PREPROCESSOR FOR EMTP POWER TRANSFORMER MODELS

Juan A. Martinez-Velasco Francisco Gonzalez-Molina
Departament d'Enginyeria Elèctrica
Universitat Politècnica de Catalunya
Diagonal 647 - 08028 Barcelona, Spain

Bruce A. Mork
Department of Electrical Engineering
Michigan Technological University
Michigan 49931-1295, USA

Abstract - **This paper presents a preprocessor which creates and edits power transformer data files for EMTP simulations. The document provides a brief summary of the transformer models proposed to date and a description of the main preprocessor features. The present version is limited to low frequency models. A short discussion on the limitations and future development is also included.**

Keywords: Modelling, Power Transformers, EMTP.

I. INTRODUCTION

An accurate simulation of power system transients requires an adequate representation of the system components taking into account the frequency range of the phenomenon. One of the most important components is the power transformer. Despite its relatively simple design, an accurate representation of this component over a wide frequency range is very difficult [1]. A significant effort on transformer modelling devoted to the development of models to be used in digital simulations has been made during the last two decades [2] - [15].

A great variety of power transformer models for every frequency range is currently available. Some of these models require the knowledge of parameters whose values cannot be easily obtained. This paper presents the first version of a preprocessor developed for helping users to choose the right model and edit the data file of a power transformer in EMTP code [16]. The current version is limited to low frequency models. Linear and nonlinear representations of multiphase n-winding transformers in EMTP code can be easily edited by means of this new tool.

The document has been arranged as follows : Modelling guidelines for transient simulations of power transformers are summarized in Section II. Low frequency models for single- and multi-phase transformers are discussed in Section III. The approaches chosen are discussed in this section. The main features of the preprocessor are detailed in Section IV, which also includes an illustrative example. The present version has obvious limitations, even for low frequency models; the main limitations and the future work are discussed in the last section of this document.

II. MODELLING OF POWER TRANSFORMERS

The development of a transformer model must be made taking into account the physical phenomena which are involved in a transient process. To justify the guidelines proposed up to date for transformer modelling, a short description of the physical phenomena that play an important role during a transformer energization is presented [19], [20]:

a) Immediately after the activation of a transformer, winding capacitances begin to charge and the current starts to flow, first in the dielectric structure, then in the winding. Flux will not penetrate in the ferromagnetic core before 1 μs. The inductance is basically that of an air core, since core losses are negligible. Transformer losses are basically due to losses in the conductors and the dielectric.
b) Flux begins to penetrate in the core after 1 μs. During the transition between 1 μs and 10 μs, the inductance characteristic passes from air to iron core. Fluxes will have penetrated the core completely at 10 μs. Current primarily flows through the capacitance structure, whose influence is still very important. However, it also starts to flow in conductors.
c) The behaviour of the transformer becomes stable after 10 μs. Losses are now occurring in the conductors, core, dielectric, and transformer tank. The conductor losses include the skin and the proximity effects, whereas the core losses include the eddy current effect.

Although power transformers have a relatively simple design, their representation can be very complex due to the high number of core designs and their different behaviour during transient phenomena. It is very difficult to achieve an acceptable representation of this component throughout the complete range of frequencies that can be present in the transient phenomena of a power system. To solve this problem, one or several models valid for a specific frequency range can be used. According to the CIGRE WG 33-02, frequency ranges can be classified as four groups with some overlapping between them [17].

Table 1 shows the importance of some parameters and effects, according to the CIGRE WG 33-02, in the modelling of a transformer for a specific frequency range. Readers are referred to [17] for more details about this subject.

