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A Reduced High Frequency Transformer Model To Detect The Partial Discharge Locations

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ABSTRACT
Transformer modeling is the first step in improving partial discharge localization techniques. Different transformer models were used for such purpose. This paper presents a reduced transformer model that can be accurately used for the purpose of partial discharge localization. The model is investigated in alternative transient program (ATP) draw for partial discharge localization application. A comparison between different transformer models is studied, the achieved results of the reduced model demonstrated high efficiency.
***Keywords* –** Reduced Model, Transformer, Partial Discharge Locations, ATP, EMTP.

I. INTRODUCTION

Partial discharge (PD) is considered as internal fault so, its location recognition is very important for treating the transformers. In the same time, it is also considered as a transient action. Therefore, low frequency transformer model isn't valid for such transient studies. To simulate PD failure in transformers, appropriate model should be used for such studies. Typically ideal transformer doesn't take into consideration the effect of mutual inductance and the internal structure of the windings. So high frequency detailed transformer model should be used to enhance the accuracy of localization. Different improvements were made to the transformer modeling in fast transient studies but still internal faults couldn't be modeled properly. After realizing the importance of building a high frequency detailed transformer model, a lot of researches were made in the past decades. Different transformer models were developed for high frequency studies. A brief literature for some of these models is given in the next paragraphs.

1.1 HYBRID TRANSFORMER MODEL BASED ON TRANSFORMER DESIGN DATA

A hybrid transformer model was verified in ATP draw. The development in the model was conducted from different points of view. Different ATP transformer models such as XFRM is developed and investigated in order to reproduce all kinds of switching transients. This model consists of inductance, resistance, capacitance, core area and length. It is used in fast transient studies but the transformer is considered as a compact block so that it can't be used in simulating internal studies [1].

1.2 IMPROVED HYBRID TRANSFORMER MODEL

Developments to the hybrid transformer model were made. These developments included core saturation and losses in the hybrid model. Core losses were presented by consideration of flux density, core section voltage and hysteresis core model that enabled residual flux and self initialization. Also this model is used in fast transient studies but the transformer is considered as a compact block so it can't be used in simulating internal studies [2].

1.3 ELECTROMAGNETIC TRANSIENT PROGRAM TRANSFORMER MODEL FOR OVER VOLTAGES

Time domain electromagnetic transient program (EMTP) transformer model based on model analysis was proposed [3]. This model was capable of accurately accounting of the frequency dependent effects of practical transformers with high computational efficiency.

Another EMTP model was presented for calculating over voltages in transformer windings under very fast transient over voltages [4].

Despite that these two models are implemented in EMTP program, there are some drawbacks. The main disadvantage of EMTP program is the simulation of internal transient studies with different types of limitations such as the amount of retrieved data.

1.4 LOW AND MID FREQUENCY TRANSFORMER MODEL

A new hybrid transformer model for low and mid frequency transient simulation was presented. This model takes into consideration the magnetic saturation of the core, frequency dependency, capacitive coupling, topologically correctness of core and coil structure. Its application was mainly at low and mid frequency behavior such as excitation, inrush, switching transients and ferro resonance. This model isn't used in high frequency studies [5].

1.5 Internal Fault Transformer Model

This model was built as an accurate model for simulation of internal faults in transformers [6]. The transformer model was developed in ATP draw. It was based on two different sources of information, test report data and design information. Test report data includes short circuit impedance, total losses and power value. Design information includes inductance, resistance, capacitance, core area and length. This kind of modeling is used for the partial discharge recognition mission not for the protection studies purpose.

1.6 Transformer Model Including Partial Discharge Mechanisms

Simulation of PD mechanism within a transformer model was investigated by using some software such as EMTP [7[. EMTP was used as a tool to show PD mechanisms. The partial discharge mechanism is discussed and simulated. The main problem was the accurate modeling of PD in localization studies [7].

1.7 Hybrid Transformer Model Based on Lumped Parameters

A hybrid transformer model was introduced to simulate the transformer winding transient process. Calculations of the hybrid transient model parameters were based on the lumped parameters of the equivalent transformer model and electromagnetic rules. Simulation was validated on an interleaved winding 25 MVA, 66 kV. PD location can be determined with maximum two discs error [8].

