MODELLING AND SIMULATION OF CONDITION MONITORING OF THREE PHASE TRANSFORMERS USING MATLAB

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Abstract*— Power transformers are important and expensive components in the electric power system. To take special attention towards the behavior of power transformer a condition monitoring system was developed. The fundamental goal of condition monitoring is to provide better reliability, maintenance, and life cycle to the transformers. There are some basic procedures for a utility by which the condition of transformer is judge in a better way: monitoring, diagnosis, and maintenance. Monitoring systems can help to decrease the transformer life cycle cost and to increase the high level of reliability. After monitoring the transformer diagnosis will takes place; Diagnosis is the interpretation of monitored data. There are various condition monitoring techniques available, in which Artificial neural network (ANN) is powerful tool for the problem with small sampling and high dimension. ANN is applied to establish the power transformers faults classification. The scheme is designed to detect the fault, estimate the faulted side, classify the fault type and identify the faulted phase.

***Keywords*— ANN, Transformer, Fault, Monitoring, etc.**

I. INTRODUCTION

Day by day need of electrical energy supply in this contemporary world for each and every field increases rapidly. They also demand electrical supply continuous and almost a no-fault operation of power system. In the power system transformers are a type of component which is very high-priced and essential components of electric power systems. The primary goal is to limit recurrence and length of undesirable blackouts of transformers puts a high directed interest on transformer defensive transfers toward work typically.

In the power system safety of large transformer is extremely difficult problem. For safety purpose power system is using protective system in which such devices are used that recognize the existence of fault with its proper location, category and it will try to detect unusual fault. The Protective system after detection of fault will command circuit breakers to disconnect the faulty part or equipment of power system.

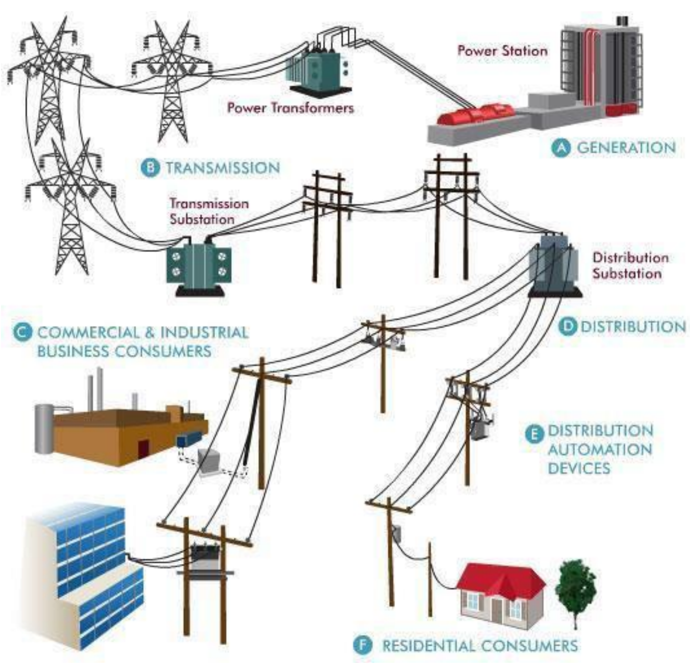


Fig 1.1 Power Distribution Network

Transformer is different from other components of power system because some certain type of problem are very strange that are occur in transformer only. One of the main problem of transformer is high magnetizing current which is having same magnitude as internal fault current and due that breakers having false tripping. A typical differential relay working based on estimation and assessment of the flows at the two sides, necessary and auxiliary face of the transformer can't keep up a strategic distance from the excursion signal throughout inrush situation.

According to research papers, transformer's magnetizing current is having high amount of second harmonic component. Hence to avoid false tripping by magnetizing current, harmonic current restraint logic integrated with differential logic is going to be used for fault finding algorithm in the digital protection of transformer.

II. CHALLENGES AND RESEARCH OBJECTIVES FOR S.G SECURITY

Many devices are used in electrical power system for the purpose of Generation, Transmission and Distribution of electrical power in which transformer is a type of device which is expensive as well as critical. The repairing and replacement of transformer is taking very long time and there is no substitute component, hence main objective is to protect the transformer from damage due to any kind of faults. Types of protection depends mainly on application and significance of transformers. Main purpose of protection of transformer is from fault and overload condition. The protection system should be such kind which will reduce the disconnection time so that risk of catastrophic failure will be reduce and only maintenance or repair will convert system into healthy condition. Any extended transformer activity under an abnormal situation, such as faults or overloads, jeopardizes the transformer's life, which means sufficient security should be offered under these circumstances for faster isolation of the transformer.

Study of different operating condition of transformer using MATLAB & SIMULINK.

a) Normal or Healthy condition
b) External Fault condition
c) Internal Fault condition
d) Magnetizing Inrush condition

Collection of testing, validating and training data from simulation and given to Artificial Neural Network (ANN) for transformer fault diagnosis.

