TRANSFORMER MODEL REDUCTION OF LUMPED PARAMETERS MODELS USING IMPERIALIST COMPETITIVE ALGORITHM

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Abstract: Detailed R-C-L-M models of power transformers, which are based on lumped parameters, are used extensively not only for transient analysis inside transformer to determine electrical stresses in windings but also for transient study in power system. Models with less number of elements are more practical for system studies due to lack of heavy computations but decreasing the number of model elements worsens model accuracy. In this paper Imperialistic Competitive Algorithm is used to reduce an R-C-L-M model with 43-nodes of a real 400 kV test object to a 21-nodes one. The accuracy of resulted model is verified by compression of transfer function of transformer resulted from imperialist competitive algorithm and Common Analytical Formula.

1 INTRODUCTION

Transformers are one of the most important apparatus in power systems which their incorrupt functioning is of high importance. Due to this importance, the transient behavior of the transformers should be investigated more precisely. The detailed R-C-L-M model is widely used in transient analysis of the transformers. The precision of the model is directly related to the number and precision of its parameters [1]. The parameters which are used in this model are derived from the structure of transformer. In this model, as the number of the model unit increase, the model becomes more accurate. Parameters of the transformer model which are derived from common Analytical Formula (CAF) have inadequate precision because of simplicities are used. Advantageous and disadvantageous of detailed R-C-L-M model are discussed in detailed in [1], [2] and [3].

Detail model is extremely appropriate for studying transient phenomena inside a transformer and calculating voltage distribution and consequently electrical stresses along windings, but presence of many elements in a detailed model, makes the calculations more time consuming and complex. Therefore, to reduce the amount of calculations and make the studying procedure more practical, researchers reduce the transformer model. There were many efforts in the field of model reduction so far. For example; in [4], which was of the first efforts, Moore worked on principle component analysis and an algorithm for computing the singular value decomposition of a matrix. As he claims, together they form a powerful tool for copying with structural instability in dynamic systems. He divided the system into 2 subspaces and finally by applying the mechanics of Kalman's minimal realization on these subspaces, he took the first step toward linear systems model reduction. After that, there were introduced many method for model reduction. [5], [6], [7].

2 HIGH FREQUENCY MODELING OF POWER TRANSFORMERS

The transformer can be basically represented as a four-terminal network. For this four-terminal network must be designed a network that determine frequency-dependent behavior. The determination of the parameters of this network can be done in several ways. One way is to calculate the parameters from the geometrical structure of the transformer. Another way is using parameter identification method for known model of transformer by using of imperialist competitive algorithm based on measured data.

A transformer can therefore modeled using several methods depending on whether only the terminal behavior or the internal stress distribution (resonances) is of interest. The methods can be divided into three groups, black-box view, physical view, and hybrid model.

If the resonance and the voltage stress inside the transformer winding are analyzed, a physical examination of the entire winding structure of a model is required. The structure of the model adopted in the form of an equivalent circuit, which takes into account all possible fundamental physical aspects of the transformer to be tested.

An important model is based on physical considerations is designated as R-C-L-M detailed model which is applied not only to electrical stress analysis, but also for error detection. The R-C-L-M model of a transformer winding and the way of its parameter identification is discussed widely in [2], [3] and [8].

3 COMPLETE AND REDUCED R-C-L-M MODEL OF THE TEST OBJECT

3.1 Test object

A 400 kV disc winding consisting of 86 discs, 9 turns in each disc with an outer diameter and height equal to approximately 1.73 m and 1.75 m, respectively, is used as a test object. The winding contains four axial oil ducts within the discs. Two aluminum cylinders are used inside and outside of the test object to model the earth potential of core and tank.

It is possible to determine the TF either using time or frequency domain measurements. The achievable accuracy of both procedures is equal [10]. In the investigation presented here the TF was measured in the frequency domain with the help of a Frequency Response Analyzer. TF is defined here by:

$$TF = \frac{\left|I_{Earth}(j\omega)\right|}{\left|V_H(j\omega)\right|} \tag{1}$$

whereat VH indicates the input voltage to the winding top terminal and IEarth indicates the output current at the winding grounded bottom terminal.

3.2 Complete and reduced R-C-L-M model

Detailed R-C-L-M model and its parameters are described in detailed in [1]. Each unit of the detailed R-C-L-M model has a number of elements include capacitive and resistive elements and self and mutual inductances. In complete model, there are 4 capacitive element, 2 resistive element and 43 self and mutual inductances.

In this model considering one double disc as a model unit gives enough accuracy in transformers transient study, therefore it is assumed as a complete model of transformers. As it is mentioned, the test object has 86 discs and we consider a 43-units model (86/2=43) for the complete R-C-L-M model. As mentioned previously, using this model in system studies not only time consuming and is of heavy computation but also in some cases is impractical.

