ in half a cycle. If the flux contains residual flux, the influence of residual flux will cause this value to grow. This leads in a doubling effect, which almost doubles the flux and also creates a significant magnetizing inrush current in the primary winding of transformer. An equivalent situation may occur when the voltage applied is approaching zero. Inrush current can be up to five times the transformer's full load current, which is almost 100 times the normal no load current. [8]

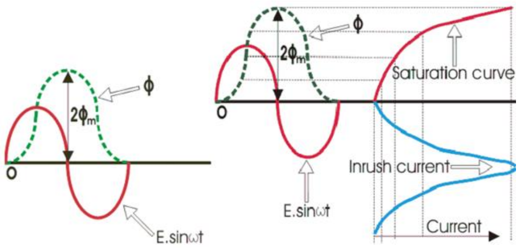

Fig. 1: transformer's Inrush current generation

The flux in the transformer's core is zero prior to energisation. It will take some time for the flux to reach the steady-state. In accordance with Faraday's law of electromagnetic induction, at the moment of energisation, the flux in the transformer core will rise from its zero value. The equation e = dφ/dt indicates the rate of flux change, which is what causes the induction of voltage in the windings. The voltage wave's integral will represent the entire flux, which is determined by;

$$e = E \sin \omega t = \frac{d\varphi}{dt} \qquad 2.1$$

$$\varphi = \int e.dt = E \int \sin \omega t \qquad 2.2$$

The flux waveform will originate from same instant as the voltage waveform if transformer is turned on at the moment when voltage is zero. After the initial half-cycle of the voltage waveform, the flux value is given by

$$\varphi_m = {}^{E}/_{\omega} \int_0^{\pi} \omega. \sin \omega t \, dt \qquad 2.3$$

$$= \varphi_m \int_0^{\pi} \sin \omega t \, d(\omega t) = 2\varphi_m \qquad 2.4$$

The maximum flow is denoted by $\emptyset_m$. As flux exceeds maximum steady-state value, the core of transformer typically becomes saturated. The maximum flux value will increase to double the steady-state amplitude when the transformer is being energized. When the flux surpasses the steady-state maximum value, the transformer's core becomes

Journal of Information Systems Engineering and Management
2025, 10(38s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/
Research Article

saturated; hence, it consumes a significant amount of current to generate the remaining flux. The term "magnetizing inrush current" refers to the high current that the transformer draws during energisation. This current's magnitude could be up to ten times the transformer's full load current.

In a power transformer, the interference of inrush current affects how a differential relay operates. High magnetizing inrush current affects the rating of fuses or breakers and also adds distortion as well as noise back into the supply mains. Therefore, it is crucial to differentiate inrush current and internal fault current in order to enhance the transformer's protection system. Together with the applied voltage, Figure 2 exhibits the transformer's magnetizing inrush current. [9]

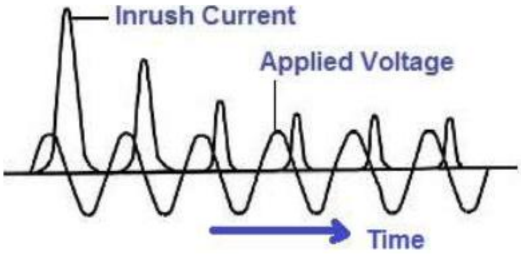

Fig. 2: Transformer's Magnetizing Inrush Current

3. METHODOLOGY

By using proxy analysis, it is feasible to model a linear sum of damped complex exponentials to uniformly sampled signals. In 1795, Prony proposed the Prony analysis. Its fundamental idea is to express the equal interval sampling data using exponential functions combined in a linear fashion. For transitory signal, it works well. The harmonic components can be extracted the even when their frequencies are same. Furthermore, Prony analysis is used to determine phase, amplitude and attenuation factor of the signal. The computing complexity is low because these numbers don't need to be calculated in the frequency domain. For this reason, this method has been widely employed in power systems. In the fields of power system electro-mechanical oscillation, biomedical monitoring, radioactive decay, radar, sonar, geophysical sensing, and speech processing, prony analysis is a frequently utilized signal analysis methodology and system identification tool.

