Discrimination between Normal Current and Fault Current for Transformer Protection Based on Artificial Neural Network

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Abstract— Transformers are vital component in power system for transfer of electricity in power system. Because of that reason protection of transformer is very much important; reliability of power system depends on transformer. Also due to high cost of the transformer and dependency of the power system on transformer, an efficient protection system has to be build which can protect transformer for any undesired condition. An ANN subroutine can build and to be used to discriminate internal fault current and magnetizing current, which can replace the traditional Fourier method and second harmonic restraining method, which are time consuming and less reliable. From study we found that now days there are certain faults, which contains second harmonic content so discrimination using second harmonic can pose a problem. This paper intends to present the advantages of ANN on other methods for discrimination between the inrush and fault condition in the transformers.

Key words: Fault Current, Normal Current, Transformer Protection, Artificial Neural Network

I. INTRODUCTION

A most vital component in power system is the Power transformers which require special protection and maintenance. Mostly, differential relays are in use for a complete and primary protection of huge transformers. Inside that relays, differential currents are checked by calculating through subtraction of primary side current and secondary side current. Percentage differential characteristic is used for calculation with operation and restricted zones, the transformer should be disconnected from the rest of the system if fault occurs. Only simply detecting of internal fault is not important because it can't discriminate it from other conditions, which are transformer energization (inrush currents),faults containing Second Harmonic Content, current transformer (CT) saturation, among others, which will result in an incorrect trip [1].This Discrimination is a challenge for today's Power system world. Traditionally Differential logic with Harmonic restraint is used to discriminate above mentioned condition.

The inrush current is find out on the basis of second harmonic which are obtained from filters, which can results in delay in protection. Artificial Intelligence Technique with New methodology aiming to improve sensibility, selectivity and operation of differential relays, which are artificial neural networks, Genetic Algorithm and fuzzy logic are in research centre recently. Different results had analyzed in the research with good results [1].

Recent Analysis in certain Studies has found that, the internal fault current might also contain considerable amount of second and fifth harmonics [1].In addition to this it also found that the new technology with high efficient and low eddy current loss amorphous core materials in modern transformer produces lower order harmonic contents also during magnetizing stage [1].

Also it was found that during inrush condition, the magnitude of the inrush current highly depends on the switching angle and instance of the connected circuit breaker. In a normal operation case, the primary and secondary current of a power transformer maintains equilibrium but when an internal fault occurs, this balance got disturbed. Also magnitude of the fault current depends upon the fault occurred zone, type of the fault (i.e. phase to phase, phase to earth etc), also on vector group of transformer (i.e. star-star, star-delta, delta-star) etc. Inrush current magnitude can be usually 15-20 times the normal load current [2].

II. MAGNETIZING INRUSH CURRENT

Transient magnetizing inrush current occurs on the primary side of transformer, when it is switched on with load. Due this inrush current differential relay sensed it as an internal fault and sends a trip command to the circuit breaker. The magnitude of inrush currents influenced by, [2]

- Input Supply voltage Magnitude Level.
- The time at which circuit breaker is closed i.e. Instantaneous value of the supply voltage at which instant Circuit Breaker closed i.e. at 0^o or at 90^0.
- The magnitude of the residual flux.
- The polarity of the residual magnetizing flux.
- Also depends on which Type of iron laminations used in transformer core.
- The saturation curve and flux density of the core of the transformer.
- The magnitude of the impedance of the supply circuit.
- The size of the transformer itself.

This all can generate the inrush current and can cause relay maloperation without of any presence of fault. The principle behind the operation of the differential relay is to compares the currents coming out from both sides of the power transformer which is primary and secondary. [4] By the effect of the magnetizing inrush current primary side current increases tremendously and the magnitude of the differential current also increases. Thus to provide a complete protection to the transformer differential relay has to recognize that this is a magnetizing current or a fault current. Here figure 1 shows the transient current and its duration and also shows time taken by the transformer to become steady.

