Discrete Wavelet Transform based Classification of Transients and Fault Diagnosis in Power Transformer

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Abstract

Conventional transformer protection methods have limited information about the transformer's condition based on terminal data, making it challenging to distinguish between magnetizing inrush current and internal faults. This study presents a method to identify transients caused by magnetization and internal faults, providing additional information to improve protection algorithms. The Discrete Wavelet Transform (DWT) technique is used to extract features and discriminate between transformer magnetization and internal fault current. MATLAB Simulink software package is used to model a power transformer and simulation conducted under various operating conditions shows that the proposed approach provides reliable discrimination between magnetizing inrush current and internal faults, leading to an improved transformer protection algorithm. The outcomes can help in developing advanced protection schemes that predict faults ahead of time and minimize downtime.

Keywords: Inrush current, internal fault, transients, second harmonic component in transformer, wavelet transform.

I.INTRODUCTION

A power transformer is an important part of the electrical power system, so protecting it against errors is necessary. Relays that rely on differential current and filters to stop false alarms generated by magnetising currents are frequently used to ensure protection. These relays currently used for protection of power transformer are differential current based and uses filters to restrain the second harmonic component and sometimes even fifth harmonic component for avoiding false tripping against the magnetizing currents [2]. However harmonic components may be produced when an electrical current passes through a transformer, which might cause problems with protective relays. Transformers can be made using particular magnetic materials in order to lower these harmonic components. The transformer core can be built to reduce these harmonics and offer better protection for the transformer by selecting the proper materials. and [4] provided a Fuzzy logic-based relaying for large power transformer protection. To differentiate between magnetising inrush from internal faults some researchers have created a protection method for power transformers using artificial neural networks (ANNs) [5]. ANN-based schemes for transformer protection has some drawbacks, including the need for an excessive amount of training data samples, slower convergence during training, and the ability to overfit data. Researchers have proposed decision making process based on the wavelet transform was suggested in [7] discriminating internal faults from inrush currents but overexcitation conditions have not considered by them. Consequently, power transformer protection method to identify magnetizing inrush conditions based complex window and pattern recognition approach that combines the S transform and pattern classifiers was later proposed in [8]. Principal component analysis (PCA) and mathematical morphology (MM) are two methodologies that have been suggested for understanding waveforms proposed by researchers [9] [10].

To safeguard power transformers from internal defects and magnetising inrush currents, researchers have suggested a number of different methods. Among these techniques are artificial neural network (ANN)-based protection techniques, wavelet transform decision-making methods, principal component analysis and mathematical morphology-based waveform identification methods, and protection schemes based on a combination of the S transform and pattern classifiers. Some of these methods, however, have disadvantages, including the need for a large number of training data samples, poor training convergence, a propensity to overfit data, and a failure to differentiate between internal faults and overexcitation conditions and [11] provided a technique for separating internal defects from the magnetising inrush using instantaneous frequency of average differential power signal. Furthermore, for the two mentioned approaches, the distinction between internal faults and overexcitation conditions has not been taken into account.

To prevent unnecessary tripping caused by magnetizing inrush current during transformer energization, blocking the differential relay using the second harmonic component is a commonly used method in power transformers. However, this approach has a significant drawback in that it can cause false tripping. To address this, the second harmonic component present in the inrush current is used as a discrimination factor between fault and inrush currents. Harmonics in the inrush currents typically originate from various sources, such as nonlinearities of transformer core, saturation of current transformers, core residual magnetization, and switching instant. To overcome these challenges, this Paper present wavelet-based method for identifying inrush current and distinguishing it from internal faults.

