Analysis of Three-Phase Faults of Power Transformer using Artificial Neural Network

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Abstract- *In this digital era, digital representation of electrical parameters makes the system operation more reliable and sensitive. A digital technique has been used here for analysing the faults. During fault detection, power transformers are prone to various harmonics and inrush current so we have to find a way that can differentiate the unwanted outages of power transformers. Differential protection is one of the most effective and sensitive method of transformer protection. It is based on the fact that during internal fault condition the current entering the electrical equipment is different from that leaving it. Differential relay is most suitable for protection of transformer and is capable of detecting very small magnitude of differential current. Inrush and fault currents are non-stationary and non-periodic signals containing both high frequency oscillations and localized impulses superimposed on the power frequency and its harmonics and transformer transient current signals during faults and inrush conditions deals with short duration. Therefore, discrete wavelet transform that can analyse these harmonic conditions effectively, is most suitable. To analyse the different fault conditions, the digital data obtained after Discrete Wavelet Transform, is fed to Artificial Neural Network. In the present paper we have to study the different operating conditions of the power transformer. Present study is focused on suitably analysing the Inrush condition and Internal faults.*

Keywords: Differential Protection, Power Transformer, Inrush current, Discrete Wavelet Transform and Artificial Neural Network.

I. INTRODUCTION

For continuous and steady supply of electrical energy Power transformer must be protected. For power transformer protection protective relay should operate flawlessly and unpredictably in order to reduce the frequency and duration of undesirable outages. It can be accomplished by no false tripping and high operating speed of circuit breaker accompanying with protective relay. With the progress in the field of digital electronics and signal processing, it is possible to construct fast responsive digital or microprocessor-based relays [1-2].

In case of power transformer one of the challenging problem in detecting the faults is the high magnetizing inrush current. A differential relay that operates on the basis of measurement and evaluation of currents at both sides of the transformer cannot avoid the trip signal during inrush condition, since the transformer inrush current is unlikely rich in second harmonic component and its amplitude may be as high as of internal fault current [3-4].

(a) Traditional Approach

To avoid the needless trip by inrush current, besides harmonic restraint logic, a differential logic is used in the fault detection algorithm in the digital differential protection of power transformer. Traditional methods consider the fact that the ratio of the second harmonic to fundamental component of differential current under inrush condition is more in comparison to that under fault conditions.

But second harmonic restraint principle approach often encounters some problems such as long restrain time because the amplitude of second harmonic and fundamental are computed by discrete Fourier transform (DFT) and the ratio is used to judge whether the current is inrush or internal fault current. But DFT is not precise if the current is contaminated by harmonics that are not integer multiples of the fundamental. DFT only accounts for frequency analysis but does not provide information in the time domain. DFT assumes a periodic signal whereas inrush current and fault currents are not stationary signals. Also, the existence of large quantity of harmonics in the inrush current can cause harm to power factor correction capacitor by exciting resonant overvoltage [5-7].

(b) Modern Approach

Now a day's Numerical differential relays are utilized for protective purpose and is based on advanced digital signal processing techniques and digital devices like microprocessors or microcontroller.

In this work numerical differential relay is devised by simulating it in MATLAB Simulink. This design is applied to protect the power transformer against internal faults and avoid interruption because of inrush currents.

II. TRANSFORMER PROTECTION

Differential protection is one of the most effective and sensitive method of transformer protection. In differential protection an internal fault is recognized by comparing the electrical parameters like currents or voltages at the terminals of the electrical equipment which is to be protected. In this method of protection, we use the fact that during internal fault the current entering the electrical equipment is different from that leaving it. Differential relay is able to detect even a small magnitude of differential current, hence it is considered as very sensitive and effective method of protection against internal faults.

For differential protection of power transformer, a pair of identical current transformers are coupled at the two sides of the power transformer which is to be protected. The winding ratio of the two current transformers are such that their secondary currents are equal during normal or external fault conditions. Therefore, the differential current that is the vector sum of secondary currents of the two current transformers will be approximately zero or very less. Connection diagram of a basic Differential Relaying is as shown in the figure Fig 1.