III. LOW FREQUENCY MODELLING

Several approaches can be considered to derive low-frequency transformer models. The selection of the most suitable representation depends on several factors: core design, available data, and transient phenomenon. A summary of some approaches for use in electromagnetic transients programs follows:

1) The representation of single- and three-phase n-winding transformers can be made in the form of a branch impedance or admittance matrix [2], derived from nameplate data. This approach cannot include nonlinear effects of iron cores. However, transformer parameters are both nonlinear and frequency-dependent. Major causes of iron core nonlinearities are saturation and hysteresis; one of the main causes of frequency-dependence are eddy currents. With this approach, nonlinearities can be incorporated by connecting nonlinear inductances at winding terminals.
2) Detailed models incorporating core nonlinearities, and valid for low frequency transient simulations, can be derived by using the principle of duality from a topology-based magnetic model [15] - [19].
3) Hybrid models based on core topology, and consisting of electric and magnetic circuits have also been derived [21].

Several options are available in most transients programs to represent these approaches:

- Built-in models with and without saturable core representation, for example Saturable Transformer Component (STC).
- Supporting routines to get the impedance or the admittance matrix, without taking into account the saturable core effects, from transformer ratings and test data, for example BCTRAN.
- User can benefit from other options available in some programs, for example the ideal transformer.
- Supporting routines to derive the representation of a specific three-phase transformer, for example the ATP SEATTLE XFORMER.

As mentioned above, the selection of the most suitable model for low frequency transient simulations has to be made taking into account the core design. Fig. 1 shows the most common three-phase transformer designs. One can deduce from this figure that, unlike the triplex core case, any three-phase core configuration includes direct magnetic coupling between phases.

Four- and five-legged transformers, as well as shell-type transformers, have low reluctance for homopolar fluxes, as they close their path across the core. Three-legged core type transformers need less quantity of material for their construction; however, they have a high reluctance path for homopolar fluxes, which close their path through the air and the transformer tank. In this design, both homopolar currents and excitation losses can have an important effect.

The modelling approaches used in the new pre-processor follow the guidelines discussed above. A short summary on the solutions implemented for single- and three-phase transformers follows :

a) Single-phase units and three-phase transformer banks
A matrix representation derived from BCTRAN usage is the most suitable choice if the saturation effect can be neglected. However, if the saturation effect is important, then other EMTP options such as the STC and the Ideal Transformer are used.

b) Three-phase transformers
The modelling guidelines presented above could also be used for single-core designs. Therefore, if the saturation effect can be neglected, the supporting routine BCTRAN is used. However, if saturation plays an important role in the transient phenomena, the representation of three-phase transformers is more complex. Some of the most accurate models have been derived from the application of the principle of duality. Fig. 2 shows the equivalent circuit of a three-phase three-legged transformer [9]. To obtain this circuit in EMTP code, both the STC option and the ideal transformers are used again. The main problem of this representation is the lack of reliable data, as no international standard suggests how to measure and calculate some parameters of this circuit.

IV. DESCRIPTION OF THE PROGRAM

The preprocessor presented in this paper is a Windows application made of several modules, subdivided in menus. Capabilities of this program allow users

- to create transformer data file in EMTP code
- to specify parameters of the equivalent circuit, using manual entry
- to create custom-made equivalent circuits
- to visualize and modify results.

As mentioned above, the current version is limited to low frequency models. Some details about the main options follow.

A. Data input

Fig. 3 shows the screen generated by the program when data input has been activated. The information to be specified in this screen includes

- transformer location
- number of phases
- number of windings and ratings of every winding
- core design
- transformer model.

The selection of the core design depends on the transformer type. For example, the designs available for three-phase transformers are triplex core, shell-core, three-legged stacked core, four-legged stacked core, five-legged stacked core, and five-legged wound core (Fig. 1).

Two different ways have been implemented for selecting a transformer model: editing a new model (NEW) or using a model previously edited (EDIT). After choosing this, and before entering the parameters needed to obtain the EMTP data file, the user has to specify the type (source) of parameters. The program has two choices: test data input and manual entry. With the first choice, either calculating parameters of the

TABLE 1 - MODELLING OF POWER TRANSFORMERS [17]

Parameter/Effect	Low frequency transients	Slow front transients	Fast front transients	Very fast transients
Short-circuit impedance	Very important	Very important	Important	Negligible
Saturation	Very important	Very important [1]	Negligible	Negligible
Iron losses	Important [2]	Important [1]	Negligible	Negligible
Eddy currents	Very important	Important	Negligible	Negligible
Capacitive coupling	Negligible	Important	Very important	Very important

1) Only for transformer energization phenomena, otherwise important.