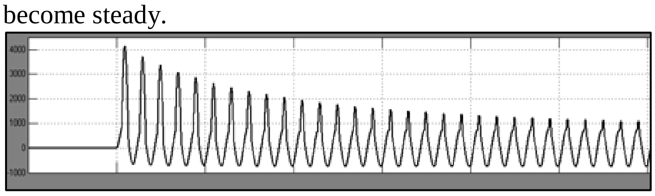

Fig. 1: Current waveform of Magnetising current

III. POWER QUALITY PROBLEMS CAUSED BY MAGNETIZING INRUSH CURRENT

Magnetizing inrush current can have two kinds of disturbances, which can be described as below,

A. Unbalance

Due to unbalance load, unbalanced current is produced which can't be considered as disturbance which are due to Asymmetry of load, From the same perspective Magnetizing current are produces current unbalance during magnetization of transformer core, also due to CT saturation unbalanced condition occurs.

B. Harmonics

During the magnetization stage as the current contains all orders of harmonics but the most relevant are the second and third harmonic contents magnitude and duration. Depending on the magnitude of residual flux, dc component magnitude is present in the first cycle. The most Significant harmonics can be given as under, [2]

- DC offset component: This is a Function of the residual flux which is present in the core and can be found present at all times in the inrush current with different magnitude at each phase.
- Second harmonic: This is present due to asymmetry in waveform of positive and negative cycle, this can be said that the function of degree of saturation. Second harmonic is inherently availing in all inrush current of all phases.
- Third harmonic: Third Harmonic is dominant component in the odd harmonic spectrum and also may be of same magnitude as second harmonic.
- Higher harmonics: Higher Harmonics also present there with different values of small size which are neglected.

IV. TECHNIQUES USED TO DISTINGUISH INRUSH AND FAULT CURRENT

For the discrimination there are many techniques were used, some of them are described below, [2]

- Desensitization method is not much used in practice.
- Wave shape recognition methods are comparatively new method but not use now days.
- Harmonic based methods This is widely used method in practice because inrush current contains some harmonic component which are not present in fault current because of symmetry of waveform. Due to this asymmetry, magnitude of second harmonic is about 30-35% of the fundamental component, present in inrush current.
- Artificial intelligent technique New techniques based on Artificial intelligent technique (Artificial Neural Network, Genetic Algorithm, Fuzzy logic) can help in make discrimination between magnetization and fault current. Let us elaborate more this technique and also evaluate its advantages over other techniques.

V. NEURAL NETWORK

Artificial neural network consist of artificial neurons which are interconnected with each other through different weights which tends to make an artificial prototype like human brain. This interconnected network uses it's intelligence for discrimination purpose, which can be made more strong by the use of training and learning process, by which we can modify synaptic weights that connects the neurons. [3]

A. The Proposed ANN Design

Before applying any problem to the ANN first it is essential to formulate the problem and which is very difficult task. In formulating process of the problem first and foremost step is to find what and how many are the inputs and outputs. While in our case inputs are differential current waveforms or it can be different types of current waveforms which can be directly fed to the neural network. Also these are to be given in form of samples of different phases for the same time stamping. Here for every instant a window of 5 consecutive current samples are taken which can be shown later, and we give six inputs to the ANN so total of 30 inputs are given to the ANN. Although No. of output is depends on the particular problem a binary output is sufficient to find out that whether it's a fault or normal inrush current. A typical structure of ANN is shown in Fig.2

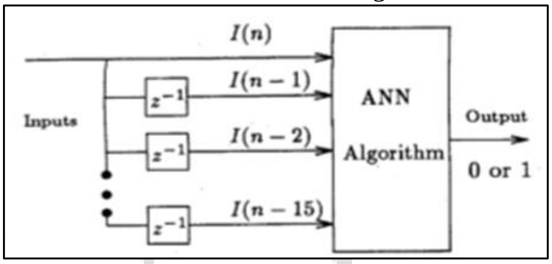

Fig. 2: ANN Inputs and Output

In our case we take faulty and normal current axis also so, if internal fault exists then it shows 1 in faulty axis and in normal condition or in only magnetizing condition it shoes 1 in normal axis. Once the inputs and output are defined, the next step is to identify or define hidden layer(s) in the network, in our case there are 15nos. of hidden layer and neurons are taken. The selection of no. of hidden layer used is a matter of trial and error, in our case gradient is comes 0.0116 [3]. The number of units in the hidden layer is varied depending on the requirement. There is a transfer function associated with each output layer and hidden layer. Generally nonlinear sigmoidal functions are used as the transfer functions. In this work, Levenberg-Marquardt technique used for training purpose, and back propagation algorithm used for training the network.

