Abstract—The high frequency model of power transformer winding is indispensable in analyzing the transients particularly caused by the very fast transients which occur at the time of disconnecting switch operations, lightening or partial discharge phenomena. The transients in transformer have been analyzed using a circuit of interlinked inductances and capacitances whose values have to be properly determined. The circuit constants have been hitherto calculated in a model taking each coil section pair as a building block. The circuit transients are computed utilizing the heuristic technique. The input current of the winding can be numerically calculated for a measured impulse voltage. The correspondence with the experimental results is satisfactory. The response shows this method's applicability to high frequency analyses.

Keywords—transient phenomena, PSO, power transformer, winding, detailed model.

I. INTRODUCTION

POWER transformer modeling has been broadly researched in order to understand transient behaviors. A large number of power transformer failures are due to high frequency transients phenomena that are unpredictable and may cause failure during live operation. The ability to determine the effect of transients may assist in predicting transformer asset health and lifetime. The modeling of propagation of high frequency signals within a power transformer winding may demonstrate attenuation or be loss free depending on the model adopted [1]. Prior to application of any modeling technique, experimental investigations could be undertaken to determine the most suitable model to be employed. The model and estimation technique described in this paper are employed based on a limited knowledge of winding dimension and a Particle Swarm Optimization (PSO) Algorithm, which in turn, means that the resistance, inductance, capacitance and mutual inductance parameters are unknown and must be replaced by harmonic decay components in frequency domain [2-3]. The measured and simulated input currents of the power transformer have been compared and parameters have been determined. The transient model of transformer winding has been simulated by using ATP-EMTP. The results of simulations have been applied to the program, which is based on PSO algorithm and can determine the fitness and parameters of winding. The validity and the accuracy of estimated parameters of transformer winding are assessed by comparing the predicted current with experimental results.

II. WINDING HIGH FREQUENCY MODEL

In the range of frequency associated to transient phenomena, the transformer winding behaves as a complex ladder network consisting of inductances, capacitances and conductances [4]. So, a model is required which describes the physical dimensions of windings as precisely as possible within the acceptable frequency range. The detailed model shown in Fig. 1 has been used for interpreting the high frequency behavior of transformer coils. The simulation model is an equivalent RLC circuit network based on the theory that should have the same external circuit behavior as that of the transformer winding. For many transient phenomena such as partial discharge localization and evaluation applications, usually it is enough to locate the disk unit of the winding in which PD has occurred. Therefore the number of the RLC units has been chosen equivalent to the number of coil sections. Thus each winding section is considered as a black-box represented by a RLC unit [5-7]. Li models the leakage inductance. CSI and Cgi represent the coil to coil and coil to ground capacitances respectively. Ri represents the loss due to the insulation between adjacent winding section. The mutual inductances between each winding section and the other ones are modeled by M. This winding model has been used for 220 kV winding with 28 disk in [8].

The inductive branch current vector,

\[ [I] = [i_1, i_2, ..., i_{n+1}]^T \]

And the nodal voltage vector

\[ [U] = [v_1, v_2, ..., v_{n+1}]^T \]

Are the variable vectors of the model. The winding could be mathematically presented by the following state equation:

\[
\begin{bmatrix}
U \\
I^d
\end{bmatrix} =
\begin{bmatrix}
-C^{-1} G & -C^{-1} A \\
-M^{-1} A^T & -R g M^{-1}
\end{bmatrix}
\begin{bmatrix}
U \\
I
\end{bmatrix} +
\begin{bmatrix}
C^{-1} B_1 \\
M^{-1} B_2
\end{bmatrix}
\]

Where M, G, and C are the nodal inductance, nodal conductance, and nodal capacitance matrixes respectively. Rg and a are the series resistance matrix and the incidence matrix of the inductive circuit respectively.