Different type of faults found in transformer

Transformer's fault can be divided into two main sections:

- External fault
- Internal fault

External Faults

External faults are kind of faults in which transformer have to be cut off if other protective devices fail to operate with in a predetermined time. In the resolution of improvement of power system security protective system always have backup protection. For external faults time graded over current relays will act as backup protection. Transformer must also not be permitted to run for long duration in case of a prolonged overload situation. For the overload condition thermal relays are used.

Internal Faults

The main goal of protection of transformer is from internal faults. Internal faults are characterized into two sub-groups:

Short circuits and connections in transformer windings: These are type of faults of intense nature and are expected to cause very fast damage to transformer.

These faults are caught at high voltage and low voltage windings terminals by unbalance condition of current and voltage. This type of faults includes LL (line to line), LG (line to ground), LLG (double line to ground) and inter-wire faults on high voltage and low voltage windings.

Incipient faults: In the beginning, incipient faults are of very low magnitude and nature which will not caught at the windings terminals by unbalance condition of current and voltage, but slowly it may converted into dangerous fault. The protective devices supposed to work under short circuit conditions are not able of detecting this type of faults, such faults include core faults, crash of the coolant and poor electrical.

Other types of faults that may happen in a transformer are:

- The inrush current that occurs during a moment when a transformer is energized can also be viewed as a fault unless the conditions for its detection are set.
- The majority of power transformers make use of oil for cooling and insulation, oil leakage can also be a reason of fault in a transformer.
- Transformer can have over fluxing condition which is occur due to operation of transformer under low frequency at rated voltage or overvoltage at rated frequency.
- As a transformer undergoes high rates of fault currents, the windings are subjected to extreme mechanical stress, leading in some cases to winding movement, deformation and brutal damage.
- On-load tap-changer faults.

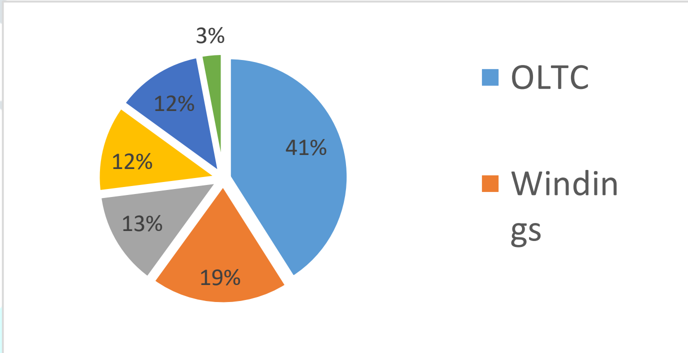


Figure: 2.1 Statistics of transformer faults

- Figure: 2.1 indicates that 19% of the fault happens in the Winding. As a general rule, explanations for transformer faults are as follows:
- Deterioration of insulation electrical characteristics inside transformer due to various causes.
- Over-voltage of power system and short circuit currents.
- Improper transformer operating conditions such as load conditions, oil leakage and sampling time for gasoline.
- Processing and/or repairing of problems.
- Cases like extreme lightning are unpredictable.

III. ARTIFICIAL NEURAL NETWORK (ANN)

The multi-layer perceptron (MLP) neural network

The multi-layer perceptron is perhaps the most common neural network used in applications for pattern recognition. For example, Figure 3.1 shows a two-layer hidden multi-layer perceptron where square represent input vectors, circle symbolize neurons and forward propagating arrows as a function signals. This system is fully linked network. As above discussed that this whole process memories play a very important role, known as weights between each layers which are not shown in the figure but it is written as w_{ij} in equation (1).

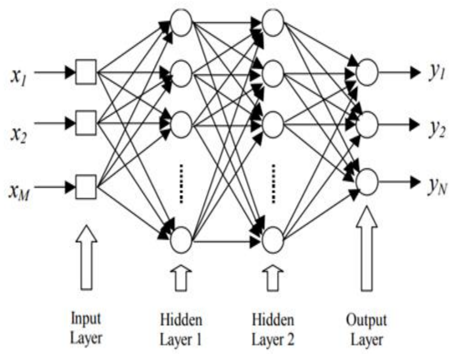


Figure 3.1 Topology of a two hidden layer MLP

$$y_j^{(l)} = \phi(v_j^{(l)}) = \phi(\textstyle\sum_{i=0}^{p} w_{ij}^{(l)}\, x_{ij}^{(l)}) \qquad (1)$$

Where,

l = the layer number (l > 0, output layer is the 3rd layer)

$y_j^{(l)}$ = the output of the jth neuron in the l th layer

$v_j^{(l)}$ =the weighted sum of the neuron's inputs

$x_{ij}^{(l)}$ =the ith input of the neuron

$w_{ij}^{(l)}$ = the contribution weights of the ith input to the neuron

Φ (•) = the activation function of the neuron.