B. Training of Neural Network

Feed forward neural network is used for training of ANN which is used for complex matching pattern problem. In the case of Multi layer feed forward network, first layer is input, after that many hidden layers and in the last an output layer is there.

All of the above layers contain processing units which is widely known as neurons. Signal first coming from input layer passed to the hidden layer at there it is processed and then reach to output layer. Supervised learning method is used by the learning algorithm in neural network in our case. The first input layer propagates until output is achieved. That output is compared with desired output; if they are not same then the error signal is generated for each output. This process is going to repeat layer by layer until the error reaches up to threshold value. In the learning process Determination of connected weights & pattern followed for solution is involved .In these process Weights are updated in each layer and iterations. It is called epoch mode. In neural network the cost function is MSE (mean square error). It can be defined as in equation (5.1) [5]

$$E = \frac{1}{N}\sum_{n=1}^{N}(d_k(n) - y_k(n))^2 \qquad (5.1)$$

Where, N is given as the number of patterns in data, $d_k(n)$ and $y_k(n)$ are the desired output and the output at layer k for nth training pattern respectively. If there is more than one output, it can be written as

$$E = \frac{1}{N}\sum_{n=1}^{N}(\mathbf{d}_k(n) - \mathbf{y}_k(n))^T(\mathbf{d}_k(n) - \mathbf{y}_k(n)) \qquad (5.2)$$

Where d_k and y_k are column vectors of desired output and actual output calculated respectively. By adjusting the weights we can minimize error function E at all the training state. When threshold value or predefined value of cost function is reached then training can be stopped.

VI. SIMULATION OF TRANSFORMER

A. *Single Phase Transformer:*

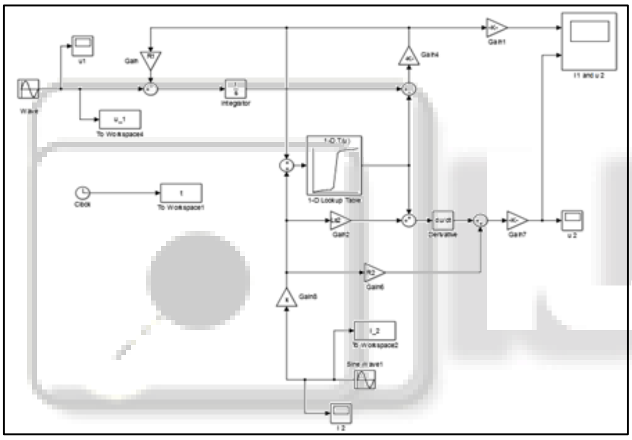

Fig. 3(a) Simulation diagram for nonlinear transformer normal condition

Using MATLAB/SIMULINK a mathematical model of Single phase transformer is designed for the transformer fault analysis. [3]

A 1.5 KVA, 60 HZ, three phase two winding transformer is connected to 1.5 KVA three phase source. In fig. 3(a) & 3(b) mathematical simulation diagram for the transformer fault is shown.