2) Only for resonance phenomena.

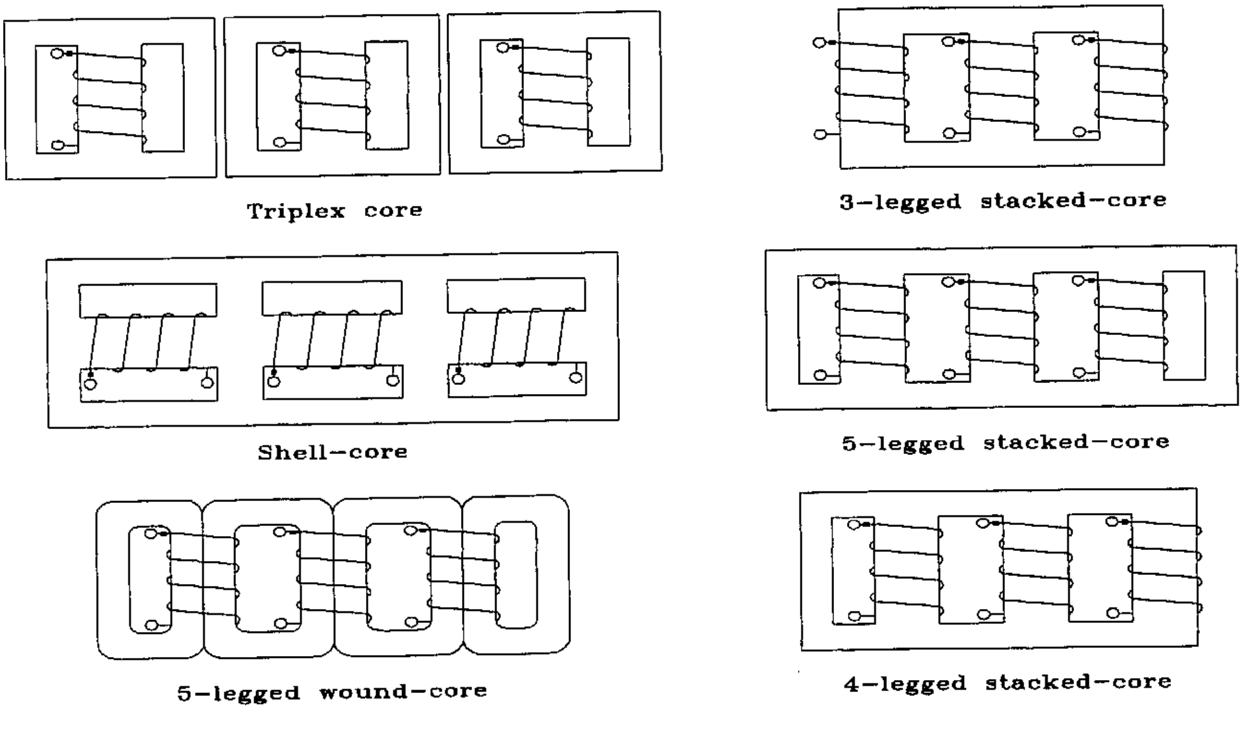

Fig. 1. Three-phase core designs.

