Identification of Internal Fault from Power Transformer Using Wavelet Transform and Anfis

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Abstract— **This paper presents a new technique for power transformer differential protection based on wavelet transform and ANFIS to discriminate internal fault from inrush currents. Wavelet transform is employed to extract important information from transient signals in both time and frequency domain. The proposed method has been on the slope pattern and amplitudes of wavelet coefficients D1-D5 in a specific frequency band generated by faults and inrush currents. Features extracted from detail 5 are used as inputs to ANFIS. The performance of the algorithm is demonstrated by simulation of different faults and switching conditions on power transformer using MATLAB/SIMULINK software.**

Keywords- Differential Protection; Magnetizing Inrush current; Power transformer; Internal fault; Wavelet transform

I. INTRODUCTION

Power transformers are the essential equipment in the modern power system and it plays a vital role in the power system network. There is a high demand imposed on power transformer protective relays; these include the requirement of dependability associated with no mal operation, security associated with short fault clearing time [1]. However the differential relays are used for protective system for reliable operation. Since the relay should not operate for nonfaulted condition, such as inrush currents and in faulted condition it should operate as fast as possible. Protection of large transformers has been challenging problem for protection engineers. Hence the discrimination between an internal fault and magnetizing inrush current has been a great concern and a challenging problem in the power transformer protection. Since magnetizing inrush current generally contain a large second harmonic component in comparison to an internal fault, conventional transformer protection schemes are designed to restrain during inrush transient phenomenon using the large second harmonic [2]. It might be due to saturation of CT's, parallel capacitances or distributed capacitances of long EHV transmission lines, which are connected to transformer. Many researches have been carried out to analyze magnetizing inrush current in three and single phase power transformers. It was found that magnetizing inrush current is dependent on factors such as instant of connecting the supply to the power transformer, the residual flux, the type of winding connections, core types, and load characteristics [3]. The proposed method in [4] based on model transform of voltage and current waveforms. Disadvantage of these method include the need of voltage transformer and increased protective algorithm, which increases the calculation cost. The operation criterion is another method based on the duration in which differential current waveforms will continue near zero [5]. Delayed fault detection is the disadvantage of these groups of algorithm. In methods such as neural networks and fuzzy logic differential current harmonics are used as inputs to train the network and Fuzzy logic [6] [7]. The problem connected with these methods is rules have to be frame for each case in fuzzy logic and requires huge number of training parameters [8]. In next approach the multi criteria aggregation technique based on fuzzy logic has been employed [9]. Wavelet based signal processing techniques have emerged recently as a powerful tool to analyze power system transient and feature extraction. In particular applications the wavelets can be employed to analysis and to detect electromagnetic transients [10], fault detection [11], data compression [12], power quality [13], recently various new protective schemes have been proposed with the fore going problem in power transformer protection based on wavelet transform [14-15]. A wavelet based method has been presented in [14]. The drawback of the method is that it requires the measurement of voltage and current that increases the cost of hardware implementation. In [16] an algorithm has been suggested using combination of wavelet transform and neural network. In [17] wavelet based algorithm has been recommended. In this paper a new approach for differential protection of power transformer based on wavelet transform for discrimination of internal fault from inrush currents. This algorithm has been developed by considering different behavior of the differential currents under fault and inrush current condition. In this method the wavelet transform is first applied to decompose the differential currents of power transformer in to series of a detailed wavelet component each of which covers a time domain signal that covers a specific frequency band. Thus many distinctive signal features that represent internal faults and inrush currents are extracted. As a result by quantifying the extracted features, take amplitude difference from the wavelet coefficients for the specific frequency band, due to the fault and inrush current. By using this amplitude for three phases, the internal faults can be accurately discriminated from inrush current less than a quarter cycle after the disturbance. The proposed method does not depends on the selection of threshold thus the effectiveness of this technique can be demonstrated and tested using 500/230 kV Y-Δ connected transformer connected to a power system. Since elements of the power system has been modeled using MATLAB/SIMULINK. The simulation results show that the proposed technique can accurately discriminate between internal fault, external fault and magnetizing inrush current in differential power transformer.

II. WAVELET TRANSFORM

The wavelet transform is an ideal way to capture the transient phenomena of the transformer. The electromagnetic transients are typically nonperiodic signals, which contain both high frequency oscillation and localized impulses superimposed on the power frequency and its harmonics.