The activation function Φ (•) is basically a nonlinear function which is having many form such as the logistic function in equation (2) and hyperbolic tangent function in equation (3).

$$\phi(v) = \frac{1}{1+\exp(-av)} \qquad a>0 \text{ and } -\infty<v<\infty \qquad (2)$$

$$\phi(v) = a\tanh(bv) \qquad (a,b) >0 \qquad (3)$$

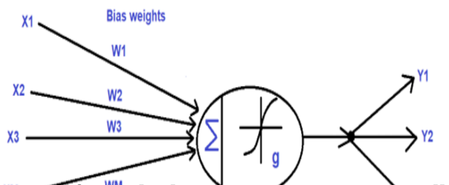


Figure 3.2 Basic Layout of ANN using Activation Function

The training of a multi-layer perceptron repeatedly uses a back-propagation algorithm which includes mainly two passes – the forward pass and the backward pass. The weights of the network are fixed in the forward pass and Equation (1) is frequently used to find outputs from the inputs across all the layers. During the reverse pass all weights are changed according to the equations mentioned below for error correction.

$$e_j(n) = d_j(n)-y_j(n) \qquad (4)$$

In the training procedure, data samples should be offered to the network randomly. Calculating all the data samples of the system at once is known as epoch. Large no of epochs are required to calculate to train a network. The epoch calculation will be stop when the averaged system error will be less than the preset values. These errors are defined as:

$$e_{squared} = \frac{1}{2}[e_j(n)]^2 \qquad (7)$$

$$e_{averaged} = \frac{1}{2N}\sum_{j=1}^{N}[e_j(n)]^2 \qquad (8)$$

To get more accurateness it is suitable to consider the root mean square RMS error on comparison to the averaged system error.

$$e_{RMS}=\sqrt{\frac{1}{2N}\sum_{j=1}^{N}[e_j(n)]^2} \qquad (9)$$

The range of a MLP in this process has deep basis. Firstly, it is very difficult to perform the fault diagnosis of transformer because it is having very complex nonlinear mapping issue as inputs and outputs variables are multiple and having no relationship predefined. Secondly, the three layer perceptron method with one hidden layer is also having ability of producing error, hence more number of hidden layers should be provide better accuracy. Thirdly, if perceptron method is used with a supervised error back-propagation (BP) training algorithm have been applied effectively to solve some complex and diverse problems. So will try multi-layer perceptron could provide better accuracy according to our requirements

Bayesian Neural Networks (BNN):

BNN is blend of Statistical Model and a Neural Network. The aim behind such a design is to bring together the strengths of Neural Networks and Stochastic Modelling. Neural Network includes universal continuous function approximated capabilities and Statistical models that require direct model specification with known interaction among data generation parameters.

A statistical model produces a full posterior distribution in the prediction process and provides guarantees on the predictions. Therefore BNNs are a distinct mixture of neural network and stochastic models with forming the heart of this integration. After data has been detected now it will be converted into posterior distribution using the bay's theorem.
Posterior distribution is basically used to find the predictions of the trained network for the new values of input variables. In the Bayesian framework they are using probability of distribution compare to weight values. During the absence of any data it will show by prior distribution which can be written as *p(w).* Here $w = (w_0, \ldots w_m)$ defined as vector of adaptive weight (and bias) parameters, also let us assume that the target data from the training set be define by $D = (y_1 \ldots y_n)$. After observing the data D now able to write expression for the posterior probability division for the weights, which can be written *p(w|D),* using

$$P(w|D) = \frac{P(w|D).P(W)}{P(D)} \qquad (10)$$

Proposed Architecture for ANN justifies to establish the transformer faults classification.

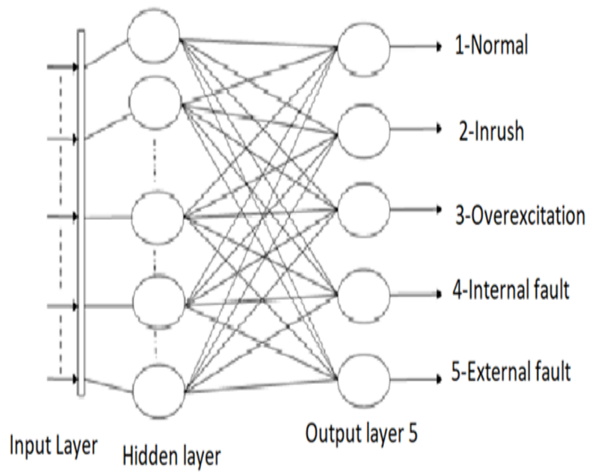


Figure 3.3ProposedArchitecture of ANN used to obtained transformer faults

IV. MODELLING OF TRANSFORMER

Modelling of transformer under Fault Conditions

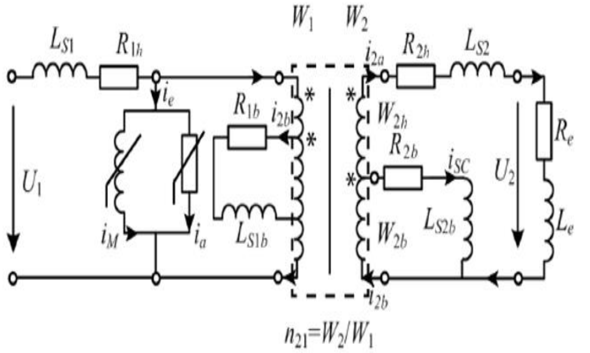
Internal fault in transformer occur when short circuits type of condition arise that is due to damage of insulation of transformer windings. In the event of major insulation damage it can create ground faults that will be between coils of different phases. Multi-winding transformer can be considered when we are taking a condition of interwire fault of transformer. Structural model of the ideal single-phase transformer is given as in case of interwire fault;

Interwire fault in secondary winding

Two magnetically coupled coils are created in the event of a short circuit between secondary winding wiresW_2.