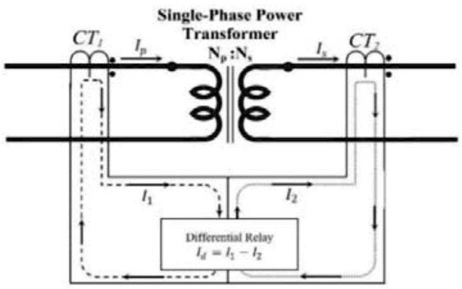


Fig. 1 Basic Connection diagram of a Differential Relaying

Such a common differential relay operating on the basis of measurement and evaluation of currents at both sides of the transformer can't avoid the trip signal during inrush condition, since the transformer inrush current is rich in second harmonic component and its magnitude may be as high as of internal fault current.

(a) Inrush Current

When a transformer is energized, a transient current that might be 10 to 15 times larger than the rated transformer current can flow for several cycles. For power transformers with low winding resistance and high inductance, such inrush current can last for several seconds till the transient will decay away (decay time is proportional to ~ X_L/R).

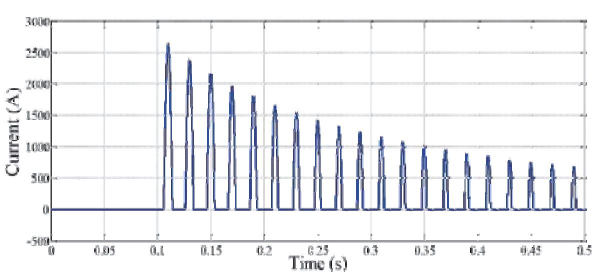


Fig. 2 Inrush current for switching angle 0°

To minimise the magnetic inrush in the transformers that has an air gap in the core, the inductive load has to be synchronously connected near a supply voltage peak in addition to the zero-voltage switching which is desired to minimize sharp edged current transients with resistive loads.

The analysis of inrush current predicts that excessive flux can build up in the transformer core depending on the instantaneous magnitude of the applied voltage and the residual flux at the instant of applying the voltage to the transformer.

(b) Reason of conflict between Inrush and Internal fault

Since transformer switching is a random phenomenon, this makes the magnetizing inrush also random. During energisation large magnitudes of currents flow into the primary winding of a transformer while no currents flow out of the secondary winding. This is similar to the conditions happening during internal faults. Hence there is a chance of incorrect tripping of the circuit breaker. Therefore, it is necessary to discriminate between an internal fault and a magnetizing inrush current.

(c) Numerical Relay

Present power systems are complex networks. Hence for the protection of such a complex network demands the relays to be reliable, secure and short time decision making. Digital relays are programmable and capable to process the information. Whereas the conventional non numerical relays perform only comparison. The digital relays have the capability to perform real time computation [8-10].

III. DISCRETE WAVELET TRANSFORM & ARTIFICIAL NEURAL NETWORK

Since inrush and fault currents are non-periodic and non-stationary signals having both high frequency oscillations and localized impulses superimposed on the power frequency and its harmonics, the current is spoiled by harmonics that are not integer multiples of the fundamental waveform. Hence, wavelet transform is an appropriate method for the feature extraction from the waveforms of power transformer under various situations. The extracted features act as the input to the neural networks. Neural network is used to classify and discriminate the various conditions and output of the neural networks are fed to the digital relay to take decision for the breaker operation. This improves discrimination between normal, inrush, over excitation and fault conditions and facilitate faster and more reliable protection for power transformers.

(a) Wavelet transform

It is associated with building a model for a non-stationary signal, with a set of components that are small waves, called wavelets. It is defined as

$$W(a, b) = \int f(t) \frac{1}{\sqrt{2}} \Psi\left(\frac{t-b}{a}\right) dt \int$$

(b) Discrete Wavelet Transform

If the wavelet transform is done in discrete steps, it is called discrete wavelet transform (DWT)". It results in a finite number of wavelet coefficient depending upon the integer number of the discretization step in scale and translation, denoted by m and n respectively.

If a_0 and b_0 is the segmentation step sizes for the scale and translation respectively, then the scaling and translating parameter will be

$$a = a_0^m \quad \text{and} \quad b = nb_0\, a_0^m$$

$$\text{DWT (m, n)} = a_0^m \int f(t)\Psi\left(a_0^m t - nb_0\right)dt$$

(c) Implementation of Discrete Wavelet Transform

Out of a large list of mother wavelets available, the choice of a particular mother wavelet plays an important role in detecting and classifying different types of fault and inrush transients of power transformer. Since the transformer transient study deals with analysing short duration, fast decaying current signals therefore Daubichies's mother wavelet of level 6 is used.