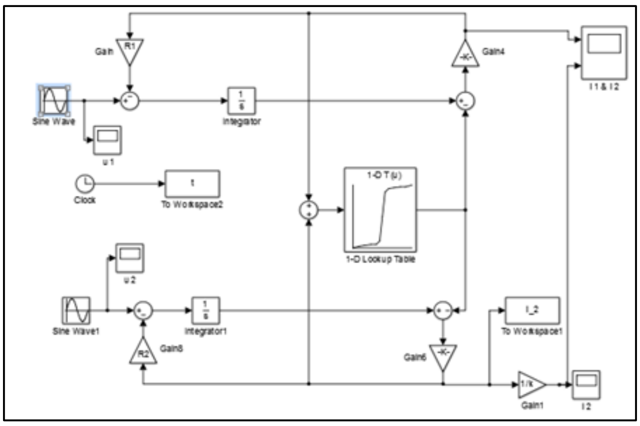

Fig. 3(b): Simulation diagram for nonlinear transformer short circuit condition

The equation used for this model is shown below,

$$u_1 = R_1 \cdot i_1 + \frac{d\psi_1}{dt}$$
$$-u_2' = R'_2 \cdot i'_2 + \frac{d\psi'_2}{dt}$$
$$\psi_1 = \psi_{u1} + L_{\sigma 1} \cdot i_1$$
$$\psi_{u1} = w_1 \cdot \phi_u$$
$$\phi_u = f(i_{1\alpha})$$
$$i_{1\alpha} = i_1 + i'_2$$
$$i'_2 = \frac{w_2}{w_1} \cdot i_2$$
$$u_2 = (-u'_2) \cdot (-\frac{w_2}{w_1})$$

For linear transformer,

$$\psi_{u1} = \frac{\frac{\psi_1}{L_{\sigma 1}} + i'_2}{\frac{1}{L_{u1}} + \frac{1}{L_{\sigma 1}}}$$

Where, u_1 indicates the instantaneous primary voltage value; i_1 indicates the primary current instantaneous value; I'_2 is the secondary instantaneous current value; u'_2 is the secondary voltage instantaneous value; 1 indicates the primary flux; 2' indicates the secondary flux; Lu1 indicates the magnetizing inductance; w1 indicates the number of turns on the primary winding; w2 indicates the number of turns on the secondary winding.

For nonlinear Transformer Equations can be given as,

$$\psi_1 = \int_0^t (u_1 - R_1 \cdot i_1) \cdot dt + \psi_1(0)$$
$$i'_2 = \frac{w_2}{w_1} \cdot i_2; \quad i_1 + i'_2 = i_{1\alpha}$$
$$\phi_u = f(i_{1\alpha}); \quad w_1 \cdot \phi_u = \psi_{u1}$$
$$i_1 = \frac{\psi_1 - \psi_{u1}}{L_{\sigma 1}}$$
$$\psi'_2 = \psi_{u1} + L'_{\sigma 2} \cdot i'_2$$
$$-u'_2 = R'_2 \cdot i'_2 + \frac{d\psi'_2}{dt}; u_2 = (-u'_2) \cdot (-\frac{w_2}{w_1})$$

$$i_1 + i'_2 = i_{1\alpha} \;;\quad \phi_u = f(i_{1\alpha}) \;;\quad w_1 \cdot \phi_u = \psi_{u1}$$
$$i_1 = \frac{\psi_1 - \psi_{u1}}{L_{\sigma 1}} \;;\quad i'_2 = \frac{\psi'_2 - \psi_{u1}}{L_{\sigma 2}} \;;\quad i_2 = \frac{w_1}{w_2} \cdot i'_2$$