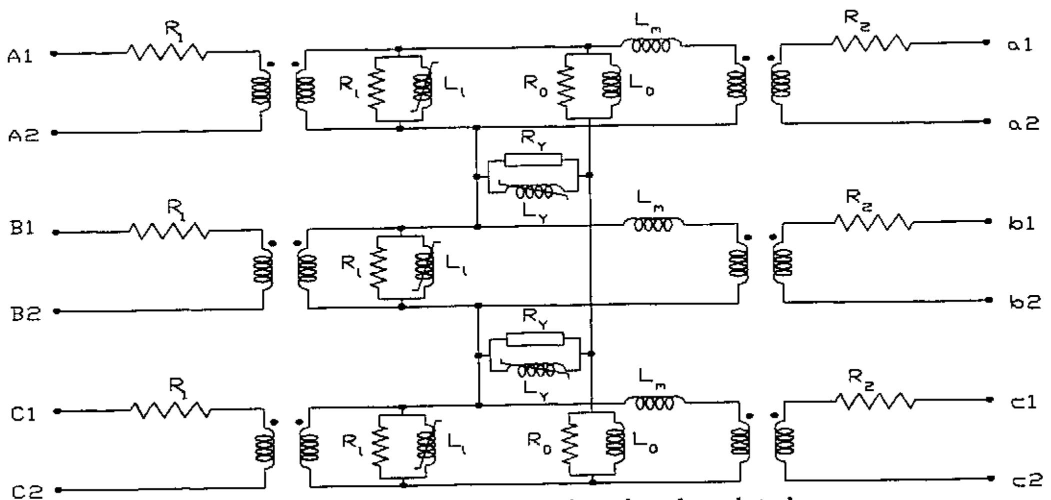

Fig. 2. Equivalent circuit of a three-phase three-legged stack-core.

equivalent circuit or deriving a matrix representation of the transformer is a program task. With the second choice, the user has to specify the parameters of the equivalent circuit. Fig. 4 shows the equivalent circuit implemented in the program for manual entry of a three-phase five-legged wound-core; this circuit has been derived by using the principle of duality [8], [9], [12], [15]. Fig. 5 shows the screen developed to specify the magnetization curve of nonlinear inductances if a saturable core is considered. Obviously, the data conversion procedure to obtain parameters of the equivalent circuit must be performed by the user. Other data input options are foreseen in future versions; for instance a procedure to obtain parameters from design information.

The data conversion procedure to be performed by the preprocessor when test data are specified can consist of different steps depending on the transformer model. When a linear representation is sufficient, the pre-processor creates a special data file and calls for the EMTP routine BCTRAN. If a nonlinear representation is needed, and excitation curves are available, the program adds the saturable inductances to the file produced by BCTRAN.

B. Custom-made models

Users can also create their own models or equivalent circuits by choosing CREATE in the screen shown in Fig. 3. Two different ways will be available to create a custom-made model: by drawing the circuit or using manual entry. Currently, only the second option has been implemented.

Once this option is selected, model components must be introduced using the library available in the program, which consists of the following components: resistances, inductances, capacitances, nonlinear resistances, nonlinear inductances, ideal transformers. Fig. 6 shows the screen that corresponds to a nonlinear inductance. This option distinguishes between single- and three-phase core designs. Transformer data can be saved in a file (.CLB) as the other existing models in the program.

C. Visualization and modification of the results

The main goal of this preprocessor is to create the data file (.PCH extension) of a power transformer in EMTP code. However, the program allows users to create two additionals files for each transformer

- a file with the description of the equivalent circuit, and .CKT extension
- a file with the main transformer data - location, number of phases and windings, type of core, used models -, and .XFR extension.

These files are edited in ASCII code, and can be visualized and modified by means of the EDIT option, located in the principal menu of the preprocessor. Fig. 7 show the EMTP data file of a single-phase linear transformer model. These additional files can also be created for custom-made models.

V. CONCLUSIONS

The tool presented in this paper promises to be very useful for editing the representation of a power transformer in EMTP code, even though it is presently limited to low frequency models. This version is the first step of a more ambitious project whose goal is to cover the data file editing of all types of transformers at every frequency range. Some data input options are still to be added. This version can be used only when all data required in a transformer representation is known; this is not always possible, and in many cases some parameters must be estimated. A short list of new features which will be added in future versions follows:

- frequency dependent models for simulation of switching and fast front transients
- saturation and hysteresis curves from the most important core material manufacturers
- eddy current effects
- parameter estimation in some representations for which reliable values are not always available or they are difficult to obtain.