For different transient current signals, the wavelet analysis in different conditions like normal, inrush, internal, external faults and over excitation are performed and observed from SIMULINK.

IV. ARTIFICIAL NEURAL NETWORK

A neural network is a massively parallel distributed processor made up of simple processing units, which has a natural tendency for storing experimental knowledge and making it available for use. It resembles the brain in two aspects.

1. Knowledge required by the network from its environment through a learning process.

2. Interneuron connection strengths, known as synaptic weights, are used to store the acquired knowledge.

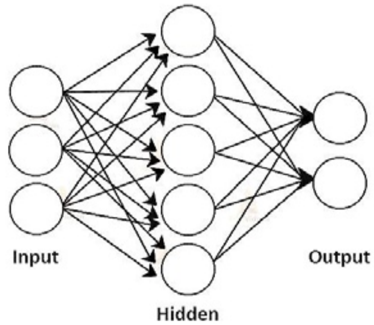


Fig. 3 Basic structure of Multilayer feed-forward ANN.

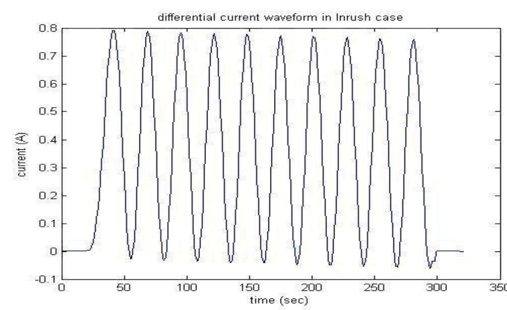
(a) Multilayer Feed-Forward ANN

It is having three layers namely input, output and hidden. Each network layer comprises of processing units known as nodes. Each node in a network layer will deliver its output to all the nodes of the next layer. In the input layer, the nodes receive signals from the outside environment. The output layer of the neural network serves as an interface that sends information from the neural network's internal processing units to the external world.

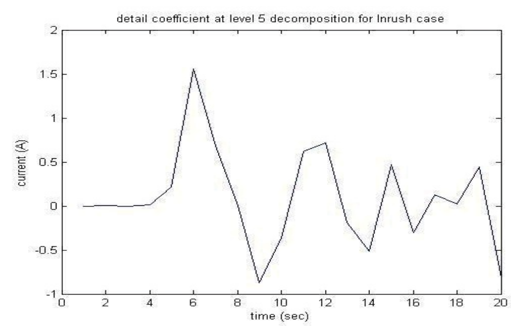
V. WAVELET ANALYSIS OF THE DIFFERENTIAL CURRENT SIGNAL

(a) Wavelet analysis in Inrush case

Transformer is switched on at 0° angle of the source voltage.



(a) Original Signal



(b) Detail 5

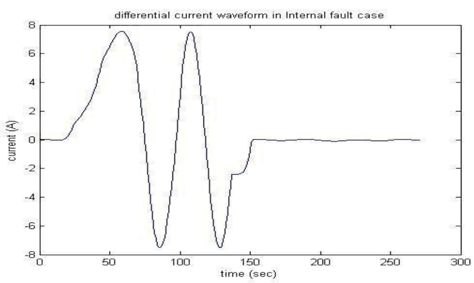
Fig. 4 Wavelet analysis of the Phase-A differential current in Inrush case.

It can be observed in Fig. 4(a) that current get distorted when transformer is switched on at 0° angle of the source voltage. Here gaps appear along the time of inrush current. Also, magnitude of inrush current changes from nearly zero value to a significant value. This sudden change should produce ripples but these ripples are not visible in time domain representation. These ripples are clearly discriminated in wavelet plots. We know that High frequency components are located better in time domain and low frequency components are located better in frequency domain. Hence, detail coefficients d1, d2 and d3 are realised better in time domain as they contain high frequency components whereas details d4 and d5 are realised better in frequency domain as they contain low frequency components.