- One coil have No. of turns W_{2b}= βW_2 ,{ β<1 and is short circuited.}
- Another coil have No. of turns W_{2h} = (1− β)W_2

The resistance specifies short circuit current as R_{2b}, number of short-circuited turns W_{2b}, leakage inductance L_{s2b} and fault resistance R_{arc-b} . Calculation of R_{2b} & L_{s2b} is established through the theory of electromagnetic fields.



It is possible to assume for a first approximation that the parameters of the short circuited component winding W_{2b} would be proportional to the relative number of short circuited turns:

$$R_{2b} = \beta R_2 \; ; \; L_{s2b} = \beta L_{s2} \tag{1}$$

Where L_{s2} & R_2 – leakage inductance and resistance of secondary winding of normal transformer, which is also related to parameters of short circuit R_{sc} and L_{sc} according to formulas:

$$R_2 = \frac{R_{sc}}{2}.n_{21}^2 \; ; \; L_{2s} = \frac{L_{sc}}{2}.n_{21}^2 \; ; n_{21}^2 = \frac{W_2}{W_1} \tag{2}$$

The secondary winding is having current i_2 with number of turns W_{2h} = {(1− β). W_2} passes through equivalent inductance L_e and resistance R_e of the load.

Constraints of winding W_{2h} are considered as:

$$L_{s2h} = (1-\beta)L_{s2} \; ; \; R_{2h} = (1-\beta)R_2 \tag{3}$$

Currents i_2 , i_{2b} and current of short circuited mesh i_{sc2} in winding W_{2b} are need to be calculated using KVL for secondary circuit on Figure 4.4

$$u_{u2} = R_{2h}\, i_2 + L_{2h}.\frac{di_2}{dt} + u_2 \tag{4}$$

$$u_{u2} = n_{21}\, u_{u1}; \quad u_{u1} = W_1\left(\frac{d\Phi_1}{dt}\right) \tag{5}$$

$$u_{u2b} = R_{2b}\, i_2 + (L_{s2b})\frac{di_{2b}}{dt} + R_{arc2} i_2 \tag{6}$$

$$u_{u2b} = \beta n_{21}\, u_{u1}; \; i_{2b} = i_2 + i_{sc2} \tag{7}$$

Where, Φ_1 – magnetic flux of core

l_c – length of core on which coils W_1& W_2 are situated

u_2 – load voltage.

V. SIMULATION RESULTS

Three phase 35/6 KV, 6 MVA The transformer is used to generate the necessary test and training patterns for various operating conditions as healthy condition, interwire fault, external fault and inrush current . All condition will be simulated using the help of MATLAB & Simulink.