With this model, there is no need for calculating the winding parameters as they are already known and should be implemented directly in the appropriate software.

1.8 Detailed Transformer Model for the Purpose of Transient Studies

High frequency transformer model was presented for transient modeling. This technique was applied on various winding types in power transformer such as foil winding and double layer winding. This model is implemented in mathematical laboratory (MATLAB) and valid to MHZ range [9].

High frequency transformer model was developed using finite element method. The model is established from construction information and the approach implements frequency dependent phenomena on a physical basis. Eddy current effects are represented accurately even with a relatively coarse mesh by using a frequency dependent complex permeability representation for the core and windings. The model can be employed in EMTP like programs for a variety of applications, such as analysis for internal and terminal stresses and transformer network interaction [10]. This model is used in this paper as a detailed transformer model.

1.9 Reduced Transformer Model for the Purpose of Transient Studies

Other models were presented in reduced forms. It is sophisticate to use detailed transformer model in EMTP/ATP draw due to its significant size. A reduced transformer model was presented and compared with IEEE model. The main idea of this model is the elimination of non dominant Eigen values of the system. This reduced model is disadvantaged by the high divergence in the values of the current wave response from the detailed model values [11].

Also a reduced transformer model is constructed for system studies from lumped parameters models [12].

In this paper a new reduced transformer model is presented for the purpose of partial discharge localization transient studies. First, detailed transformer model is simulated in ATP draw and different PD pulses are injected. Second step is reducing this model and capturing the current responses of the transformer windings. Then these current responses are compared with the current response in the case of detailed transformer model in the transient study. Also the efficiency of the reduced model is demonstrated and compared with the detailed model ones.

II. Transformer Modeling

Typically ATP Draw is used in fast transient's studies such as PD. The detailed model is presented in ATP draw as shown in figure (1).

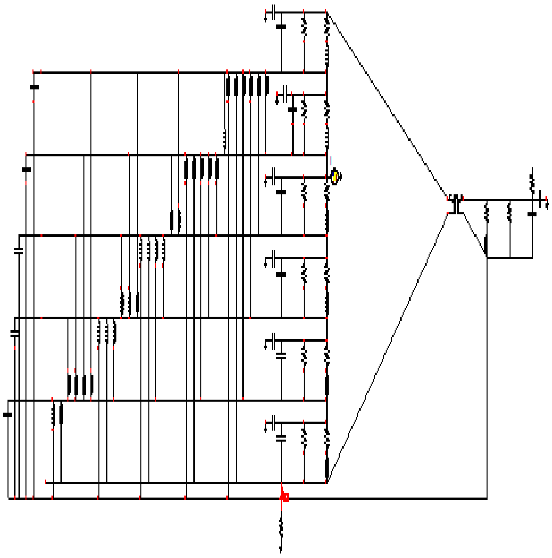

Fig.1. Detailed Transformer model in ATP Draw

Then the reduced model is formed from the detailed model as shown in figure (2). This reduced model neglects the effect of mutual inductance, mutual capacitance, ground capacitance and core resistance. But the main mutual inductance between the primary and secondary sides of the transformer is taken into consideration.

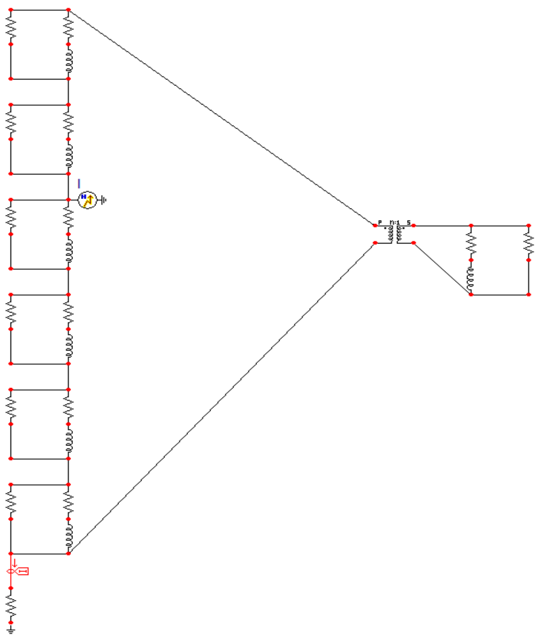

Fig.2. Reduced transformer modeled in ATP Draw

III. COMPARISON BETWEEN DETAILED MODEL AND REDUCED MODEL CURRENT RESPONSES

To validate the reduced transformer model, comparison must be made. The current response is chosen as a comparison criterion between the detailed model and the reduced model. Different PD pulses are injected in the detailed model and the reduced model in the same location and the current response is studied.