The linear combination of exponential functions serves as the mathematical basis for the Prony analysis. Equation 3.1 is its mathematical representation.

$$x'(n) = \sum_{i=1}^{p} b_i z_i^n \quad n = 0,1, \ldots \ldots N-1 \qquad 3.1$$

Equations 3.2 and 3.3 express the complex variables bi and zi in Equation 3.1.

$$b_i = A_i \exp(j\theta_i) \qquad 3.2$$

$$z_i = \exp[(a_i + j2\pi f_i)\Delta t] \qquad 3.3$$

In Equations 3.2 and 3.3,

f_i is the frequency of the signal.

A_i = Amplitude of Signal, θ_i = phase and a_i = attenuation factor.

All of the components are evidently dampened in prony analysis in Eq. 3.3. With the exception of the aperiodic component, every element in the complete wave Fourier algorithm appears to be stationary. From this vantage point, the whole wave Fourier technique is less accurate than the prony analysis. An algorithm can be used to calculate f_i, A_i, θ_i, and a_i.

3.1 Mathematical Analysis

As illustrated in Figure 3, The mathematical formulation for the original Prony study will be obtained by analysing a Pulsed Corona Reactor (PCR) as a linear time-invariant (LTI) dynamic system.

Journal of Information Systems Engineering and Management
2025, 10(38s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/

Research Article

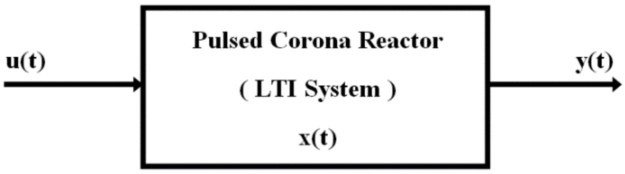

Fig. 3: LTI setup for a pulsed corona reactor

The signals in Figure are denoted by the following terms:

y(t): Response PCR system , x(t): PCR system State, u(t): Input to PCR system .

The PCR system's state evolution is represented by following equation:

$$\frac{dx(t)}{dt} = Ax(t) + Bu(t) \qquad 3.4$$

Where, A and B = constants matrices.

Assuming that, by applying an input pulse, the PCR is brought to its "initial state" at time t_0. It can be phrased as follows if the input is eliminated and the system receives no more inputs:

$$\frac{dx(t)}{dt} = Ax(t) \qquad 3.5$$

The n×n matrix A in this instance has left eigenvectors of qi, right eigenvectors of pi, and eigenvalues of λi. In the equation above, n stands for system order. The sum of n components indicates an outcome as:

$$x(t) = \sum_{i=1}^{n} (q_i^T x_0)\, p_i e^{(\lambda i t)} \qquad 3.6$$

We represent y(t) as follows since we view the PCR as an LTI system:

$$y(t) = Cx(t) + Du(t) \qquad 3.7$$

Where, C and D = constant matrices.

The equation above becomes simpler if the input is eliminated (u(t)=0).

$$y(t) = Cx(t) \qquad 3.8$$

When a sum of complex damped sinusoids is fitted to uniformly spaced sample (in time) values of the output, the Prony analysis specifically predicts the parameters of the Eigen structure given in the third equation.

$$\hat{y}(t) = \sum_{i=1}^{L} A_i e^{(\sigma i t)} \cos(2\pi f_i t + \phi_i) \qquad 3.9$$

For component $\boldsymbol{i}$, equation 3.9 shows

A_i = Amplitude,

σ_i = Damping coefficient,

f_i = Frequency,

$\hat{y}L$= The total number of exponentially damped components,

$\hat{y}(t)$= An estimation of the observed information for y(t) with N samples

$$y(t_k) = y[k],$$

Journal of Information Systems Engineering and Management
2025, 10(38s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/

Research Article

$k = 0,1,2, \ldots, \mathrm{N}-1$ that are evenly spaced.