II.NEED OF FREQUENCY INFORMATION

In many cases, information that is not easily visible in the time domain can be visualized in the frequency domain, as in the case of electrocardiogram (ECG) signals, which record the electrical activity of the heart. The shape of a healthy ECG signal is familiar to cardiologists and can be used as a reference for identifying abnormalities or irregularities in the signal. In the context of electrocardiogram (ECG) signals, the characteristic shape of a healthy ECG signal is a well-known feature that is easily recognizable by cardiologists. Any significant deviation from this shape can be indicative of a pathological condition. This exemplifies the importance of frequency analysis in signal processing, as certain frequency content that may not be readily visible in the time domain can reveal crucial information about the underlying pathology of a signal. Today Fourier transforms are used in many different areas including all branches of engineering. Although FT is probably the most popular transform being used (especially in electrical engineering), it is not the only one. There are many other transforms that are used quite often by engineers and mathematicians. Hilbert transform, short-time Fourier transform (more about this later), Wigner distributions, the Radon Transform, and of course our featured transformation, the wavelet transform, constitute only a small portion of a huge list of transforms that are available at engineer's and mathematician's disposal. Every transformation technique has its own area of application, with advantages and disadvantages, and the wavelet transform (WT) is no exception. For a better understanding of the need for the WT let's look at the FT more closely. FT (as well as WT) is a reversible transform, that is, it allows to go back and forward between the raw and processed (transformed) signals. However, only either of them is available at any given time. That is, no frequency information is available in the time-domain signal, and no time information is available in the Fourier transformed signal. The natural question that comes to mind is that is it necessary to have both the time and the frequency information at the same time? The particular application and the nature of the signal in hand. Over the years, various incipient fault detection techniques, such as dissolved gas analysis and partial discharge analysis have been successfully applied to large power transformer fault diagnosis. Since these techniques have high-cost and some are offline, a low-cost, online internal fault detection technique for transformers using terminal measurements would be very useful [14].

A powerful method based on signal analysis should be used in monitoring. This method should discriminate between normal and abnormal operating cases that occur transformers such as internal faults, magnetizing inrush. There have been several methods, based on time domain techniques, frequency domain techniques or time-frequency domain techniques. In previous studies, researchers have used Fourier transform (FT) or windowed-Fourier transform. In recent studies, wavelet transform based methods have been used for analysis of characteristics of terminal currents and voltages. Traditional Fourier analysis, which deals with periodic signals and has been the main frequency-domain analysis tool in many applications, fails in transient processes such as magnetizing inrush and internal faults. The wavelet transform (WT), on the other hand, can be useful in analyzing the transient phenomena associated with the transformer faults. Since the FT gives only frequency information of a signal, time information is lost. Therefore, one technique known as windowed FT or short-time FT (STFT) has been developed. However, the STFT has the limitation of a fixed window width. So it does not provide good resolution in both time on other hand, WT provide great resolution in time for high frequency component of signal and great resolution in frequency for low frequency components of a signal. In a sense, wavelets have a window that automatically adjusts to give the appropriate resolution.[14].

III. WAVELET APPLICATION

Wavelet techniques are popular for analyzing signals in time and frequency domains. They can handle non-stationary signals and are used in image and signal processing, data compression, and feature extraction. In power transformers, wavelet methods can distinguish between magnetizing inrush currents and internal faults by extracting high-frequency components through wavelet decomposition. This proposed method can improve transformer protection and reduce downtime by predicting faults ahead of time. Wavelet techniques also aid in feature extraction and data analysis for a better understanding of transformer faults and failures. Wavelets localize the information in the time frequency plane; in particular, they are capable of trading one type of resolution for another, which makes them especially suitable for the analysis of non-stationary signals. One important area of application where these properties have been found to be relevant is power engineering. Due to the wide variety of signals and problems encountered in power engineering, there are various applications of wavelet transform. These range from the analysis of the power quality disturbance signals to, very recently, power system relaying and protection. The main difficulty in dealing with power engineering phenomena is the extreme variability of the signals and the necessity to operate on a case by case basis. Another important aspect of power disturbance signals is the fact that the information of interest is often a combination of features that are well localized temporally or spatially (e.g., transients in power systems). This requires the use of analysis methods sufficiently which are versatile to handle signals in terms of their time-frequency localization. Our discussion is organized into two main parts: (1) a discussion of the main properties of WT and their particular relevance to power engineering problems and (2) a critical review of power engineering applications. In Section II, we start by examining the properties of WT that are most relevant to power engineering problems. We consider the primary power engineering applications, provide the reader with the relevant background information, and review recent wavelet developments in these areas.