VI. REFERENCES

[1] M. Bollen, "The search for a general transformer model", Proc. of the 16th European EMTP Meeting, Paper 89-07, Dubrovnik, May 28-30, 1989.

[2] R.C. Degeneff, "A method for constructing terminal models for single-phase n-winding transformers", Paper No. A 78 539-9, *1978 IEEE PES Summer Meeting*, July 16-21, Los Angeles.

[3] E.P. Dick and W. Watson, "Transformer models for transient studies based on field measurement", *IEEE Trans. on Power Apparatus and Systems*, vol. 100, no. 1, pp. 401-419, January 1981.

[4] V. Brandwajn, H.W. Dommel and I.I. Dommel, "Matrix representation of three-phase n-winding transformers for steady-state and transient studies", *IEEE Trans. on Power Apparatus and Systems*, vol. 101, no. 6, pp. 1369-1378, June 1982.

[5] J. Avila-Rosales and F.L. Alvarado, "Nonlinear frequency dependent transformer model for electromagnetic transient studies in power systems", *IEEE Trans. on Power Apparatus and Systems*, vol. 101, no. 11, pp. 4281-4288, November 1982.

[6] D.N. Ewart, "Digital computer simulation model of a steel-core transformer", *IEEE Trans. on Power Delivery*, vol. 1, no. 3, pp. 174-183, July 1986.

[7] P.T.M. Vaessen, "Transformer model for high frequencies", *IEEE Trans. on Power Delivery*, vol. 3, no. 4, pp. 1761-1768, October 1988.

[8] C.M. Arturi, "Transient simulation and analysis of a three-phase five-limb step-up transformer following an out-of-phase synchronization", *IEEE*

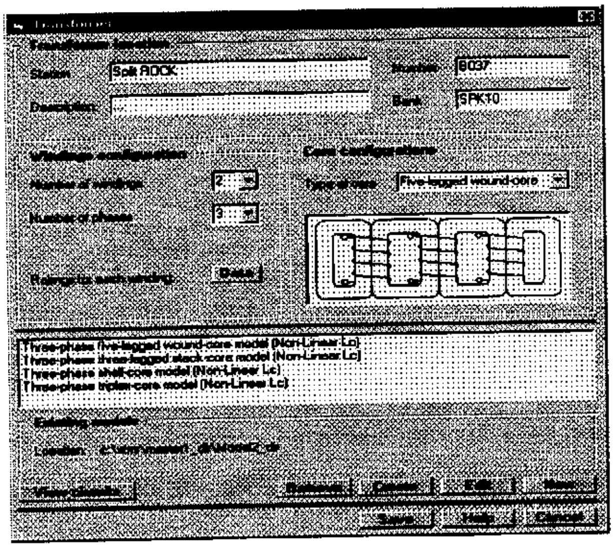

Fig. 3. Main data input screen.