In the proposed reduced model each four discs considered as a model unit. In this way, 21 model units yields in which first 20 units consist of 4 discs and the last unit has 6 discs (20*4+1*6=86). The proposed reduced model also has some capacitive and resistive elements and some self and mutual inductances. Since the reduced model is not symmetrical in terms of structure, therefore the parameters of the last unit which has 6 discs would be different and need to be determined. Therefore, unlike the complete model, there would be a set of self and mutual inductances in addition to those describe the first 20 units. Thus, despite of model reduction, the numbers of elements which describe the reduced model are not decreased. In this model there are 5 capacitive elements and 3 resistive elements and as described and explained previously, there are 41 self and mutual inductances.

By means of this reduced model, in spite of no change in the number of parameters of the model, mutual inductance matrix becomes smaller and reduced nearly to a quarter of the complete model and this leads to have a faster evaluation of the transformer transients.

4 IMPERIALIST COMPETITIVE ALGORITHM

Imperialistic Competitive Algorithm is a new evolutionary algorithm which is proposed recently by Atashpaz and Lucas [10]. ICA is the mathematical model and the computer simulation of human social evolution. Like other evolutionary algorithms, ICA has its own definitions and operators which is listed and described briefly in the following:

4.1 Creation of initial empires

Like other evolutionary algorithms, the parameters of the function to be optimized are regarded as an individual. Each of the individuals in the ICA is called a country.

In an Nvar-dimensiona optimization problem, a country is a $1 \times N_{var}$ array. This array is defined by:

$Country = [P_1, P_2, \ldots, P_{Nvar}]$

The variable values in the country are represented as floating point numbers. Each variable of the country can be interpreted as a socio-political characteristic of a country. Power of each country is calculated using a fitness function. In the beginning of the algorithm, after generating some countries randomly; we select N_{imp} of the most powerful countries to form the empires. The remaining N_{col} of the population will be the colonies each of which belongs to an empire. Then we have

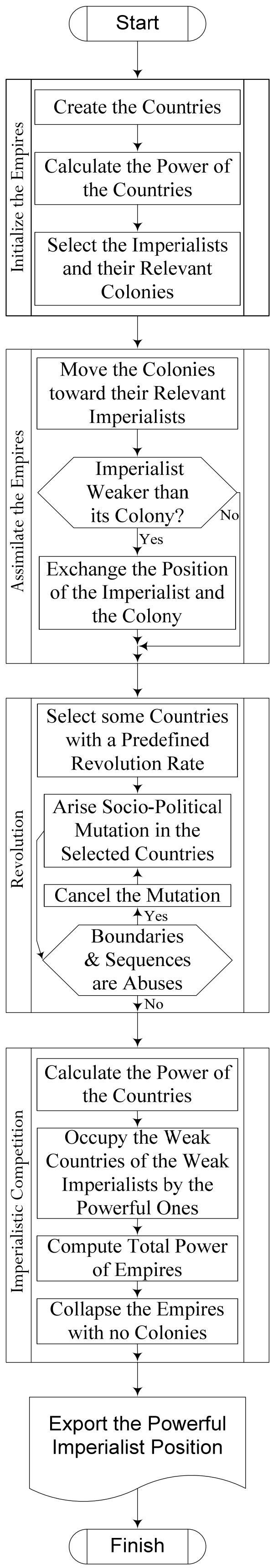

Figure 2: Flowchart of the imperialist competitive algorithm

two types of countries; imperialist and colony [10]. After selecting the imperialists, the colonies should be divided between them. They are divided in a manner which the most powerful imperialist seizes more colonies and the weaker less. To do this, a normalized cost of an imperialist is defined which is described widely in [10].

4.2 Assimilation

Imperialist countries started to improve their colonies. This kind of behavior is modeled by assimilation. This operation moves colonies toward their imperialists along different socio-political axis. A unit step length is defined and the size of each step is scaled between the distance of imperialist and the related colony. In this manner, after some steps, the colonies and their empires would be fully assimilated into the imperialist. This operation helps the algorithm to broom the spaces between imperialists to find a better optimum. Definitely, to have an effective search, assimilation of the colonies has a random behavior. While moving toward an imperialist, a colony may reach a position with lower cost than that of the imperialist. In such a case, the imperialist moves to the position of that colony and vice versa. Then an imperialist will follow the algorithm in the new position and colonies start moving toward that position.

4.3 Revolution

When a sudden change in a country's socio-political characteristic take place, there would be a revolution. To have a revolution in a country one of its socio-political characteristic (one of the parameters of each individual) is selected and muted according to the predefined limitations and the conditions which the problem has. This operation helps the algorithm to escape from being trapped in local minimum. The occurrence of the revolution is controlled by a coefficient which is called revolution rate. In this work, the revolution rate is considered 0.3.