Time-Frequency Localization

Wavelets are mathematical functions derived from a single function by scaling and translating operations. This generates a family of functions that can represent signals at multiple scales in both time and frequency domains, making them useful for analyzing non-stationary signals with time-varying frequency components. Wavelet techniques have various applications, including audio and image processing, data compression, and feature extraction, and can be used to gain a better understanding of complex signals and develop more sophisticated algorithms for data analysis and processing.

Some mother wavelets are shown in Fig.1. The difference between these wavelets is mainly due to the different lengths of filters that define the wavelet and scaling functions. Wavelets must be oscillatory, must decay quickly to zero (can only be non-zero for a short period), and must integrate to zero. The scaling operation is nothing more than performing “stretching” and “compressing” operations on the mother wavelet, which in turn can be used to obtain the different frequency information of the function to be analyzed. The compressed version is used to satisfy the high frequency needs, and the dilated version is used to meet low frequency requirements. Then, the translated version is used to obtain the time information of the function to be analyzed.

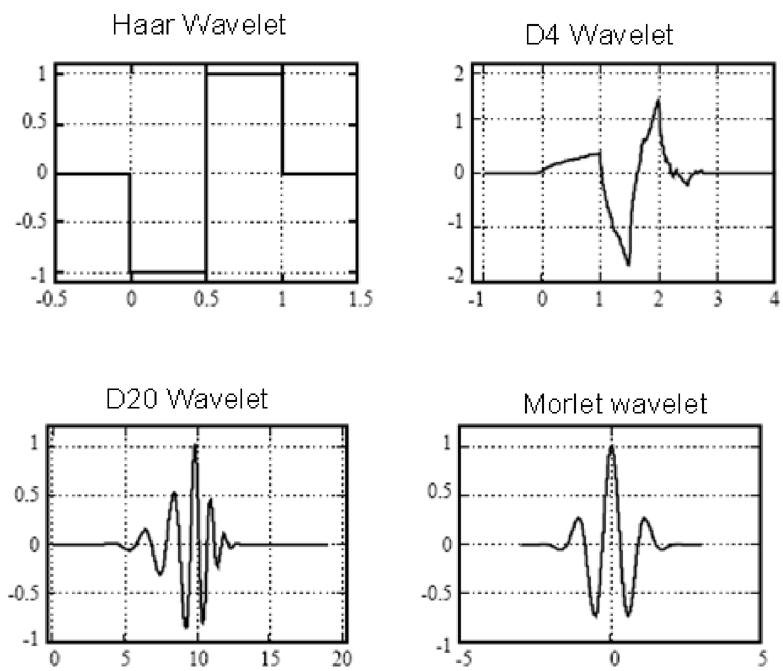

Fig.1. Four mother wavelets often used in wavelet analysis

In this way, a family of scaled and translated wavelets is created and serves as the base, the building blocks, for representing the function to be analyzed. The scaled (dilated) and translated (shifted) versions of the Daubechies mother wavelet are shown in Fig.2. Daubechies wavelets belong to a special class of mother wavelets and actually are used most often for detection, localization, identification and classification of power disturbance.