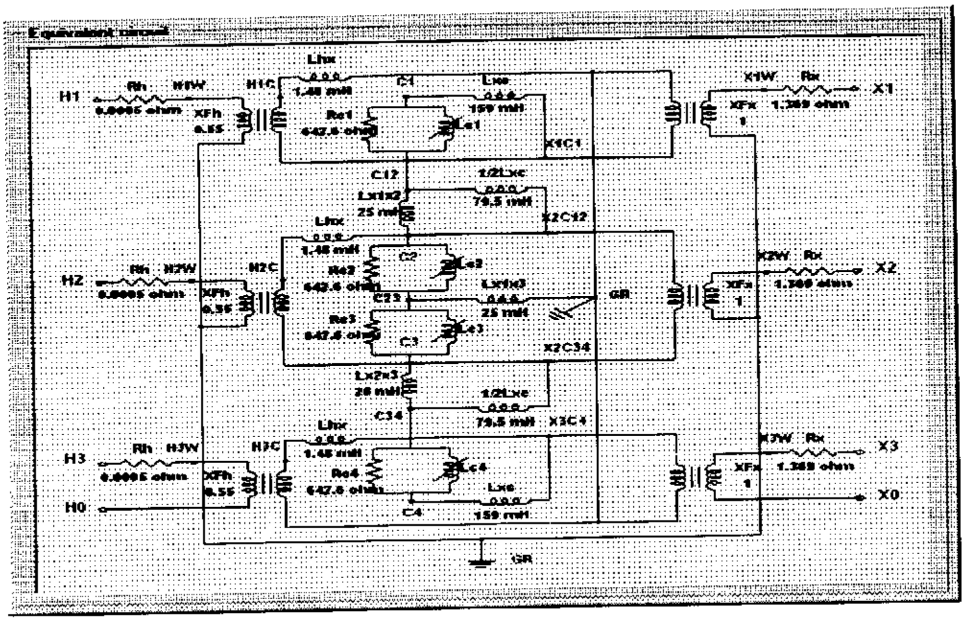

Fig. 4. Equivalent circuit of a three-phase five-legged wound-core.

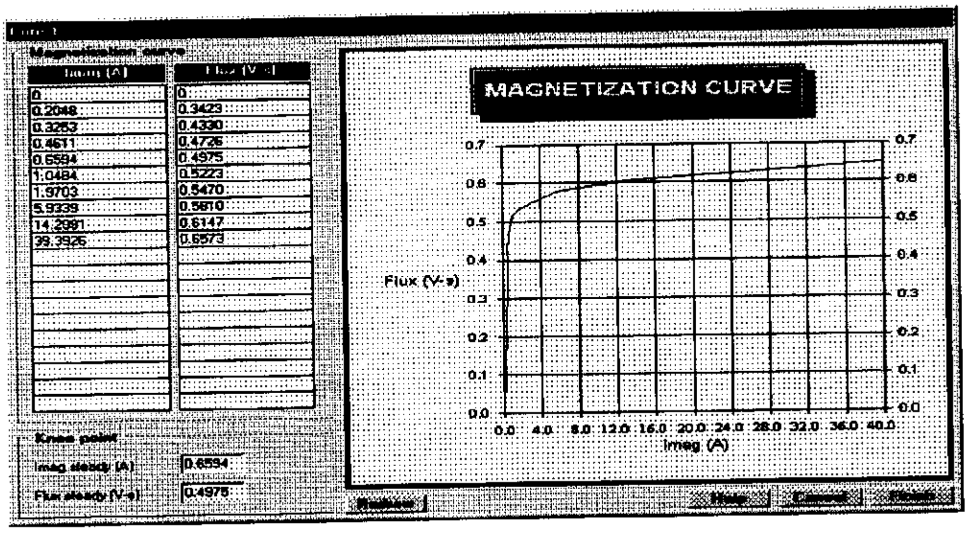

Fig. 5. Magnetization curve - Manual entry.

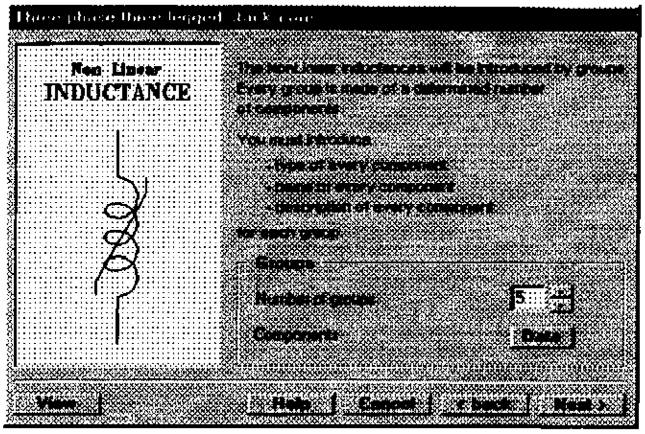

Fig. 6. Component input - Custom-made equivalent circuit choice.