4.4 Uniting similar empires

In the movement of colonies and imperialists toward the global minimum of the problem some imperialists might move to similar positions. If the distance between two imperialists becomes less than threshold distance, they both will form a new empire which is a combination of these empires. All the colonies of two empires become the colonies of the new empire and the new imperialist will be in the position of one of the tow imperialists.

4.5 Imperialistic Competition

Total power of an empire is calculated using the imperialist power and the mean power of its colonies, but it is mainly affected by the imperialist country. This fact is modeled by means of equation 1.

T.C.n =
 Cost(Imperialistn) +
ξ(mean{Cost(ColoniesOfEmpirs n)} (1)

at which, T.C. n is total cost of the n_{th} empire and ξ is a number considered less than 1 to decrease the effect of the colonies against the Imperialist. In this work ξ is considered 0.2.

According to the total power of empires the imperialistic completion starts. In this competition, the weakest empire losses its possessions and powerful ones try to gain it. This process is relative to some extend. As an imperialist becomes powerful, the probability of its win increases.

Weaker empires will collapse in the imperialistic competition and their colonies will be divided among other empires. In this work, the empires which have lost all its colonies will collapse. At last, the most powerful empire will take the possession of other empires and win the competition.

5 VALIDITY OF THE SCHEME

In this session, the results of the proposed scheme are demonstrated. First a criterion of goodness is introduced to have a tool to compare the results.

5.1 Correlation Factor

The correlation factor is a measure for the similarity of two curve progressions. For two TFs, TFA and TFB, this factor can be determined as follows [11]:

$$\rho = \frac{\sum_{i=1}^{N}\left(TFS^*(f_i)\cdot TFE^*(f_i)\right)}{\sqrt{\sum_{i=1}^{N}\left(TFS^*(f_i)\right)^2\cdot\sum_{i=1}^{N}\left(TFE^*(f_i)\right)^2}} \quad (3)$$

at which

$$TFS^*(f) = |TFS(f)| - \frac{1}{N}\sum_{i=1}^{N}|TFS(f_i)|$$
$$TFE^*(f) = |TFE(f)| - \frac{1}{N}\sum_{i=1}^{N}|TFE(f_i)| \quad (4)$$

In equation 4 TFE is transfer function of the transformer resulted from experimental data and TFS one which resulted from simulation of the transformer model by predicated parameters by ICA algorithm.

In this paper mentioned correlation factor is used as fitness function for ICA optimization algorithm which maximization of it means precise parameters for transformer and accurate transfer function.

5.2 Discussion

The parameters of the reduced model are identified by the ICA. As it is mentioned previously, the parameters derived from CAF are considered as the starting point of the search in ICA. After some iteration, the optimized parameters were obtained. In figure 2 measured, CAF and ICA associated TFs are demonstrated.

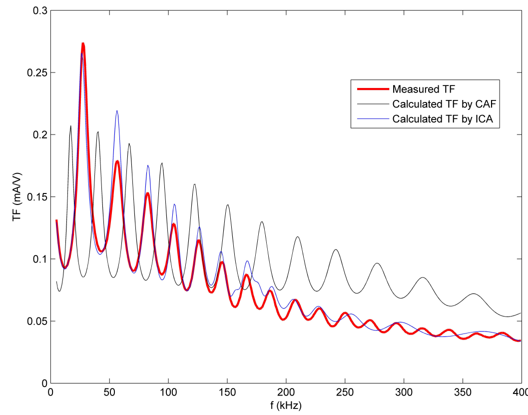

Figure 2: Comparison between the TFs calculated by CAF and ICA methods to evaluate the accuracy of the defined method.

As it is can see, the transient behavior of the winding, represent a significant superiority of ICA performance to CAF. Resonance frequencies and amplitude at resonance frequencies are the most important properties of the transfer functions in transient analysis of power transformers.

Figure 2 clearly shows that these properties are better in the TF which is obtained by ICA than the one obtained by CAF.

The correlation factor is a good criterion to compare two curves. More, the correlation factor is described and more comparisons take place.

Correlation factor is calculated for both CAF and ICA transfer functions. The results are presented in table 2. From the results given in table 2 it can be concluded that the similarity of ICA transfer function to the measured TF is more than the similarity of CAF transfer function.

Table 1: Correlation Factor of The Methods

Method	Correlation Factor
ICA	0.9829
CAF	0.3903

6 CONCLUSION

The present work uses a real 400 kV transformer to reduce the order of its model. In this work, Imperialist Competitive Algorithm is uses to identify the reduce order model parameters. By the proposed method, not only the transformer model reduces but also there would be a great improvement in compare with what are yields by calculated common formulae.

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