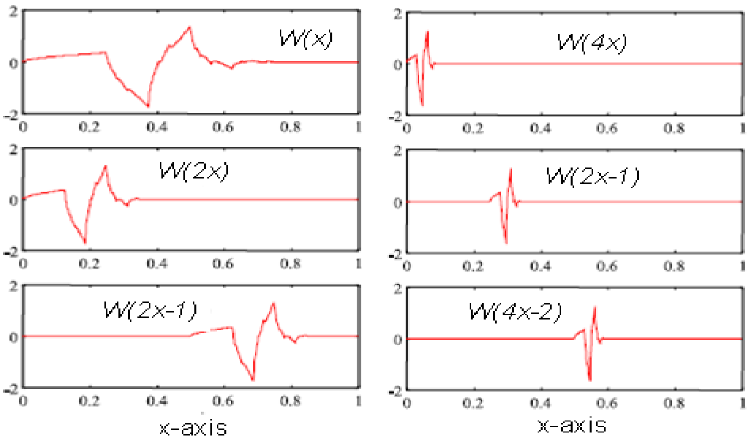

Fig.2 Scaled and translated version of D4 wavelet

III. POWER SYSTEM CONFIGURATION

In order to investigate the applicability of the proposed algorithm, a detailed simulation study has been carried out on power system model shown in the Fig 3. A 3-phase, 50-Hz, 500-MVA, 500/230-kV power transformer that was taken into consideration for this paper. The modeling is performed using the MATLAB Simulink. Three-phase differential current samples for one-cycle duration are acquired through CTs connected on both sides of the power transformer. The method used for generating several simulation cases for various internal fault types and other disturbances will be covered in the next sections.

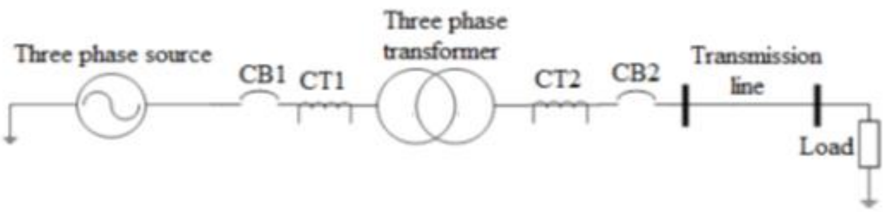

Fig.3. Single-line diagram of the simulated electric power system

A. Internal faults

MATLAB Simulink was used in this work for various types of internal fault in a power transformer. Line to Ground, Line-to-line faults, Double-line-to-ground, turn-to-turn faults, and primary-to-secondary winding faults are listed below.

Line to Ground (LG), Line to Line (LL), and Double Line to Ground (LLG) Faults: A model is developed in MATLAB Simulink to simulate various types of internal faults. That mimics various internal transformer fault types Line to Ground, Line-to-line faults, Double-line-to-ground faults are applied at the terminal of the transformer, with a varying fault inception angle and with various source impedances to evaluate the efficiency of the protection system.

Turn to Turn Fault: Turn-to-turn insulation failures is major and frequent reason for power transformer failures. These problems occur as a result of insulation breakdown brought on by thermal, electrical, and mechanical loads. These errors have the potential for degeneration and to develop into more serious ground faults, which may lead to arcing in the transformer tank if not detected in time. Traditional relays are capable of identifying these defects, but they might not do so in a timely manner, which could result in interwinding faults. In this work, turn-to-turn faults were simulated in Simulink by shorting the windings on the transformer's primary and secondary sides.

B. Other System Disturbances

The simulation has also taken into consideration other disturbances that could happen in a power transformer, like a magnetising inrush. When a transformer is first turned on, a phenomenon known as magnetising inrush causes an abrupt increase in current that may be misinterpreted as a problem. There are different kinds of magnetising inrush, including residual inrush, sympathetic inrush, and recovery inrush these situations have been considered for generating simulation cases.

Magnetizing Inrush: Magnetising inrush, a sudden burst of current that might occur when a transformer is turned on or off, is possible. When the magnetic field of the transformer is out of phase with the electrical signal coming in or going out, this occurs. Sometimes, magnetic energy may remain in the core of a transformer even after it has been shut off. The remaining inrush current surge that results after turning it back on may be caused by this. It's essential to comprehend these surges and take them into account in simulations because they can interfere with the transformer's protection systems. Simply put, we've created an example in which a transformer is activated when its internal magnetic field isn't as expected. As a result, the transformer experiences what is known as a magnetising inrush, a surge of electricity. A second burst of electricity, known as an initial inrush, may occur if the transformer is turned on and then off again because there may be residual magnetic field left over. This situation has been simulated with a variation in source impedance at different switching angels having the positive and negative polarity of residual flux and with different loading conditions on the transformer.