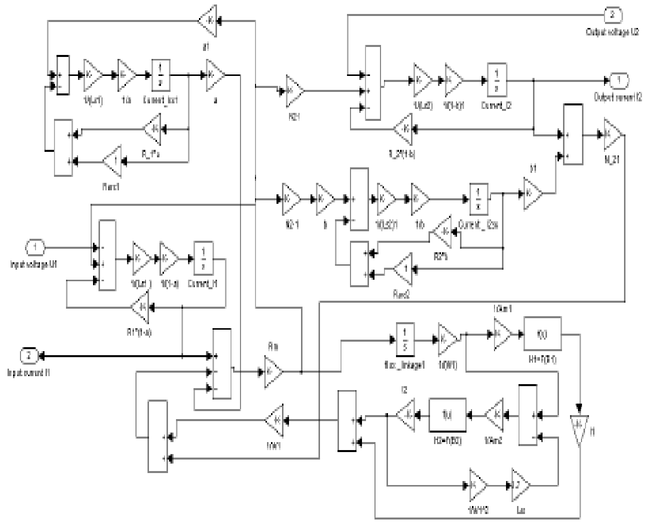


Fig 5.1- Structural diagram of calculation of transformer constitutive equations

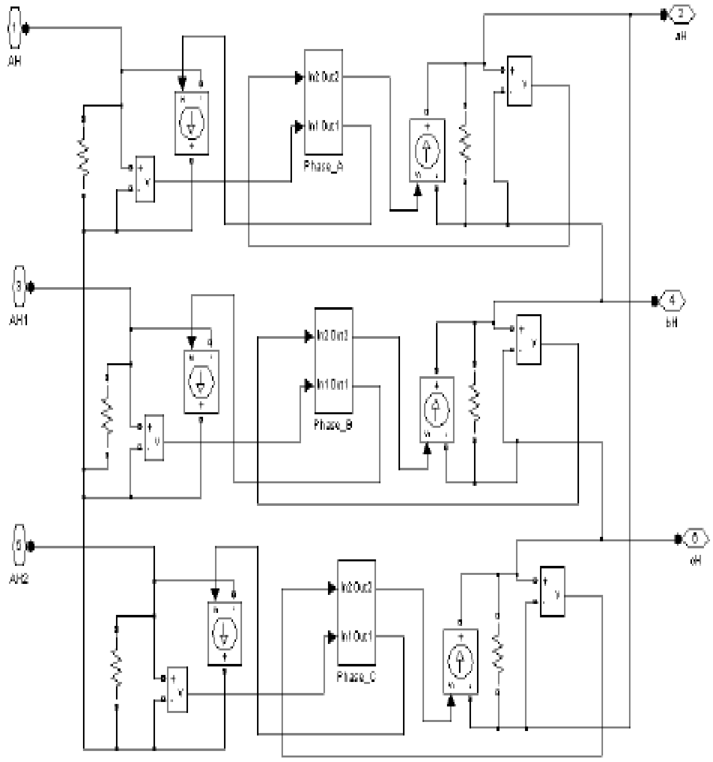


Fig 5.2-Structural diagram of Sim Power Block Set connection implementation

Simulation of proposed system

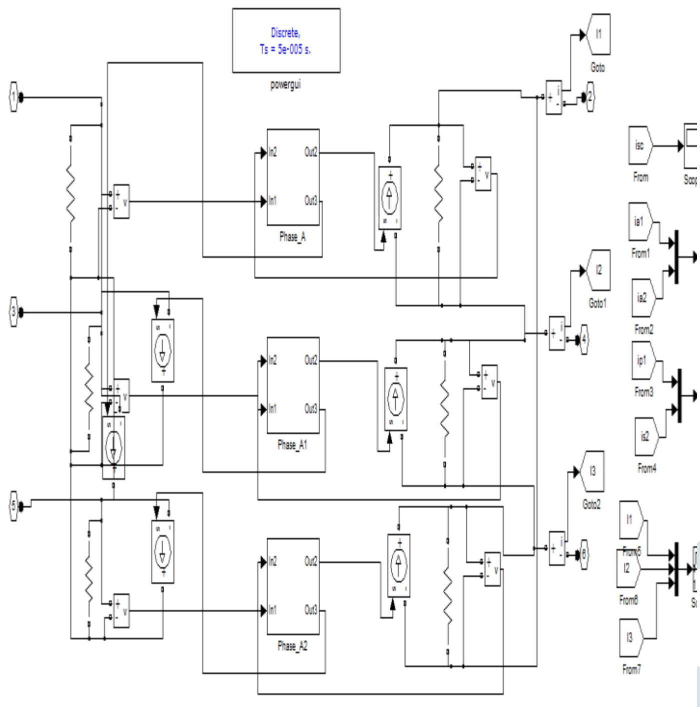


Fig. 5.3 Structural diagram of Sim Power Block Set connection implementation

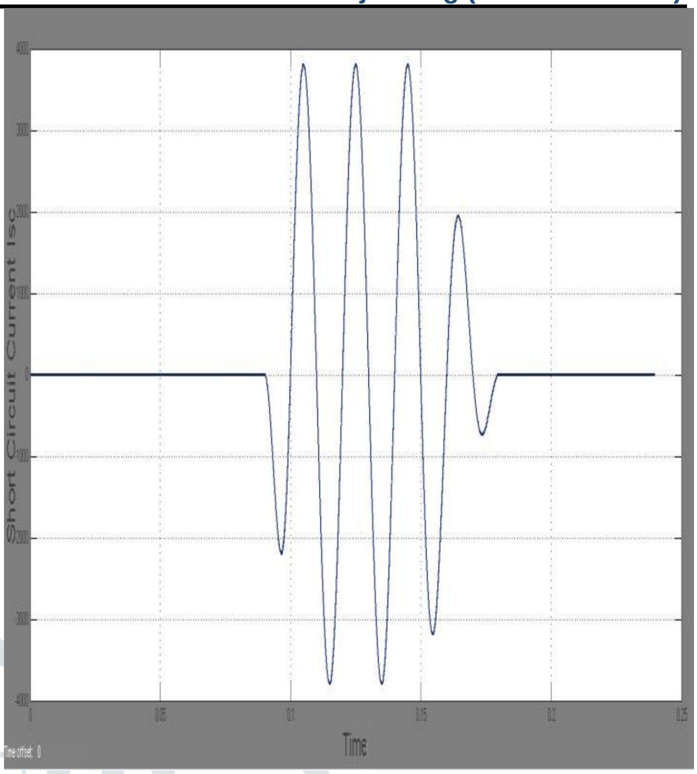


Fig 5.5- Short circuit current