B. *Waveforms:*

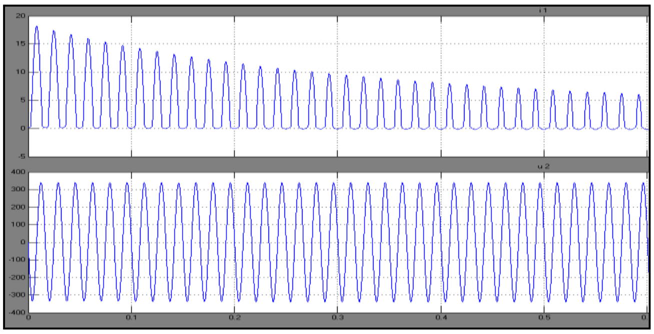

Fig. 4: Waveform for fault current in transformer

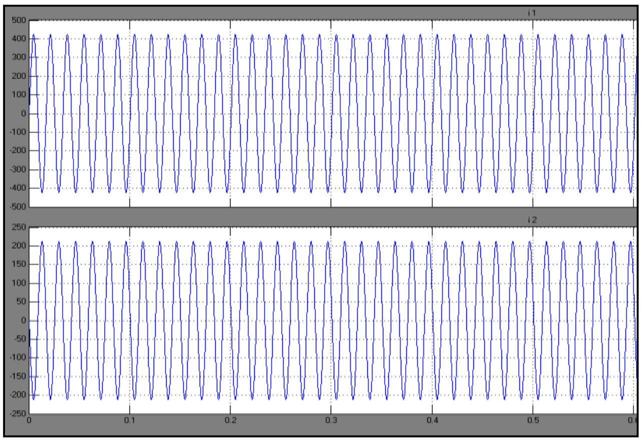

Fig. 5: Waveform for normal current with inrush in transformer

C. Three Phase Transformer Simulation

For building Simulation of three phase transformer a three phase transformer with following parameters are taken for our case, which is shown in below table,

Parameter	Measurement Unit	Magnitude
Rated Power	MVA	100/3 per phase
Transformation Ratio	V/V	11/33
Frequency	Hz	50
Type	Step-up	

Table 1: Three Phase Transformer Simulation

A replica of real power transformer is made up in the MATLAB software using simulation for applying ANN to it, and can find out how it can help us to discriminate fault current and inrush current, for three phase transformer. Simulation of which is shown in the below figure 6,

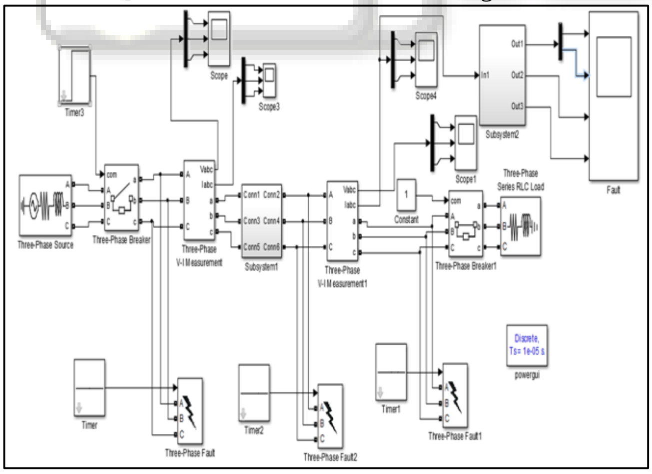

Fig. 6: Simulation of three phase transformer

Here, as shown in the figure7 to make transformer internal fault we take a multi tapping transformer and make available to choice the condition that in what condition, we want to run transformer either in normal, inter turn fault or in tapping condition. This condition is shown in below figure8.

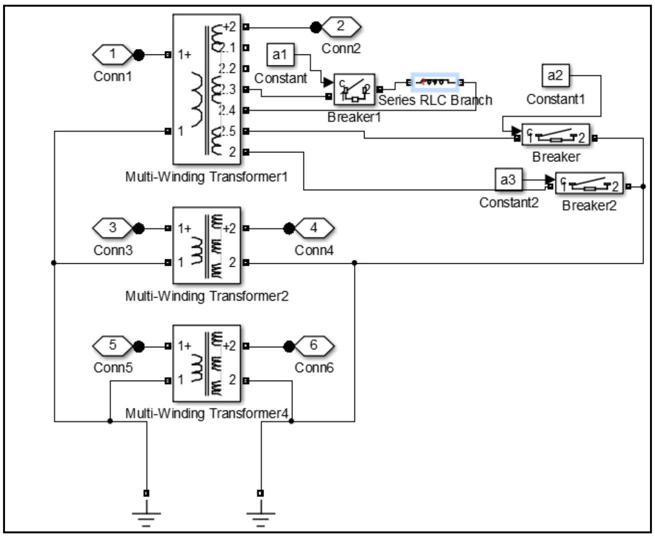

Fig. 7: Internal Structural diagram of the transformer

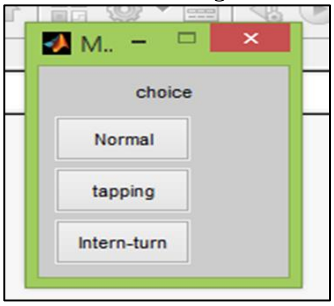

Fig. 8: Choice dialog box in transformer simulation

VII. RESULT & DISCUSSION

In MATLAB we perform the ANN Training for discrimination purpose for fault current and normal current & we finally understand that ANN can very accurately and quickly perform the task of the discrimination.