IV. CASE STUDY

TRANSFORMER SPECIFICATION

A cast resin dry transformer 10 MVA, 22/3.3 kV is used for testing. The high voltage (HV) winding includes 6 discs and the low voltage (LV) winding includes 32 layers. During the modeling mission, the LV coil is considered as one part because typically PD doesn't occur in LV winding. The detailed transformer is modeled in ATP draw as shown in figure (1). The reduced transformer is modeled in ATP draw as shown in figure (2).

V. RESULTS DISCUSSION

A PD pulse of 2 amperes peak value is injected in the second disc of both models and the current responses are compared. The current response of the detailed transformer model is shown in figure (3). The magnified current response of the detailed model is shown in figure (4) and the current response of the reduced model is shown in figure (5).

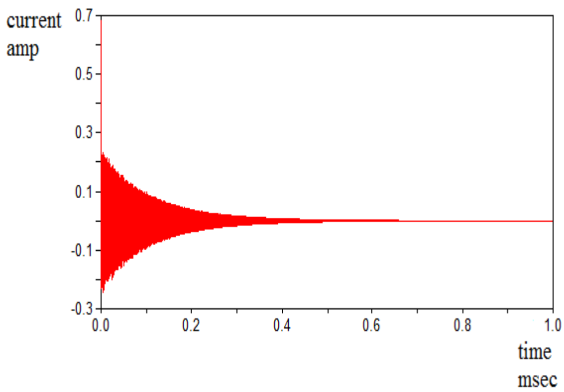

Fig.3. Current response of the detailed transformer model

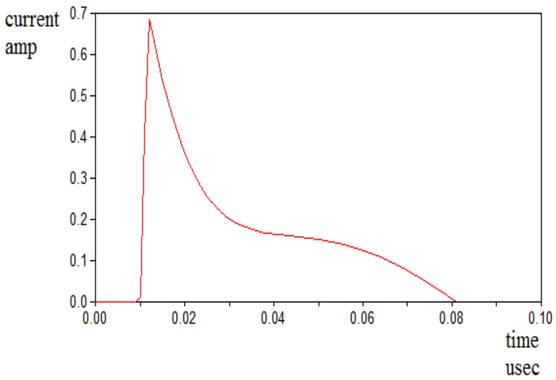

Fig.4. Magnified current response of the detailed transformer model

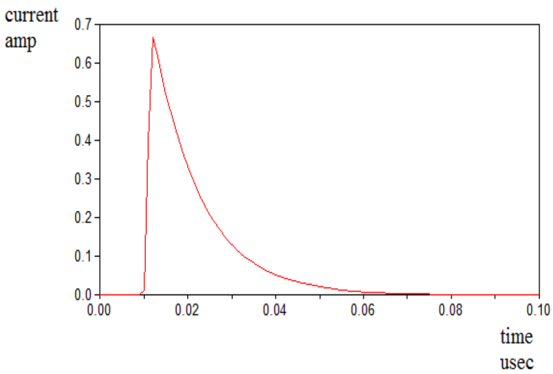

Fig.5. Current response of the reduced transformer model

It is recognized from these two figures that the current responses are very similar. Also we still can extract various features from the current finger print that are useful for the purpose of PD locations detection.

VI. BACK PROPAGATION NEURAL NETWORK ACCORDING TO LEVENBERG MARQUARDT ALGORITHM

Different features are extracted from these waveforms. The extracted features are used for the purpose of neural network training. The differentiating feature extracted in the case of detailed transformer model and in the case of reduced transformer model has the same value. The neural network training module used in this paper is back propagation neural network according to Levenberg Marquardt algorithm as shown in figure (6). Typically the efficiency of this type of neural network is evaluated by the mean square error and regression between the network output values and the required target.