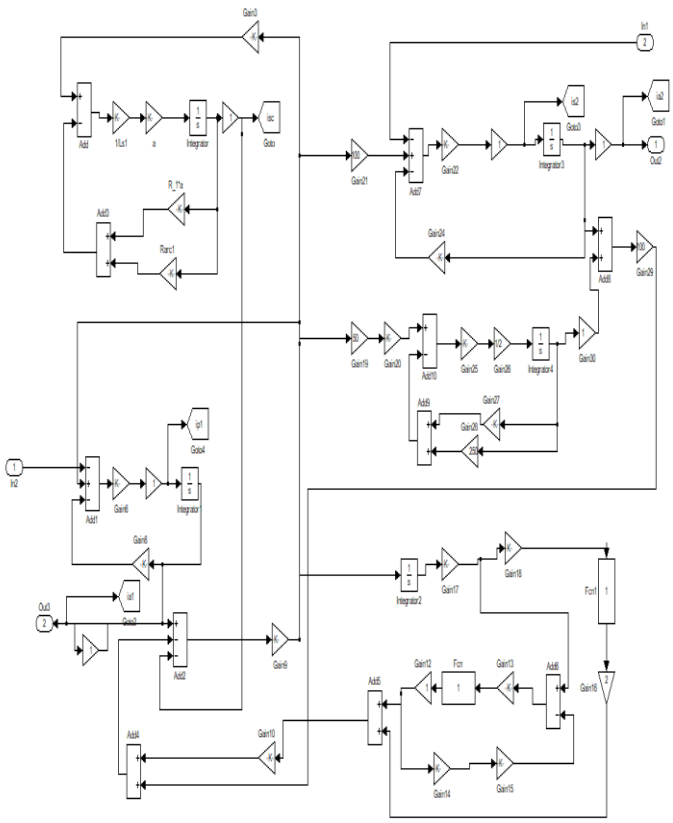


Fig. 5.4 Structural diagram of calculation of transformer constitutive equations

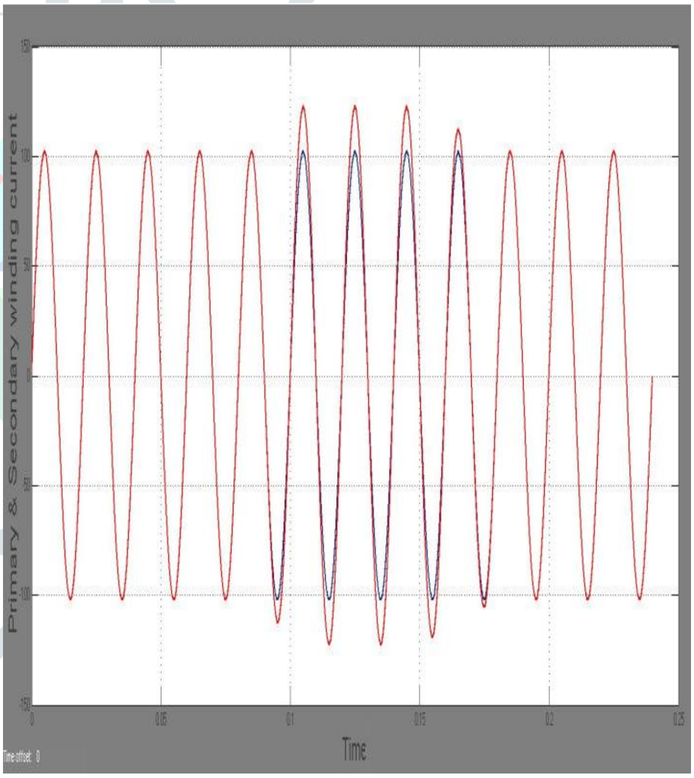


Fig 5.6 current of primary (1) and related current of secondary (2) windings - b) for the case of 5% short circuited wires in secondary winding

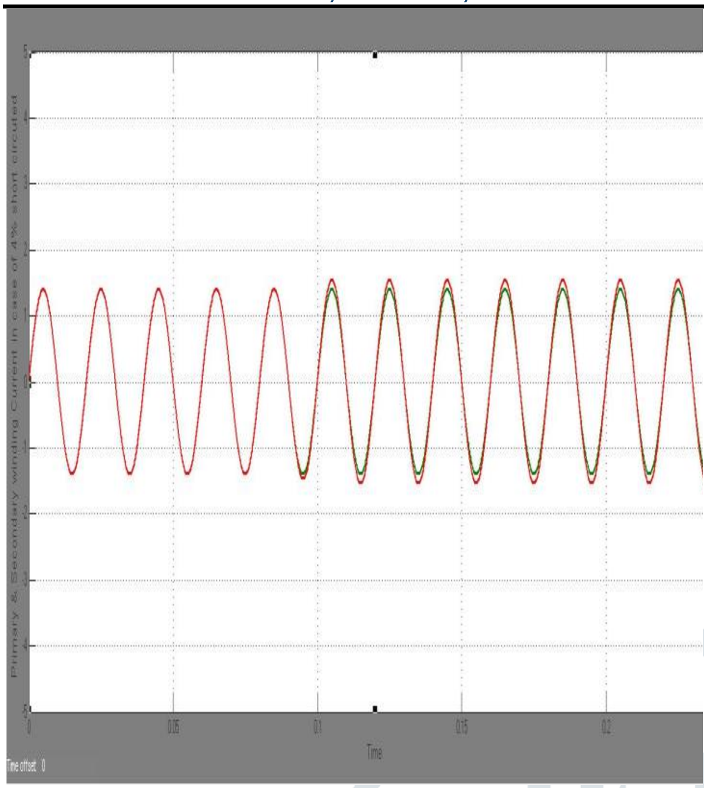


Fig 5.7- Current of primary (1) and related current secondary (2) windings in case of 4% short circuited wires in secondary winding