Wavelet transform gives the both time and frequency information of the signal at which these frequencies occur. Thus wavelet transform ensures that it is a powerful signal processing tool used in power system [15-18] Fig. 1 illustrates the implementation procedure of discrete wavelet transform in which X(n)is the original signal, h(n) and g(n) are low pass and high pass filter respectively. At the first stage, an original signal is divided in to two halves of the frequency bandwidth and sent to both HPF and LPF then the output of the LPF is further cut in half of the frequency bandwidth and sent to the second stage, this procedure is repeated until the signal is decomposed to a predefined certain level.

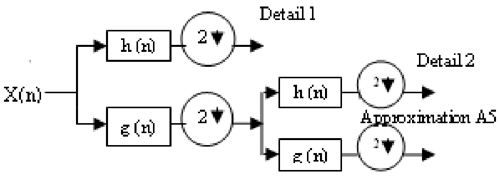

Figure 1. Implementation of DWT

The set of signals thus attained represents the same original signal but all corresponding to different frequency bands. If the original signal x (n) is being sampled at Fs Hz, the highest frequency that the signal could contain, from nyquist theorem would be Fs/2 Hz. This frequency would be sent at the output of the frequencies between Fs/2, Fs/4 would be captured in detail1, similarly the band of frequencies between Fs/4, and Fs/8 would be captured in detail 2 and so on. The sampling frequency considered in this paper is 10 kHz.

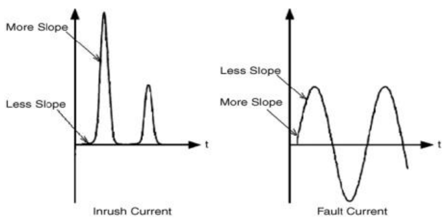

Figure 2. Different behavior of internal fault and inrush current

A. Details of the investigation carried out

It has been reported in [18] that the algorithm using wavelet transform of decomposition level D1-D7 and few switching angles. In our investigation we have used decomposition levels D1-D5 and Db9 mother wavelet. Large numbers of switching angles were tested and the results reported in this paper. The Proposed algorithm and details of the relay flowchart are given below. The new technique of discriminating inrush current from internal fault is based on different behavior of these waveforms following disturbance. However the magnetizing inrush current corresponding to the transformer core saturation the inrush current has conical shape (non sinusoidal)in other words inrush current at the switching time increases very slowly, as time passes its slope increases. Since when fault occurs the differential current has higher slope compared with the starting of the inrush current and its slope decreases as time passes. Fig.2 illustrates the above mentioned features [20]. However these features stem from the different nature of the currents, parameters of transformer and connected power system has no influence on it. So these features may be used as the basis for discriminating the fault from the inrush current.

The proposed algorithm is based on the two principles

1. The differential current due to fault begins with a higher slope and then its slope decreases but differential current due to inrush current begins with a low slope and then its slope raised.

2. A larger slope in the time domain shows that there are higher frequencies in the frequency domain.

Based on the above principles it is expected that following the internal fault, the amplitude of the higher frequencies at the initial instants has decreasing trend; it means that its value drops from large value to small value. This trend has been shown in the Fig. 3 (D1-D5) where the differential current due to ab-g internal fault at time t = 0.05 sec and frequency levels from the wavelet transform are visible.

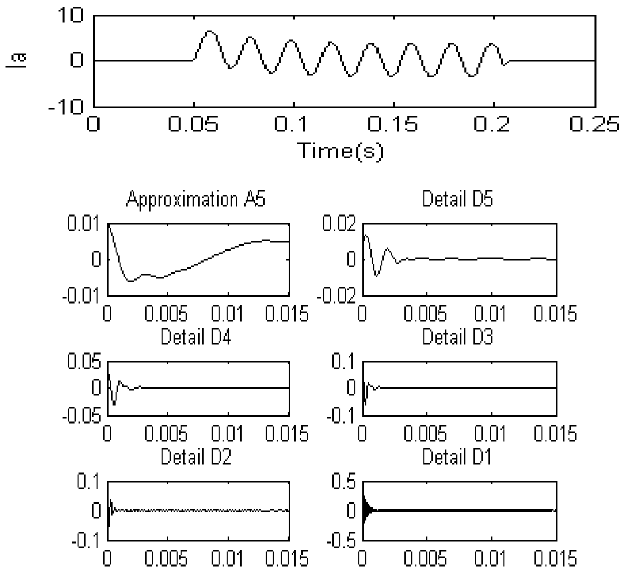

Figure 3. Successive details and approximations for internal faults ab-g on high voltage side during load

Its is also expected that following the inrush current the amplitude of the high frequency components at the initial time of fault has increasing trend. It mean that higher amplitude increase from low value to high value. the differential current due to the inrush current at t = 0.05 and resultant frequencies from wavelet transform are visible as shown in the Fig. 4 D1 to D5. Therefore these mentioned features are clearly visible at frequency level D5. Fig. 5 shows the differential current waveform due to the fault current and inrush current at frequency level D5. In order to introduce a criterion function for discriminating the inrush current from internal fault current, the amplitude of the first two peaks of the differential current in D5 are considered following the disturbances, and called X and Y. In a power system there is a significant difference between symmetrical conditions and unsymmetrical conditions.