A. FFT Analysis for Normal Condition

By performing FFT analysis for different condition of transformer and taking current of primary side, analysis can be shown as in below figure with percentage harmonics present with percentage of fundamental component and whole harmonic spectrum can be shown.

This below figure shows the waveform and FFT analysis for normal condition on primary side current.

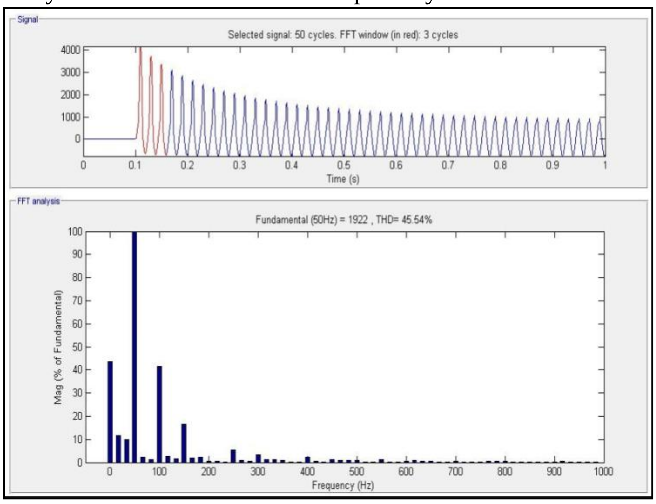

Fig. 9: Waveform with FFT analysis of primary side current of transformer for normal condition

B. FFT Analysis for Faulty Condition

Below given figure shows the waveform and FFT analysis for faulty condition on primary side of the transformer.

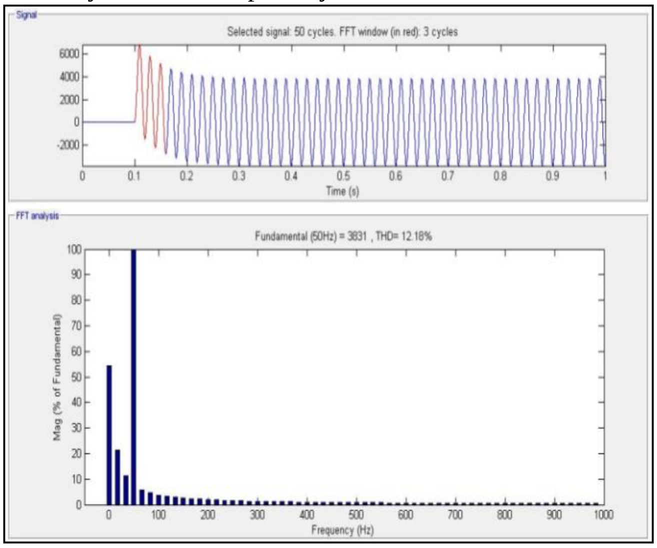

Fig. 10: Waveform with FFT analysis of primary side current of transformer for faulty condition

VIII. CONCLUSION

From the above simulation results we can find that the content of second harmonics is varying in normal and faulty conditions, as per the symmetry of the waveform of current on primary side of the transformer. From the waveforms and FFT analysis we can see that the magnitude of second harmonics is 40-50% of the fundamental component in normal condition while during faulty condition it could be about below 10% of the fundamental component. So, from the above results we can discriminate the Fault current and Inrush current. By giving this signals or results to the ANN we can train it in such a way that if an internal fault persist during the starting or inrush condition it will discriminate it and sent a trip signal to the circuit breaker and can provide complete protection to the transformer also during inrush condition. [9]

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