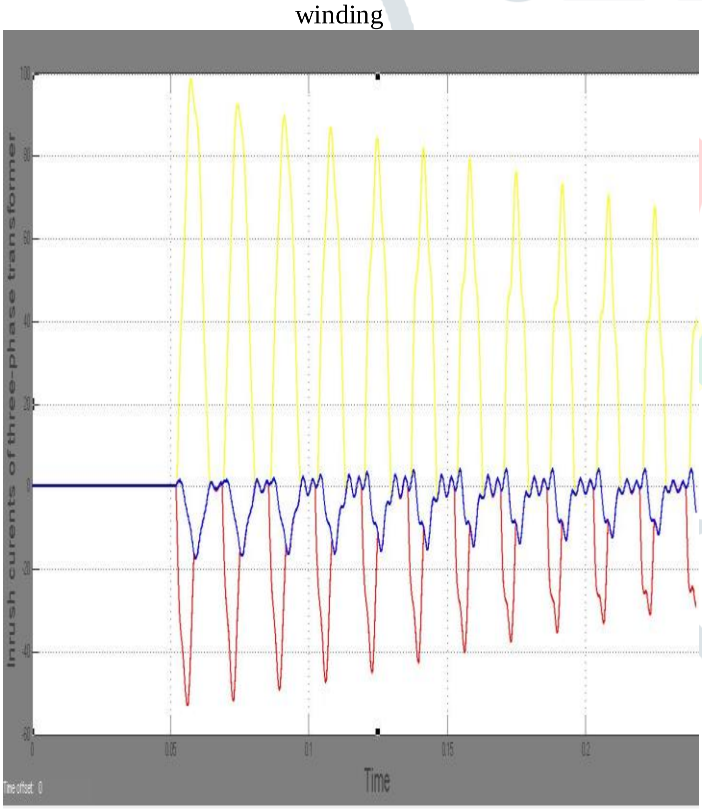


Fig 5.8- Inrush currents of three-phase transformer

External fault condition

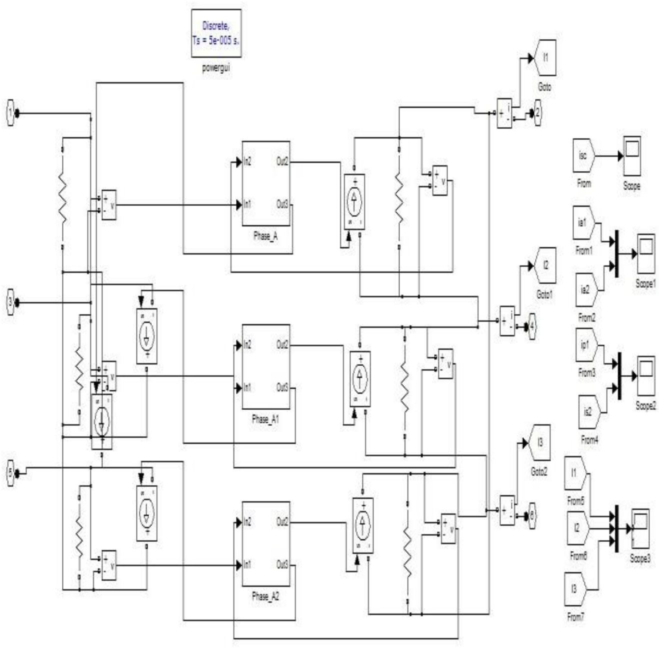


Fig 5.9- External fault condition

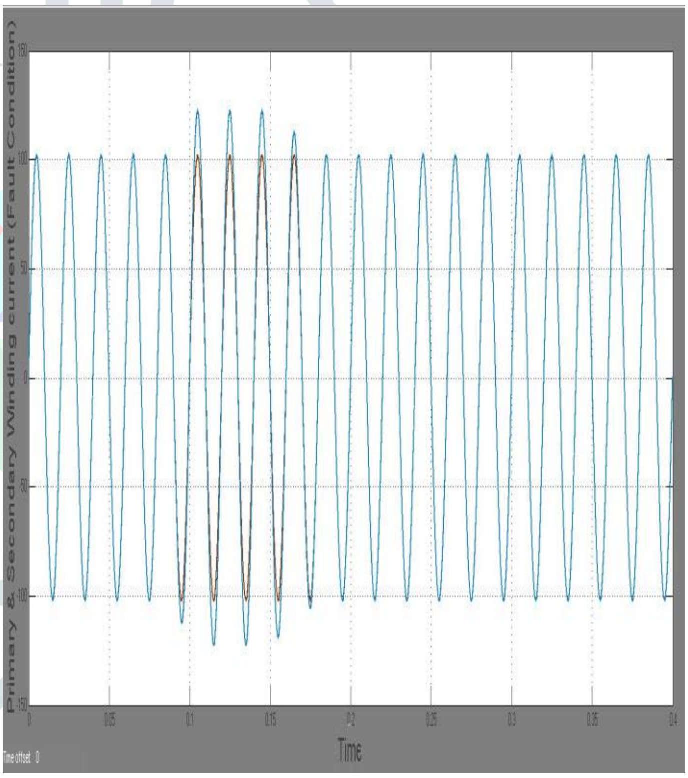


Fig 5.10- current of primary (1) and related current of secondary (2) windings - b) for external fault