When two transformers are linked in parallel, a phenomenon known as sympathetic magnetising inrush occurs. As a result, the inrush current may include a DC component, which may cause the operational transformer to become overloaded and generate more inrush current. Simulations with varying loads and source impedance phase angles were run in order to explore this phenomenon.

IV. PROPOSED APPROACH

A mathematical method called the wavelet transform is used for analysing signals and identifying transformer faults. Mother wavelets come in a variety of forms, including the Harr, Daubichies, Couflet, and Symmlet. The accuracy of the analysis is impacted by the mother wavelet selection, which is crucial because it is effective at locating errors in transformer signals, the Daubichies wavelet (db) is frequently utilised. The choice of the mother wavelet plays an important role in the characterization of the signal under study. The mother wavelet, whose characteristics match closely with the signal under consideration, would be the best choice. It has found in the literature that the db wavelet is the most suitable one for fault signals [12]. The wavelet transform has some advantages when compared to the FT. Wavelets have compact support, which means that wherever the function is not defined it will have a value of zero. It helps in speeding up the computations and also tells us about the locality of the wavelet in the time domain.

Formulation of DWT is related to filter bank theory shown in fig. 4, in many of the good references. It divides the frequency band of input signal into high and low frequency components by using low pass h (k) and high pass g (k) filters. This operation may be repeated recursively, feeding the down sampled low pass filter output into another identical filter pair, decomposing the signal into approximation c (k) and detail coefficients d (k) for various resolution scales. In this way, DWT may be computed through a filter bank framework, in each scale, h (k) and g (k) filter the input signal of this scale, giving new approximation and detailed coefficients respectively. The filter bank framework is shown in fig. 4. The down pointing arrow denotes decimation by two and boxes denote convolution by h (k) or g (k).

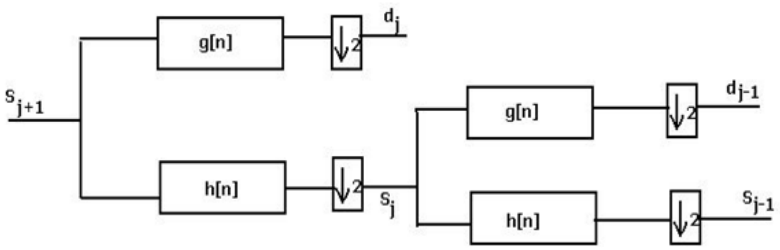

Fig 4. Two band Multi-resolution analysis of Signal

Wavelet analysis is about analyzing the signal with short duration finite energy functions. They transform the considered signal into another useful form. This transformation is called Wavelet Transform (WT).

Let us consider a signal f(t), which can be expressed as

$$f(t)=\sum_{l} a_{l}\,\varphi_{l}(t) \qquad (1)$$

$$f(t)=\sum_{k}\sum_{j} a_{j,k}\,\varphi_{j,k}(t) \qquad (2)$$

In (2), j and k are both integer indices and φjk(t) are the wavelet expansion function that usually form an orthogonal basis. The set of expansion coefficients ajk are called Discrete Wavelet Transform (DWT).

The DWT is implemented using a multiresolution signal decomposition algorithm to decompose a given signal into scales with different time and frequency resolution. The analysis filter bank divides the spectrum into octave bands.

V. RESULTS AND DISCUSSION

At the first stage an original signal is divided in to two halves of the frequency bandwidth, and sent to both Low Pass Filter (LPF) and High Pass Filter (HPF). The coefficients of filter pairs are associated with the selection of mother wavelet, the Daubechies Db-4type wavelet is used as mother wavelet. Then the output of LPF is further cut in half of the frequency bandwidth and then sent to the second stage, this procedure is repeated until the signal is decomposed to a pre-defined certain level.