Euler's theorem can be applied to express cos ($2\pi f_i t + \emptyset_i$) as a total of the exponential functions:

$$\cos(2\pi f_i + \phi_i) = \frac{e^{j(2\pi f_i + \phi_i)}}{2} + \frac{e^{-j(2\pi f_i + \phi_i)}}{2} + \frac{e^{j2\pi f_i + j\phi_i}}{2} + \frac{e^{-j2\pi f_i - j\phi_i}}{2} \qquad 3.10$$

The samples are rewritten as follows once t = kT and equation 3.7 is inserted into equation 3.6:

$$y[k] = \sum_{i=1}^{L} C_i \mu_i^k \qquad 3.11$$

Where,

$$C_i = \frac{A_i}{2} e^{j\phi_i} \qquad 3.12$$

$$\mu_i = e^{(\sigma_i + j2\pi f_i)T} \qquad 3.13$$

Which we refer to as “poles”

The sample period is denoted by T in equation 3.13.

By three simple steps in the original Prony study, C_i and μ_i are calculated.

3.2 Signal to noise ratio (SNR) research

Two metrics, SNR (Signal to Noise Ratio) and DVR (Dynamic Change Rate), must be introduced in order to demonstrate the accuracy of the fitted waveform.

$$SNR = \frac{rms[x(n)]}{rmsn[x'(n) - x(n)]} \, dB \qquad 3.14$$

$$DVR = \frac{\sum_{n=0}^{n=N-1} |x'(n) - x(n)|^2}{\sum_{n=0}^{n=N-1} |x'(n) - x_0|^2} \qquad 3.15$$

Where, rms represents root mean square value,

x(n) used for sample data of original signal and

x'(n) for data from the fitted waveform.

A statistic used in science and engineering that compares the strength of a desired signal with that of the surrounding noise is designated as the signal-to-noise ratio, occasionally shortened as SNR. It is proportion of power of signal and power in noise and measured in decibels. There is more signal than noise when the ratio is larger than 1:1 (more than 0 dB). As frequently employed for electrical signals, SNR can be used to any sort of signal. (e.g., isotope levels in an ice core or biological transmission between cells).

The ratio of accurate information to inaccurate or unnecessary information in a discussion or exchange is frequently referred to as the "signal-to-noise ratio" in a metaphorical sense.

In general, the fitting result can be accepted when the SNR value is around 20 dB. If the SNR is greater than 40 dB, ideal fitting result is achieved. The fitting outcome is better with a smaller DVR. When the DVR is less than 0.01, the fitting result will be accepted.

Circuit Diagram

The transformer is a multi-winding, 1-phase, 2-KVA, 230/230 V transformer with one winding on the left and one on the right. There have been ten tapings. The magnetization resistance of transformer is 2850 pu, leakage inductance of its winding is 0.00396 pu, where its winding resistance is 0.825 pu.

Journal of Information Systems Engineering and Management
2025, 10(38s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/

Research Article

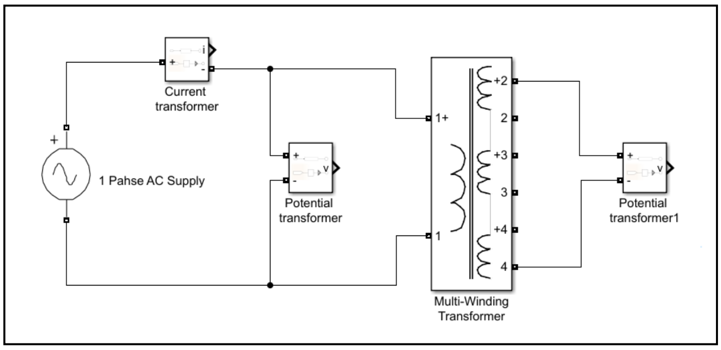

Fig. 4: Inrush Condition Experimental Circuit Model

The readings are taken by supplying power to the primary side of transformer with secondary kept open from the associated ADC in order to calculate the inrush current. The MATLAB software receives these readings as input, and a time vs. IP graph is produced. We can use Prony Analysis to fit a curve using these graphs.