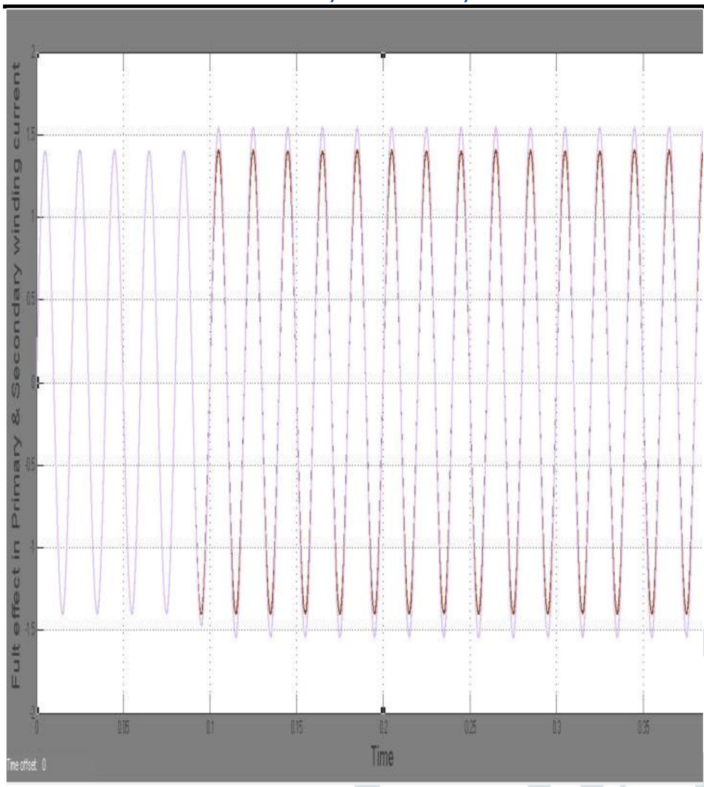


Fig 5.11- Primary and secondary winding currents during the external fault

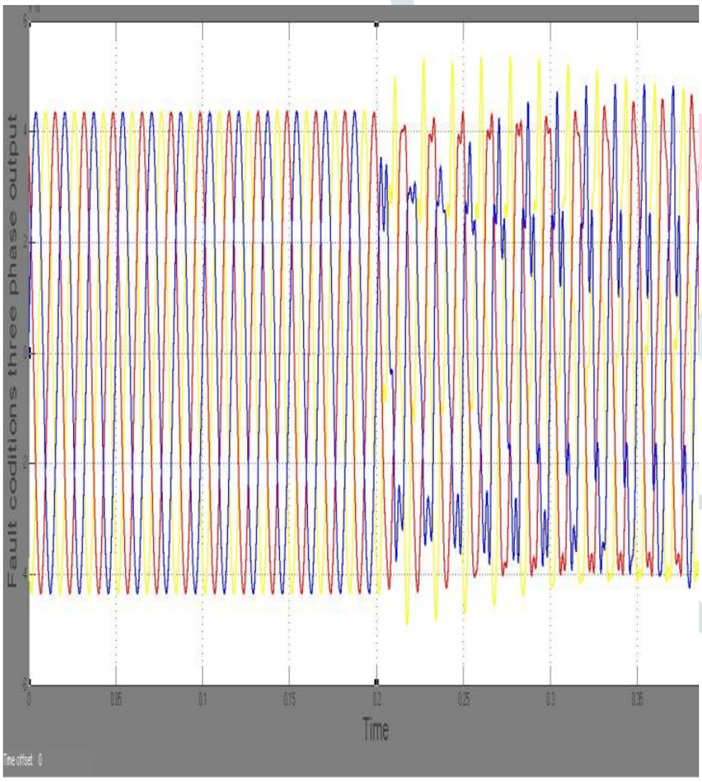


Fig 5.12- Primary winding currents during the external fault – a) and after fault clearance – b).

VI. CONCLUSION

The literature survey is carried and various method is used to discriminate transformer faults and among all method an advanced technique has been developed Support Vector Method (SVM) which provides effective discrimination between internal faults and other disturbances. It is also having more than 99% accuracy for Fault discrimination. In case of Interwire faults transformer can be viewed as multi winding transformer. Fault currents are limited by resistance and leakage inductance of formed coils, and fault resistance. In order to implement developed structural diagram of calculation of transformer constitutive equations into Sim Power Systems Block Set model, transformer was connected through Controlled Current Source and Voltage Measurement blocks. Model was applied for analysis of transients in power transformer, such as inter wire fault, transformer inrush, and fault in transformer connections. Results of simulations showed, that developed model adequately represents those processes. The developed model allows simulation and analysis of Interwire faults and other transients in one-phase or three-phase transformers.

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