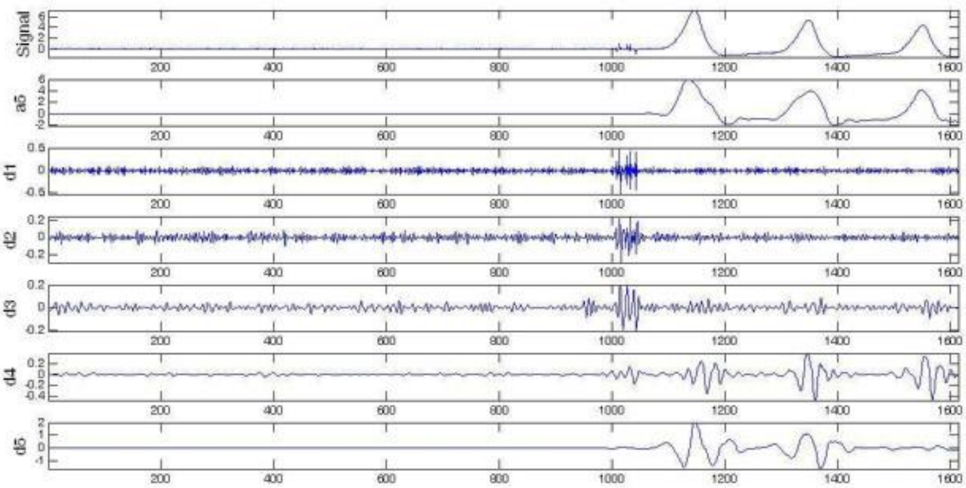

Fig. 5 Wave form and decomposition levels of Inrush differtial current

If the original signal were being sampled at Fs Hz, the highest frequency that the signal could contain, from Nyquist's theorem, would be Fs/2 Hz. This frequency would be seen at the output of the high pass filter, which is the first detail 1; similarly, the band of frequencies between Fs/4 and Fs/8 would be captured in detail 2, and so on. Based on visual scrutiny of fig. 5 and fig.6 characterize the transient and discriminate between magnetization inrush and interturn fault. In these two figures d1 and d2 are nearly similar and discrimination is difficult. By keen observation at decomposition level d3 and d4 of figure 5, the wavelet coefficients are corresponding to magnetization peek.

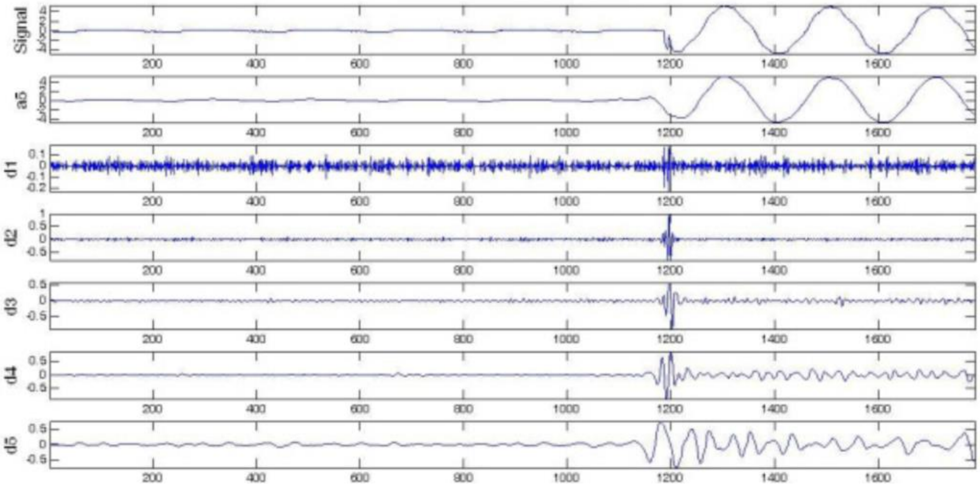

Fig 6 Wave form and decomposition levels of Primary fault differtial current

Whereas in figure 6, the large wavelet coefficients for the decomposition level d3 to d5 appears at the instant of switching and attenuates with the length.

