Decriminition between Magnetising Inrush from Interturn Fault Current in Transformer: Hilbert Transform Approach

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Abstract: Transformer protection is a critical issue in power system as issue lies in the accurate and rapid discrimination of magnetizing inrush current from internal fault current. This paper presents a technique to classify inrush current and inter-turn fault current based on Hilbert Transform (HT) and Artificial Neural Network (ANN). A custom-built three-phase transformer is used in the laboratory to collect the data from controlled experiments. Hilbert transform is used as a tool for feature extraction. Envelop are extracted from differential current signal and fourteen statistical parameters are computed from this envelop which are then used input to ANN for classifying of inrush current and fault current.

Keywords: Three phase transformer, Inter-turn fault, Inrush current phenomenon, Hilbert Transformation, ANN (Artificial Neural Network),

1. Introduction:

Transformer protection has always been a challenging problem for protection engineers. The faults occur in transformer are open-circuit faults, earth faults, phase to phase faults, over heating faults and inter-turn faults. Inter phase short circuit are most frequent on leads of three phase transformer, while the inter phase short circuit within the winding are less frequent. Earth fault and inter-turn fault have the highest probability on the transformer. Winding short circuit also called as the internal faults, generally result from failure of insulation due to temperature rise or deterioration of transformer.

In [1],The traditional method used for transformer protection is current differential protection, which is used for protecting the transformer windings against internal faults based on the simple property that the ratio of current entering and leaving the transformer is equal to the inverse of the transformation ratio. This ratio is affected by either internal fault or inrush current during transformer magnetization. In order to avoid mal-operation of a differential protection relay due to inrush current , a discrimination must be made between the inrush current and internal fault currents in transformer.

Transformer protection is of critical importance in power systems. Any transformer protective scheme has to take into account the effect of magnetizing inrush currents. This is because the magnetizing inrush current, which occurs during the energization of the transformer, sometimes results are 10 times full load currents and therefore can cause mal-operation of the relays is happening. Thus, the commonly employed conventional differential protection based on second harmonic restraint will face difficulty in distinguishing inrush current and internal faults. Thus, an improved technique of protection is required to discriminate inrush current and internal fault.

To overcome this difficulty and prevent the malfunction of differential relay, many methods have been presented to analyze and recognize inrush current and internal fault currents. As both inrush current and internal faults are non-stationary signals, wavelet based signal processing technique is an effective tool for power system analyze and feature extraction [2]. However the wavelet-based methods have better ability of time-frequency analysis but they usually require long data windows and are also sensitive to noise. The method presented in uses WT and ANFIS to discriminate internal faults from inrush current. Since the values of wavelet coefficients at detail 5 (D5) are used for pattern recognition process, the algorithm is very sensitive to noise.

In [3], a new algorithm for transformer differential protection, based on pattern recognition of the instantaneous differential currents. A decision logic by wavelet Transform has been devised using extracted features from differential currents due to internal fault and inrush currents. on this logic, diagnostic criterion is based on time difference of amplitudes of wavelet coefficients over a specified frequency band. The proposed algorithm is evaluated using various simulated inrush and internal fault current cases on a power transformer that has been modeled using Electromagnetic Transients Program software. Results of evaluation study show that, proposed wavelet based differential protection scheme can discriminate internal faults from inrush currents in less than 5 ms.

Accurately discriminating magnetizing inrush currents from internal faults has long been recognized as a very challenging problem. The technique use in this paper is based on discrimination between magnetizing inrush current and short-circuits currents in transformers by combining HT with ANN. Hilbert transform which is used as a tool for feature extraction. The statistical parameter is extracted from envelop which are then feed as an input to ANN for classifying the inrush current and transient signal.

2. Hilbert transform:

Hilbert transform is a signal analysis method that is frequently used in different scientific fields. Mathematically Hilbert transform of a real signal $x(t)$ is defined as time domain convolution of $x(t)$ with 1/t and is defined for all t by equation 1. [19]

$$y(t) = H(x(t)) = \frac{1}{\pi t} * x(t) = \frac{1}{\pi} \int_{-\infty}^{\infty} \frac{x(\tau)}{t-\tau} d\tau$$

(1)

Following are the properties of Hilbert Transform

A real signal $x(t)$ and its Hilbert Transform $y(t)$ are mutually orthogonal

Mathematically $\int_{-\infty}^{\infty} x(t)\, y(t)\, dt = 0$

(2)