Unsymmetrical conditions may occur during power system faults caused by, e.g. lightning, switching surges, insulating contamination or by unsymmetrical loads Fig. 5 shows the absolute value of the differential current from D5 and points X and Y based on the above explanation. In the case of inrush current X<Y and in the case of internal fault X >Y. In the second case there exists in equality in one phase and the trip command is issued as shown in the Fig. 5 the above inequality can be used to discriminate the inrush current around a quarter cycle which is very quick also suggested criterion function is simple and it avoid complications and huge computation time. As shown in the Fig. 3 and 4 amplitude of wavelet coefficients in D5 are larger than D1-D4, which enhances the precision of the obtained X and Y this is the reason for using D5 in this proposed algorithm. A simplified flow chart of the proposed algorithm has been show in the Fig. 6. Block 1 represents the calculation of differential currents and the restraining currents and block 2 signifies that the relay is activated if any one of the differential currents is more than the setting of the differential protection. If the output of the block 2 is YES there is an internal fault or inrush current. Which must be discriminated and the proposed algorithm starts from block 3 and its aim is to discriminate internal fault from inrush current block 3 implements the wavelet transform to the differential currents, block 4 estimates X and Y where Xa means X phase and Yb means Y phase and so on. Details of computing XaYa, XbYb, XcYc is as follows. It will observe the first two peak of the level D5 namely Xa and Ya. Similarly Xb, Yb and Xc, Yc will also be noted. Finally the decision is made by block 5 to discriminate internal fault from inrush currents and relay issues trip signal if internal fault is detected or the relay will restrain. The relay will continuously monitor the currents and test for faults. As and when the trip signal appears, the relay will trip.

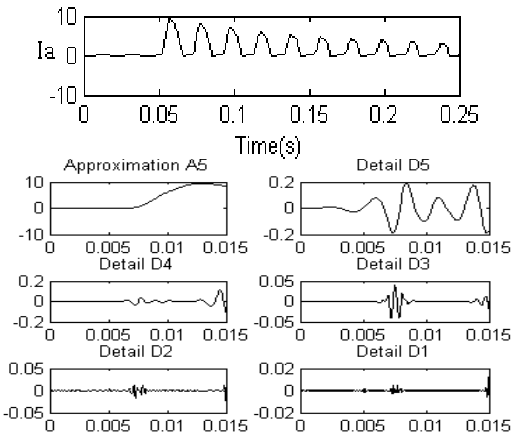

Figure 4. Successive details and approximation inrush current

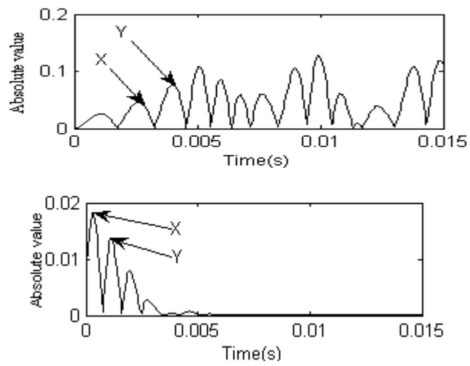

Figure 5. Absolute value for (a) Inrush current (b) Internal fault in D5

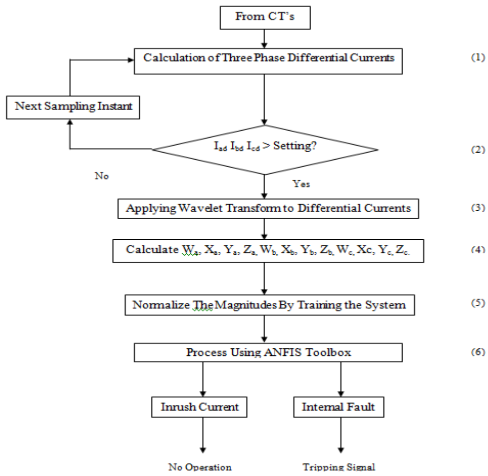

Figure 6. Flow chart of the proposed algorithm

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III. SYSTEM STUDIED

In order to investigate the applicability of the proposed algorithm simulation of power transformer model for different condition is carried out using the Fig. 7. The source is simulated by an equivalent 50 Hz 450 MVA synchronous machines with 500 kV load is connected in parallel. A (500/230) kV star to delta connected transformer is employed with its neutral grounded. The CT's used in the primary side is delta connected and star connected in the secondary side. The relay unit is connected to the CT's on both HV, LV sides of the transformer, and sampling rate of 10 kHz is considered for 300 samples per power frequency cycle band of 50Hz. The proposed algorithm is tested for different transient event as given in the tables.