2. Inter-Turn Current

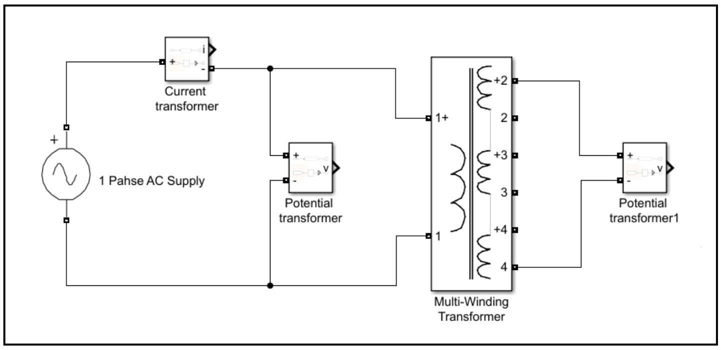

Fig. 5: Experimental Circuit Model for a 2 KVA Fault Situation

Supply is applied to the transformer's primary side, one winding of the secondary is shorted, and measurements are obtained from the linked ADC in order to calculate the fault current. These readings are given as input to MATLAB program and graph of time Vs I_p obtained. We can use Prony Analysis to fit a curve using these graphs.

Flow Chart

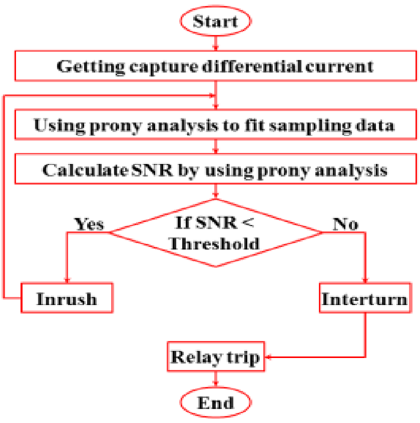

Fig. 6: Flowchart of Prony analysis

Procedure

1. Connect the circuits.

Journal of Information Systems Engineering and Management
2025, 10(38s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/ **Research Article**

2. Create an Excel file from the IP readings using the ADC of 1000 samples.

3. Open MATLAB and load the Excel file.

4. Using MATLAB Prony Analysis tools, produce a graph which demonstrates the transformer's time and current signal.

5. Use the fitted curve to determine parameters such as SNR, DVR, and attenuation factor.

4. RESULT

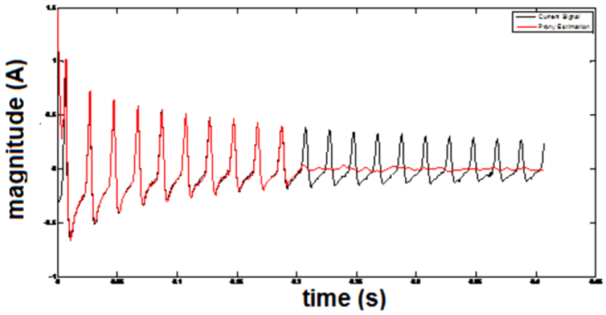

Fig. 7: Fitted waveform of inrush current

The current waveform above, which is produced at modal point 592 for inrush current, is displayed in the figure. In essence, there are 20 samples in a cycle. Two cycles, or 40 samples, are taken into consideration here. The Prony Algorithm can now be used to determine characteristics like SNR and DVR. Thus, the resulting values are DVR = 0.000263 and SNR = 18.1907.

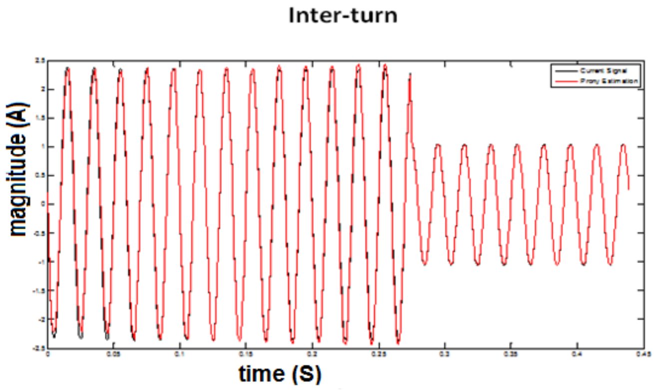

Fig. 8: Fitted inter-turn current waveform

For an inter-turn fault, the current waveform seen in the above image can be acquired at modal point 560. In essence, there are 20 samples in a cycle. Two cycles, or 40 samples, are taken into consideration here. The Prony Algorithm can now be used to determine characteristics like SNR and DVR. Thus, the resulting values are DVR = 0.0008412 and SNR = 23.8154.