If $y(t)$ is Hilbert Transform of $x(t)$ then Hilbert Transform of $y(t)$ is $-x(t)$

(3)

$\pm \frac{\pi}{2}$ Phase shift is another basic property of Hilbert transform. Phase of positive frequency components is shifted by $-\frac{\pi}{2}$ and phase of negative frequency components is shifted by $+\frac{\pi}{2}$

$$\theta(\omega) = \frac{\pi}{2} \quad \text{For } \omega < 0$$

$$\theta(\omega) = -\frac{\pi}{2} \quad \text{For } \omega > 0$$

(4)

A real function $x(t)$ and its Hilbert Transform $y(t)$ are such that they together create an analytic signal $z(t)$.

$$z(t) = x(t) + jy(t)$$

(5)

Signal $z(t)$ has the property that all negative frequencies of $x(t)$ has been filtered.

Envelope E(t) of a signal is defined as

$$E(t) = |z(t)| = |x(t) + jy(t)|$$

(6)

And instantaneous phase is defined as

$$\theta(t) = \arctan\left(\frac{y(t)}{x(t)}\right) \quad (7)$$

3. Artificial neural network

Computers are great at solving algorithmic and math problems, but often the world cannot easily be defined by a mathematical algorithm. Facial recognition and language processing is a couple of examples of problems that cannot easily be quantified into an algorithm; however these tasks are trivial for humans. The key to Artificial Neural Networks is that their design enables them to process information in a similar way to our own biological brains, by drawing inspiration from how our own nervous system functions. This makes them useful tools for solving problems like facial recognition, which our biological brains can do easily.

a) Architecture of ANN

The Neural networks are a combination of various layers and layers made of a number of interconnected nodes. The input layers patterns present in the network, which communicates one or more hidden layers where actual processing is done via a system of weighted connection. The hidden layers then link with out- put layers and final answers is out-put as shown in figure 1. An input is presented to the neural network and a corresponding desired or a target response set at the out-put. An error is composed from the difference between the desired response and system out-put. This error information is fed back to the system and adjusts the system parameters in systematic fashion. The process is repeated until the performance is acceptable.

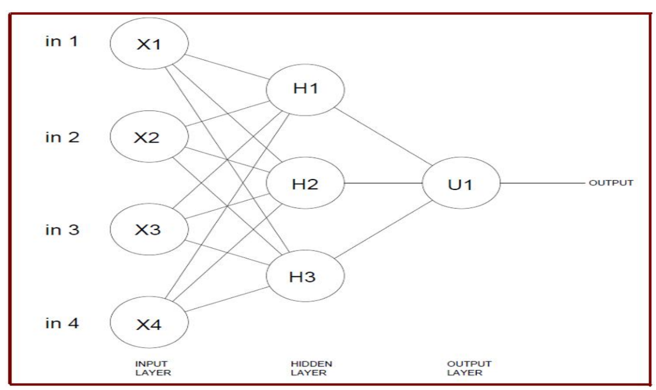


Figure 1. Architecture of Artificial Neural Network

4.Experimental setup:

A transformer during operation encounters any one of the following conditions Normal condition, magnetizing inrush/Sympathetic inrush condition, and internal fault condition. To evaluate the developed algorithm, experimental tests were performed on a custom-built 440V/440V, 5KVA, 50Hz star-star connected three-phase transformer with externally accessible taps on both primary and secondary to introduce inter-turn faults. Experimental set up is as shown in Fig 2. Differential current of three phases Ia, Ib, and Ic are captured using the experimental setup.

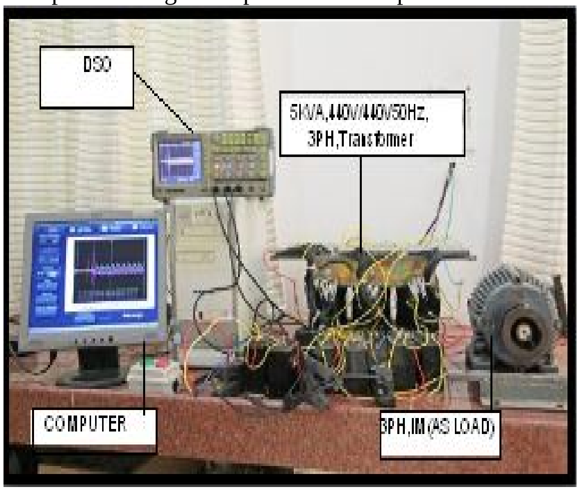


Figure 2: Experimental setup

Tektronix DSO, TPS 2014 B series, with 100 MHz bandwidth and adjustable sampling rate of 1GHz, has been used, and current probes of rating 100 mV/A, input range of 0 to 70 Amps AC RMS, 100A peak and frequency range DC to 100KHz are used to capture current signals. These signals are recorded at a sample rate of 1KHz.