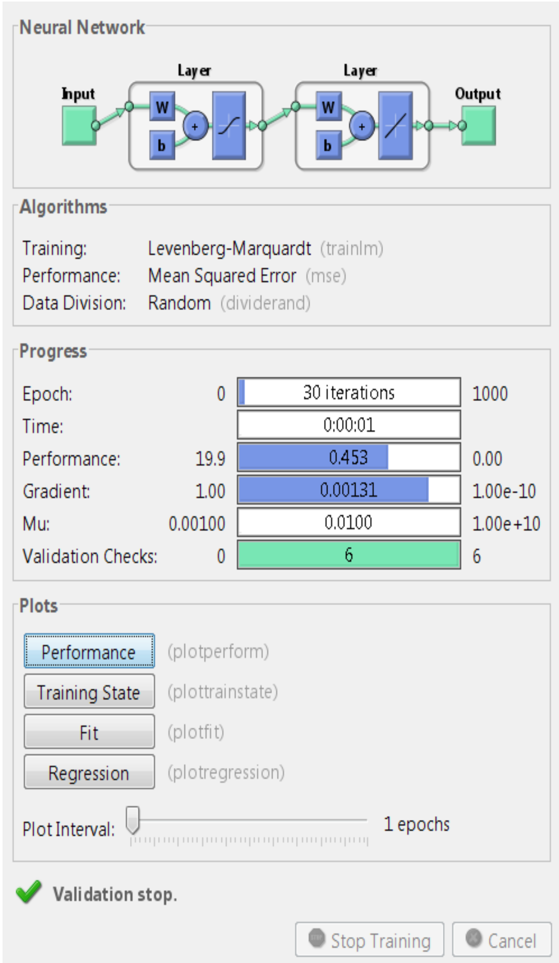

Fig.6. Neural network training module

VII. PD LOCATIONS DETECTION EFFICIENCY IN THE REDUCED TRANSFORMER MODEL

The neural network reaches 24 iterations and the mean square error becomes minimum and the training function stops as shown in figure (7).

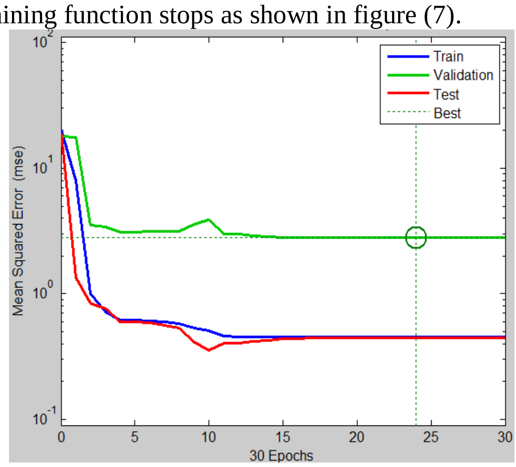

Fig.7. Neural network performance evaluation

The mean square error and the regression between the network input and network output in the case of training and validating and testing processes are illustrated in next table.

Table 1 Training, validation and testing values

	Mean Square Error	Regression
Training	0.453	91.9%
Validation	2.79	78.2%
Testing	0.446	94%

The fitting function of the neural network process is shown in figure (8).

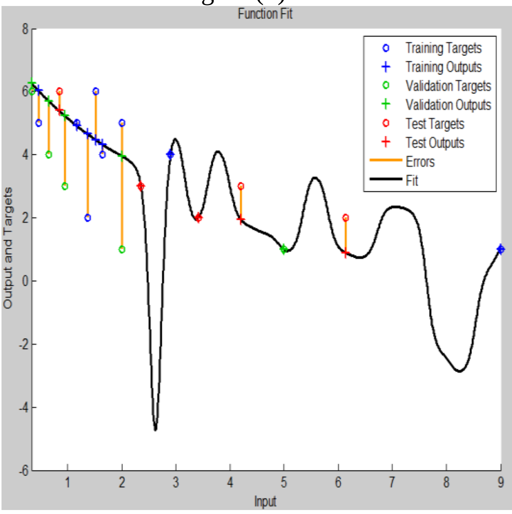

Fig.8. Neural network fitting function

The regression of the network in case of training, validating, testing and the integrated processes is shown in figures (9, 10, 11 and 12) respectively. In these figures T was referred to the target output and Y for the calculated output.