5.CONCLUSION

This work develops a novel technique for distinguishing between interturn faults and magnetizing inrush current of a power transformer. The differential current's discriminating features are extracted via Prony analysis. Fitting the wave derived from inrush and fault current is how this technique is accomplished. It is determined that the inter-turn fault current's SNR is higher than the inrush current's. To distinguish between inrush current and fault current, take into account SNR threshold value.

The acquired result unequivocally demonstrates that the system is capable of distinguishing between defective and inrush scenarios. This will assist in preventing relay malfunctions.

DATA AVAILABILITY STATEMENT

All the data is collected from the simulation reports of the software and tools used by the authors. Authors are working on implementing the same using real world data with appropriate permissions.

FUNDING

No fund received for this project

CONFLICTS OF INTEREST

The authors declare that they have no conflict of interest.

REFERENCES

[1] Sunil Kumar Gunda, and Venkata Samba Sesha Siva Sarma Dhanikonda, Discrimination of Transformer Inrush Currents and Internal Fault Currents Using Extended Kalman Filter Algorithm (EKF), https://www.mdpi.com/journal/energies,https://doi.org/10.3390/en14196020, Energies 2021, 14, 6020, pp. 1-2.0

[2] YashasviTripathi, KushagraMathur, Dr. S. V. N. L. Lalitha, Dr. M. Ramamoorty, Discrimination of magnetic inrush current from fault current in transformer-A new approach, International Journal of Pure and Applied Mathematics, http://www.ijpam.eu, ISSN: 1311-8080 (printed version); ISSN: 1314-3395 (on-line version), Volume 114 No. 12 2017, pp. 615-625.

[3] M. Rasoulpoor, M. Banejad and A. Ahmadyfard, Discrimination Between Inrush and Short Circuit Currents in Differential Protection of Power Transformer Based on Correlation Method Using the Wavelet Transform, Iranica Journal of Energy & Environment, IJEE an Official Peer Reviewed Journal of BabolNoshirvani University of Technology, 2 (4), ISSN 2079-2115, DOI: 10.5829/idosi.ijee.2011.02.04.3139, pp. 302-312.

[4] Shao-feng Huang, Hong-mingShen, Jia Wang, “A New Method to Discriminate the Inrush Current Based on Prony Analysis”, Advanced Materials Research Vols 516-517 (2012) pp 1671-1677 © (2012) Trans Tech Publications, Switzerland.

[5] S. R. Paraskar, M. A. Beg, G. M. Dhole, Discrimination between Inrush and Fault in Transformer: ANN Approach, International Journal of Advancements in Technology http://ijict.org/, ISSN 0976-4860, Vol 2, No 2, April 2011, pp. 306-318.

[6] J. P. Patra, A New Approach for Discrimination between Inrush Current and Internal Faults in Power Transformers, International Journal of Electronics and Communication Engineering, http://www.irphouse.com, ISSN 0974-2166 Volume 4, Number 4 (2011), pp. 409-414.

[7] Prof. P. R. Bharambe, Mr. V. S. Karale, ShivaniManatkar, KomalTayade, Abhishek Patil, Adarsh Moon, SumitMahajan, AshwiniRajagur, Discrimination Between Inrush Current from Interturn Fault Current in Transformers based on the Non-Saturation Zone, International Journal of Advanced Research in Science, Communication and Technology (IJARSCT), www.ijarsct.co.in, DOI: 10.48175/IJARSCT-4354, ISSN (Online) 2581-9429, Volume 2, Issue 7, May 2022, pp. 312.

[8] AnupamSinha, SarpreetKaur, Different Methods of Differentiating Inrush Current from Internal Fault Current in Transformer, International Journal of Computer Applications (0975–8887), International Conference on Advances in Emerging Technology (ICAET 2016), www.ijcaonline.org, pp. 35-41.

[9] Purushottam R. Bharambe, Sudhir R. Paraskar, Saurabh S. Jadhao, A Review of Techniques Used For Discrimination of Inrush Current and Internal Fault Current of A Power Transformer, Online International Conference on Multidisciplinary Research and Development, ICMRD-21, www.iejrd.com, SJIF: 7.169, http://mkct.org.in/icmrd/, pp. 1-14.