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III. PSO ALGORITHM

PSO is a population based stochastic optimization algorithm developed by Eberhart and Kennedy, inspired by social behavior of bird flocking or fish schooling. It is a useful technique to solve many optimization problems [9-11]. PSO shares many similarities with evolutionary computation techniques such as Genetic Algorithms (GA). The system is initialized with a population of random solutions and searches for optima by updating generations. However, unlike GA, PSO has no evolution operators such as crossover and mutation. In PSO algorithm, the potential solutions, called particles, fly through the problem space by following the current optimum particles. Equation (4) could describe the content of this concept.

\[
\begin{align*}
    V_{el_i}^{(t+1)} &= \omega V_{el_i}^{(t)} + c_1 r_{and_1}(.) (P_{best_i} - X_i^{(t)}) \\
    &+ c_2 r_{and_2}(.) (G_{best} - X_i^{(t)}) \\
    X_i^{(t+1)} &= X_i^{(t)} + V_{el_i}^{(t+1)}
\end{align*}
\]

Where \( V_{el_i} \) is Velocity of the ith particle, \( r_{and_1}(.) \) and \( r_{and_2}(.) \) are random numbers between 0 and 1, \( P_{best_i} \) is best previous experience of the ith particle that recorded and \( G_{best} \) is best particle among the entire population.

The constants \( c_1 \) and \( c_2 \) are positive weighting coefficients of the stochastic acceleration terms which stimulate each particle towards \( P_{best} \) and \( G_{best} \) positions. Low values allow particles to go far from the target region and high values result in abrupt movements toward, or backward the target region. The inertia weight \( \omega \) presents the degree of the particles momentum. The appropriate selection of inertia weight \( \omega \) in equation (4) provides a proper global and local search as it is essential to minimize iteration average to achieve a sufficient optimal solution. Approximately the coefficient \( \omega \) often decreases linearly from 0.9 to 0.4 during a run.

IV. SIMULATION

The PSO has been used to estimate parameters of transient models of Transformer winding. The detailed model of winding has been simulated by EMTP [12]. The parameters of transformer winding model, determined by PSO algorithm in MATLAB, are imported to the EMTP. The simulation is carried out by using an impulse voltage. During optimization, the input current of the winding is determined by EMTP and then it is transferred to PSO algorithm in MATLAB to evaluate the fitness function. This procedure continues until the optimal solution has been determined for parameters of the model. The input current of simulations is compared to the experimental data of [8].

So, using the state equation presentation of the transformer winding, the input current of the winding can be numerically calculated for a measured impulse voltage. The measured and simulated input currents of the transformer are compared in Fig.2. As seen in the figure, a logical coordination is obvious between the results in the first 0.5 ms of the test that can verify the validity of the transformer winding model. The difference between these curves for the times after 0.5 ms can be neglected for detection and localization of winding faults considering the acceptable frequency range of transient phenomena.
V. CONCLUSION

In this paper, a new algorithm based on PSO algorithm, and linking the MATLAB and EMTP programs has been proposed to estimate the parameters of detailed model of transformer winding. The goal is proposed a new modeling procedure for power transformers winding in order to obtain reasonable accuracy in the MHz range. Using the proposed method, the parameters of winding are estimated based on the input current of winding. It is shown that the estimated parameters of winding model in the simulation results are in a good agreement with the input current measurements. The proposed method is very flexible and can be applied to other models easily.

REFERENCES


Fig. 2 Input current of the transformer winding:

a. measurement

b. simulation

Mehdi Nafar was born on April 24, 1979 in Marvdasht, Iran. He received his BS, MS and Ph.D. degrees in electrical engineering in 2002, 2004 and 2011 from PWIT University, Tehran, Iran and Amirkabir University of Technology (AUT), Tehran, Iran and Islamic Azad University, Science and research Branch, Tehran, Iran, respectively, graduating all with First Class Honors. He is an assistant professor of Electrical Engineering Department, Marvdasht Branch, Islamic Azad University, Marvdasht, Iran. He is the author of more than 40 journal and conference papers. His teaching and research interest include power system and transformers transients, lightening protection and optimization methods in power systems.