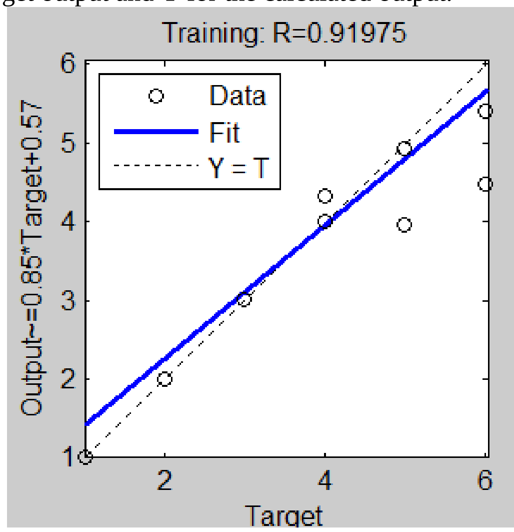

Fig.9. Regression of training process

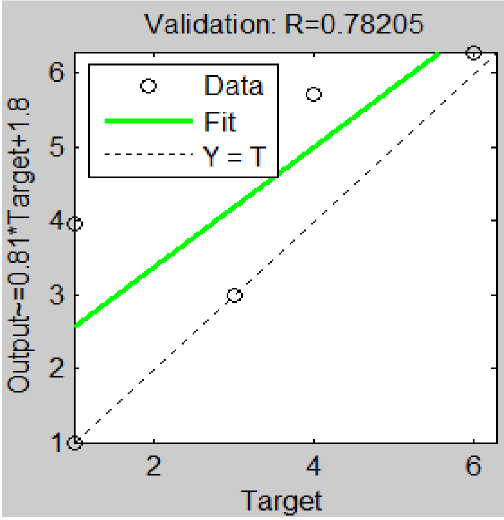

Fig.10. Regression of validating process

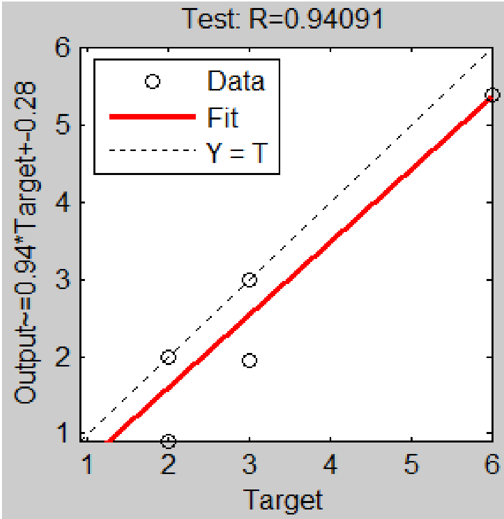

Fig.11. Regression of testing process

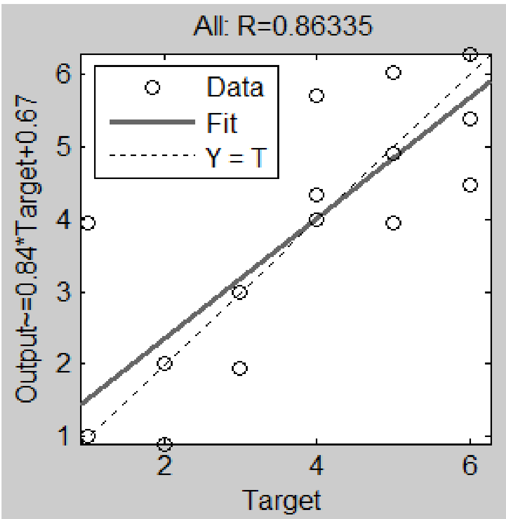

Fig.12. Regression of integrated processes

VIII. CONCLUSION

Different models can be used for transformer studies. Each model has its limitation for some applications. For partial discharge application, high frequency model must be used. Detailed transformer model requires a lot effort and time for simulation within ATP. This paper presented a reduced model which can be used for the purpose of partial discharge application. The reduced model is proved to be very efficient for this purpose.

In order to facilitate the search approach reduced transformer models are used and the impact of this reduction on the neural network performance is analyzed. Reduced transformer model can be used with the same accuracy of the detailed transformer model.

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