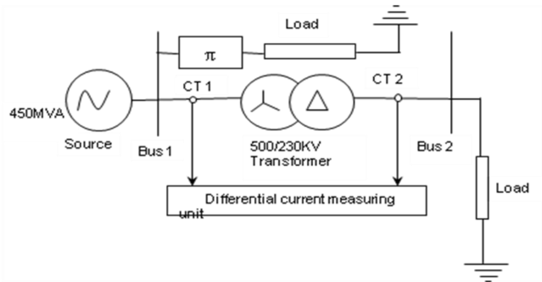

Figure 7. Power system model

IV. CLASSIFICATION USING ANFIS

The energy value obtained from the wavelet transform processed to ANFIS to classify internal fault from inrush current.

A. Anfis result for inrush current:

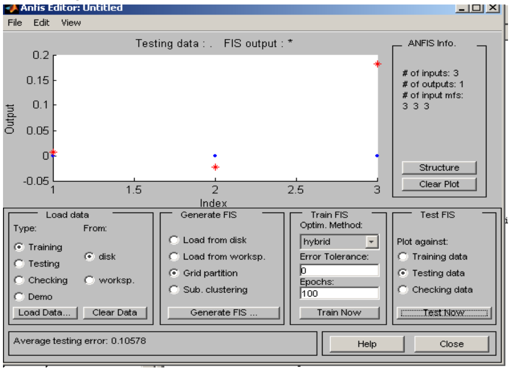

Figure 8. ANFIS result for inrush current

Figure.8 shows ANFIS results for inrush current. The energy values obtained from the wavelet transform processed to ANFIS shows zero after classification from internal fault current.

B. ANFIS results For internal fault current:

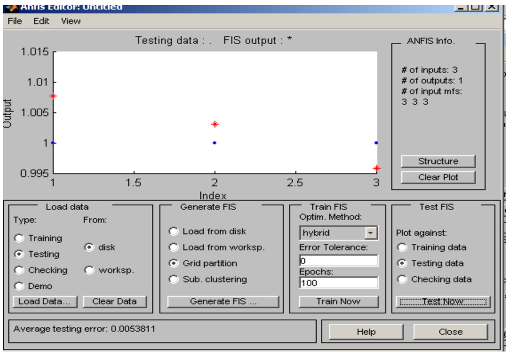

Figure 9. ANFIS result for internal fault current

Figure.9 shows ANFIS results for internal fault current. The energy values obtained from the wavelet transform processed to ANFIS shows one after classification from inrush current.

C. Error obtained from ANFIS :

Fig.11 shows training error obtained after classification. The parameters for ANFIS training for inrush case set the output vector has 0,for fault current case set the output vector has 1.For training trial and error methodology is used then rmse error is minimum. In this case study rmse error is minimum for having no.of mf is 3 mf type is gaussmf fistype is linear no.of epochs is 100.

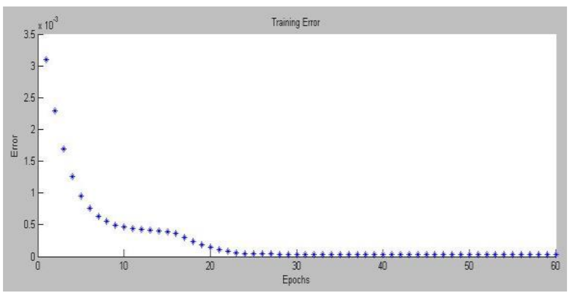

Figure 10. Training error after classification

V. CONCLUSION

In this paper, the proposed approach for discrimination between inrush current and internal fault in the power transformer is done using wavelet transform and signals are scaled to D1-D5. Criterion function is applied to D5 coefficients and Db9 mother wavelet has been used. The proposed method was defined based on the slope pattern and the amplitudes of wavelet transform co-efficient over a particular frequency band generated by internal fault and inrush currents. The method does not require any coefficients or threshold values. The proposed method can discriminate fault from inrush quickly than a quarter cycle after the disturbance. The ability of the new method was demonstrated by simulating various cases on a typical power system. Thus the test results confirm the effectiveness and reliability of the proposed algorithm.

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