The transformer winding is designed with 415 turns per phase, external tapping after every 10 turns are provided for creating inter-turn short circuit faults. The Inrush current is captured keeping secondary winding open circuited and for inter-turn fault current, 30 turns on the primary are shorted.

Current signals recorded for normal conditions and inter-turn fault condition in three phase transformer are shown in figure 3, figure3(a) shows inrush current and figure 3(b) shows inter-turn primary side current.

Figure 3(a): Inrush current

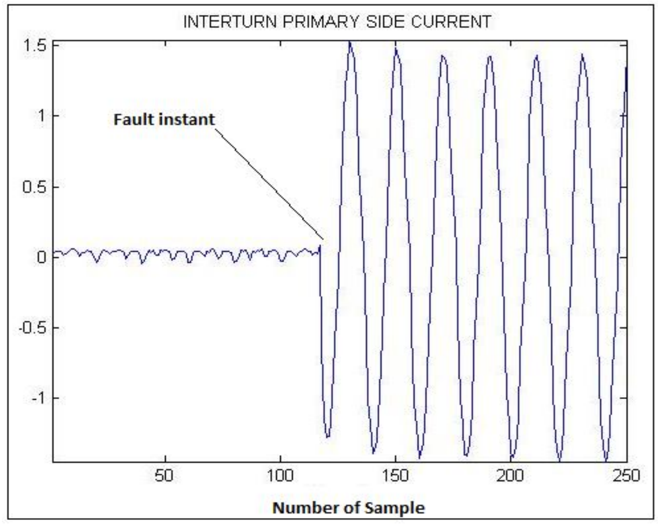
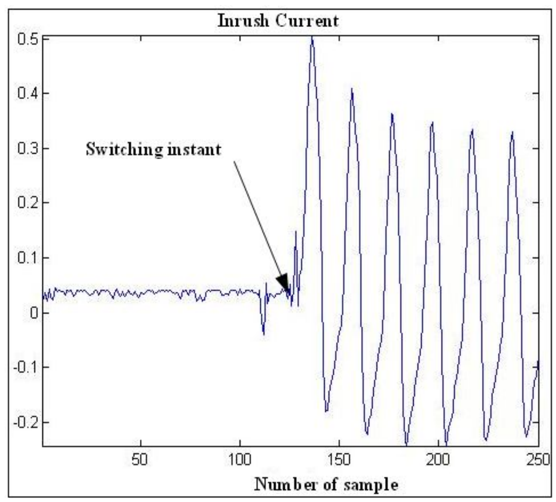


Figure 3(b): Inter-turn primary side current.

5. Feature extraction using Hilbert transform:

Envelope obtained for different conditions of three phase transformer are as shown in figure 4, figure 4(a) shows envelop of inrush current and figure 4(b) shows envelop of inter-turn fault current.