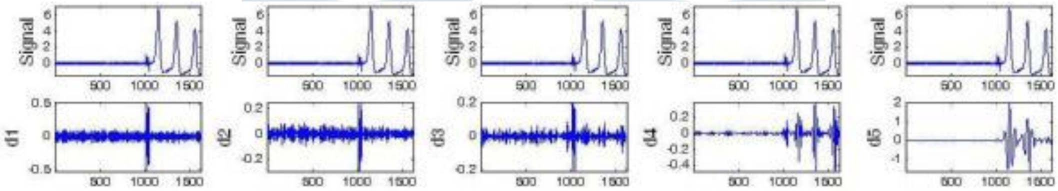

Fig 7 (a) Wave form and decomposition levels of magnetization inrush differtial Current along original signal

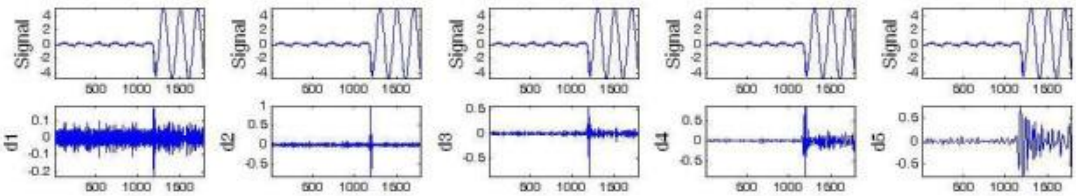

Fig 7 (b) Wave form and decomposition levels of primary fault differtial Current along original signal

figure 7(a) and figure 7(b) shows each decomposition level along with original signal for readily justification of above lines. The analysis of fault current in a power transformer involves the use of wavelet decomposition at different levels, which provides a comprehensive understanding of the nature of the fault. By examining the differential current signal in conjunction with the original signal, it is possible to justify the remarkable difference observed in the fault current. The wavelet decomposition process involves the use of a mathematical tool that breaks down a signal into different frequency components at various scales. This approach enables the identification of specific features in the signal that may not be visible in the time domain. By decomposing the signal at different levels, it is possible to obtain a more detailed and nuanced understanding of the signal's behaviour. When analyzing the differential current signal, the wavelet decomposition approach provides a powerful tool for identifying specific features that are indicative of a fault. For example, the presence of high-frequency components in the signal may indicate a short circuit or an internal fault, while low-frequency components may suggest a ground fault or a problem with the insulation.

By comparing the differential current signal with the original signal, it is possible to gain further insight into the nature of the fault. The original signal provides a baseline against which to compare the differential signal, allowing for a clearer understanding of the changes that occur during a fault. This approach also enables the identification of any noise or interference that may be present in the signal, which can help to improve the accuracy of the fault analysis. Overall, the use of wavelet decomposition at different levels, along with the original signal, provides a powerful tool for analyzing fault current in power transformers. By leveraging these techniques, it is possible to obtain a more comprehensive and detailed understanding of the fault, enabling more effective fault detection and diagnosis.

CONCLUSION:

This paper discussed efforts to characterize transients for transformers, resulting from various types of faults. Various Simulation cases are conducted to analyze transformer internal faults and magnetizing inrush current. The data pertaining to different transformer operational scenarios such as transformer magnetization and internal faults were acquired from a model. The data were analyzed using discrete wavelet transform and characteristics of the cases and differences between cases are presented. The results show great potential for using this method for predictive maintenance and maintaining reliability of transformers. Future work will investigate using characteristics of fault data with an intelligent soft computing method for a discrimination process and life estimation of transformer.

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