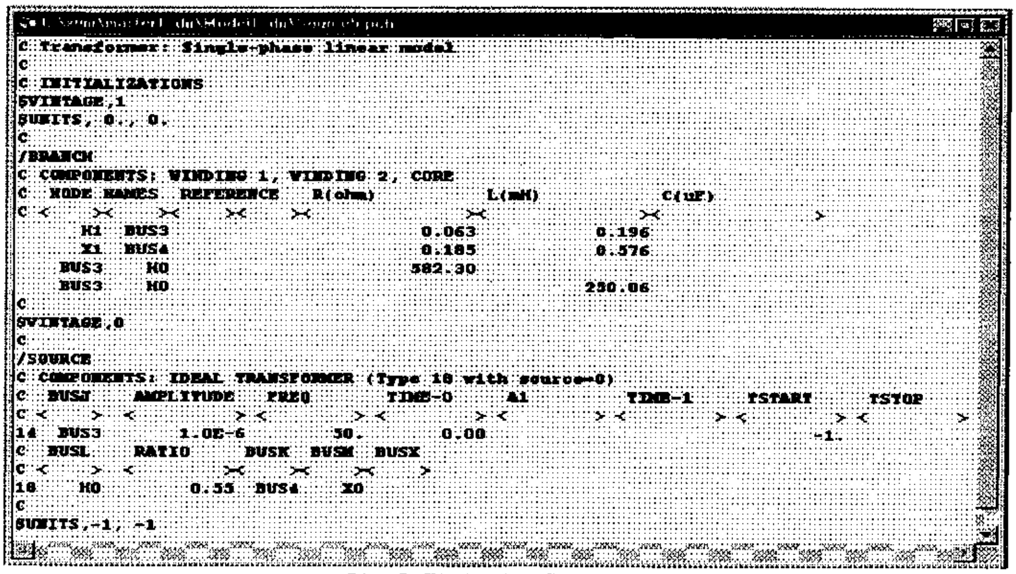

Fig. 7. EMTP data file (*.pch).

Trans. on Power Delivery, vol. 6, no. 1, pp. 196-207, January 1991.

[9] D.L. Stuehm, "Final report. Three phase transformer core modeling", Bonneville Power Administration Award No. DE-BI79-92BP26700, February 1993.

[10] A. Morched, L. Marti and J. Ottevangers, "A high frequency transformer model for the EMTP", *IEEE Trans. on Power Delivery*, vol. 8, no. 3, pp. 1615-1626, July 1993.

[11] F. de León and A. Semlyen, "Complete transformer model for electromagnetic transients", *IEEE Trans. on Power Delivery*, vol. 9, no. 1, pp. 231-239, January 1994.

[12] A. Narang and R. H. Brierley, "Topology based magnetic model for steady-state and transient studies for three-phase core type transformers", *IEEE Trans. on Power Systems*, vol. 9, no. 3, pp. 1337-1349, August 1994.

[13] S. Chimklai and J.R. Marti, "Simplified three-phase transformer model for electromagnetic transient studies", *IEEE Trans. on Power Delivery*, vol. 10, no. 3, pp. 1316-1324, July 1995.

[14] X. Chen and S.S. Venkata, "A three-phase three-winding core-type transformer model for low-frequency transient studies", *IEEE Trans. on Power Delivery*, vol. 12, no. 3, 775-782, April 1997.

[15] B.A. Mork, "Five-legged wound-core transformer model: Derivation, parameters, implementation, and evaluation", Paper PE-414-PWRD-0-12-1997, presented at the *1998 IEEE PES Winter Meeting*, February 1-5, 1998, Tampa.

[16] H.W. Dommel, *Electromagnetic Transients Program. Reference Manual (EMTP Theory Book)*, Bonneville Power Administration, Portland, 1986.

[17] CIGRE Working Group 02 (SC 33), "Guidelines for Representation of Network Elements when Calculating Transients", 1990.

[18] Can/Am EMTP Users Group, *ATP Rule Book*, Portland, 1997.

[19] A. Greenwood, *Electrical Transients in Power Systems*, John Wiley, Second Edition, New York, 1991.

[20] R. Degeneff, " Modeling frequency dependent characteristics of transformers", Panel Session on Frequency Dependent System Models, *IEEE PES Winter Meeting*, New York, February 2, 1995.