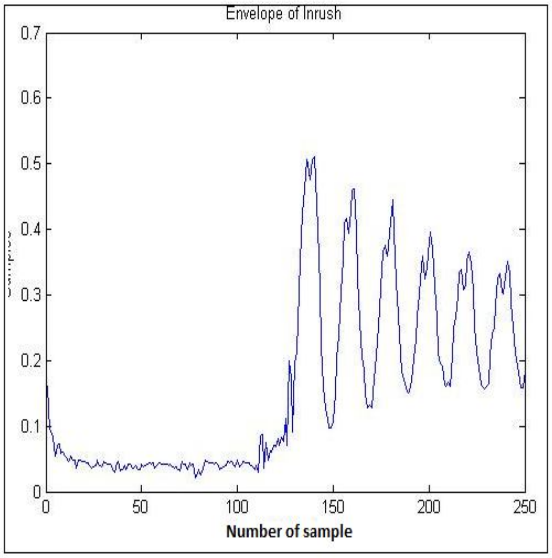


Figure 4(a): Envelope of inrush current

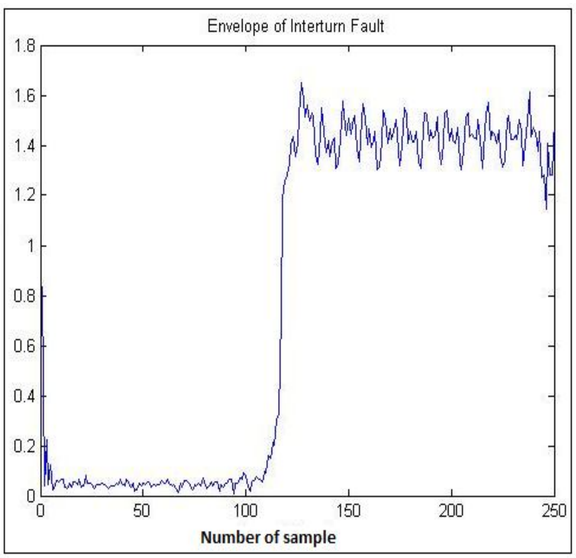


Figure 4(b): Envelope of inter-turn fault current

The main problem facing the use of ANN is the selection of best inputs and how to choose the ANN parameters making the structure compact and creating highly accurate networks. For the proposed system to create a training pattern fourteen statistical parameters named as Minimum, Maximum, Mean, Median, Sum, Absolute sum, RMS value, Energy, Kurtosis, Crest factor, Shape factor, standard deviation, Variance and Skewness are obtained from the current envelopes extracted from different conditions on three phase transformer.

6. Results and discussion:

Result in a time domain signal containing a rapidly oscillating component. The amplitude of the oscillation varies slowly with time,and the shape of the slow time-variation is called the envelope. The envelope often contains important information about the signal. By using the Hilbert transform the rapid oscillations can be removed from the signal to produce a direct representation of the envelope alone.

Application of ANN to various decision making, forecasting and classification problem has gained a lot of attention. An ANN with its excellent pattern recognition capabilities can be effectively employed for fault classification of three phase transformer. In the present study three layer fully connected multilayer perception network (MLP) is used and trained with supervised learning algorithm back propagation. MLP consists of one input layer, one hidden layer and one output layer. Input layer consists of fourteen neurons, the inputs to these neurons are the statistical parameters computed from envelopes of inrush and fault currents. Output layer consists of two neurons representing healthy and inter-turn fault.

Configuration is selected to build MLP network is mention in Table.1:

Table 1: Configuration of Artificial Neural Network

Layers	Number of PEs	Learning Rate	Momentum	Training data	Testing data	Transfer function	Epochs
Input	14	0.6	0.8	75%	25%	Tansig	1000
Hidden	1						
Output	2						

With this network the variation of average mean square error and correct percent accuracy for both inrush and fault with respect to the number of processing elements in the hidden layer is obtained. It is found that for a training method of Levenberg-Marquardt for one hidden layer and only one processing element in the hidden layer the mean square error is minimum and correct classification accuracy is hundred percent. Figure 5 shows the percentage of correct classification accuracy with respect to the number of processing elements (PE)

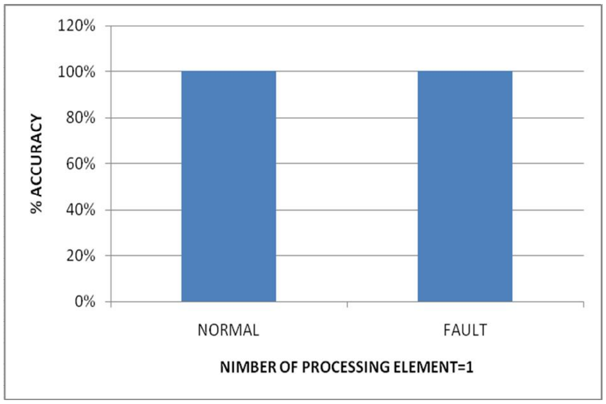


Figure 5: PE's Vs % correct classification Accuracy

7. Conclusions:

A novel Hilbert Transform based approach is presented in this paper for classification of inrush current from inter-turn fault in a custom built three phase transformer., Hilbert transform is used as a tool for feature extraction. Envelop are extracted from differential current signal and fourteen statistical parameters are computed from this envelop which are then used as an input to ANN for classifying of inrush current and fault current. Hundred percent correct classification accuracy is obtained at only one processing element in the hidden layer. The developed algorithm can be implemented in a digital relay for on line monitor and protection of transformer.

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