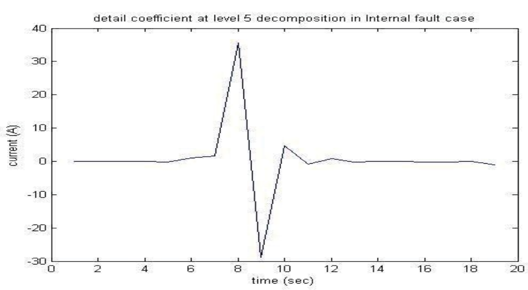
(b) Wavelet analysis in Internal fault case

In internal fault case, wavelet analysis is performed on the differential current signal of power transformer.

Transformer is switched on at 0^{o} angle of the source voltage. It is shown in Fig. 5. The Fig. 5(a) shows the original differential current signal during LG fault in internal fault case while Fig. 4(b) shows decomposed detail coefficient signals at level-5. This analysis is performed for all the three phases. Faults is thrown for the period of two cycles of waveform i.e., for the time 0.10 to 0.14 seconds. Fault resistance is varied over 50 Ω to 100 Ω for getting different samples of data.



(a) Original Signal



(b) Detail 5

Fig. 5 Wavelet analysis of the Phase-A differential current in LG fault case.

From Fig. 5(a), it can be witnessed that there is large frequency distortion in the differential current waveform during internal fault. This distortion is due to the effect of distributed inductance and capacitance of transmission line which results in significant second harmonics in internal fault. This causes difficulty in correct discrimination between internal fault and inrush fault by protection method based on DFT.

Similarly, results are obtained for other internal fault cases like LLG fault, LLLG fault, LL fault, LLL fault cases.

VI. ANN Modelling and its Performance

(a) ANN Model

Feed-forward ANN is utilized for pattern recognition which uses back-propagation algorithm and is capable to identify different fault cases precisely. Sigmoid function is used as activation function whose value lies in the range of 0 to 1.

The statistical data found after wavelet analysis of the differential current signal is first normalized to get a set of data in the range of 0 to 1.

The modelled ANN has 9 input nodes and 9 output nodes to classify 9 types of faults. The number of nodes in the hidden layer is varied to get satisfactory result.

(b) Best suitable architecture of ANN

Number of input nodes = 9
Number of nodes in hidden layer = 15
Number of output nodes = 9
Momentum factor, m = 0.9
Learning Rate, n = 0

VII. Simulation

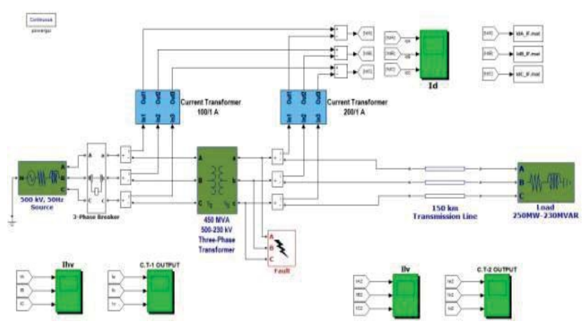


Fig. 6 Simulation Setup

VIII. Conclusion

From the study and analysis accomplished in this work, it is observed that DWT is suitable for extracting the transient differential current signal in both the time and frequency domain. It visualized the high frequency detail components (d1, d2 and d3) better in time domain and lower frequency detail components (d4 and d5) better in frequency domain. Also, it is capable to visualize ripples in inrush current which cannot be visualized in time domain. Thus, it is able to discriminate inrush current from internal fault current.

Pattern recognition neural network in combination with DWT technique adequately identified the different fault patterns. Also, the performance of network is found satisfactory i.e., mean square error is within the limit. This numerical relay, based on DWT and ANN, shows very less operating time with desirable accuracy.

(a) ANN verses SVM

Support vector machine is other classifier that analyse data and recognize patterns. Here sample data are represented as points in space and are mapped such that other sample data can be divided by a clear boundary. Test data are then mapped into same space and predicted to belong to a category based on which side of boundary they fall on.

(b) Performance of DWT in noisy environment

Wavelet transform gives time depended resolution of time-frequency domain. So, it is considered that it might be susceptible to noise. So, its performance analysis needs to be observed in noisy environment.

(c) Application of S transform in combination with ANN for transformer protection

S-transform is a recent technique of signal processing. It is variable window of STFT (Short time Fourier transform) or an extension of wavelet transform. It gives frequency dependent resolution of time-frequency domain, so it is merely susceptible to noise. It may give better result in noisy environment.

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