



HAL
open science

Integration of feed back control in a field circuit coupled model

Gilbert Manot, Yvan Lefèvre, Hubert Piquet

► **To cite this version:**

Gilbert Manot, Yvan Lefèvre, Hubert Piquet. Integration of feed back control in a field circuit coupled model. ISEF 2001 – 10th International Symposium on Electromagnetic Fields in Electrical Engineering, 2001, Cracow, Poland. pp. 475-478. hal-01618156

HAL Id: hal-01618156

<https://hal.science/hal-01618156>

Submitted on 17 Oct 2017

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Open Archive Toulouse Archive Ouverte (OATAO)

OATAO is an open access repository that collects the work of Toulouse researchers and makes it freely available over the web where possible.

This is an author-deposited version published in: <http://oatao.univ-toulouse.fr/>
Eprints ID: 18457

To cite this version: Manot, Gilbert and Lefevre, Yvan and Piquet, Hubert
Integration of feed back control in a field circuit coupled model. (2001) In:
ISEF 2001 – 10th International Symposium on Electromagnetic Fields in
Electrical Engineering, 2001 - 2001 (Cracow, Poland)

Any correspondence concerning this service should be sent to the repository administrator:
staff-oatao@listes-diff.inp-toulouse.fr

INTEGRATION OF FEED BACK CONTROL IN A FIELD CIRCUIT COUPLED MODEL

Manot. G, Lefèvre. Y, Piquet H.

Laboratoire d'Electrotechnique et d'Electronique Industrielle
Unité Mixte de Recherche INPT-ENSEEIH/CNRS
BP7122 – 2, rue Camichel 31071 – Toulouse Cedex 7 France
E-mail: manot@leei.enseeiht.fr

Abstract - In this paper, we present a method accounting for feedback control in coupled field circuit models. This method can manage all kind of electronic switches which can be controlled by means of different electric or magnetic quantities calculated during the simulation (flux, currents, voltages, ...). Electrical systems involving magnetic devices, power electronic converters and their control devices can be simulated in presence of phenomena such as eddy currents or saturation of the magnetic materials.

Introduction

Many works have been dealing with field circuit coupled model [1][2]. This paper relates the implementation of feedback control loops in a coupled field circuit model. This model allows us to study electromagnetic fields in structures fed by power electronic circuits. These circuits contain active Power Electronic Components (PEC) and have a time dependent topology. This model is based on 2D Finite Element Method (FEM) to discretize the magnetic field equations and external circuits are represented by the state equations formulation [3]. A novel method is used to link the two systems. The different windings of the electromagnetic structure are taken into account as voltage sources of the circuit, this method simplify the global formulation [4]. The whole field-circuit system written in matrix form is solved by a step by step integration algorithm. In order to take advantage of this powerful formulation and in order to deal with industrial applications involving feedback control configurations, we present a method accounting for the control loops in field circuit models [5][6].

In this paper , we apply this method to model a multi-windings transformer. The latter is made of one primary winding and four secondary windings and is associated to four power electronic converters in a railway traction drive system[7]. To assure a power factor close to unity and to attenuate the harmonics present in the ac electric supply the currents in the secondary windings of the transformer are regulated.

First, we sum up the coupled field circuit formulation using 2D FEM method, then we present a method accounting for the feedback control strategy and lastly we present the simulation of the multi-windings transformers associated with for power electronic converters.

Coupled 2D FEM field circuit model

A magnetic vector potential formulation is established from a 2D transverse magnetic hypotheses. We consider only magnetic devices with windings made of stranded conductors. The current density \mathbf{J} is assumed to be uniform in the conductors and is related to the magnetic vector potential \mathbf{A} by:

$$\mathbf{curl} \mathbf{v} \mathbf{curl} \mathbf{A} = \mathbf{J} = -\sigma \frac{d}{dt} \mathbf{A} - \sigma \mathbf{grad}(\Phi) = n \frac{I_{stc}}{S_{sct}} \mathbf{u} \quad (1)$$

where \mathbf{v} and σ are respectively the reluctivity and the conductivity of media, Φ is the electric scalar potential, I_{stc} , the current in a winding, S_{stc} , the total section occupied by a winding, n , the number of stranded conductors in a winding and \mathbf{u} is a vector perpendicular to the study plane. The field equations in matrix form are obtained by discretisation of the study domain using 2D FEM and are given below:

$$[M]\{A\} + [N]\frac{d}{dt}\{A\} + [P_{ST}]\{I_{WST}\} = \{0\} \quad (2a)$$

$$\{U_{WST}\} = [R_{WST}]\{I_{WST}\} + [Q']\frac{d}{dt}\{A\} \quad (2b)$$

where M is the permeability matrix and N is conductivity matrix of the media. P_{st} makes the link between the nodes and the currents in the windings. U_{WST} , I_{WST} , R_{WST} represent respectively the voltages, the currents and the resistors values related to the windings made with stranded conductors.

The external circuit equations are obtained automatically from the topological description of the circuit by using the Welsh algorithm and are written in the state form:

$$\frac{d}{dt}\{X_c\} = [A_c]\{X_c\} + [B_c]\{U\} + [B_{WST}]\{U_{WST}\} + [E_c]\frac{d}{dt}\{U\} \quad (3)$$

X_c represents the state variables which are the branch capacitor voltages and the link inductor currents. U is the vector of the real current and voltage sources. The matrix A_c , B_c , B_{WST} , E_c are evaluated automatically at each step according to the operating mode of the converters.

In these equations, each winding of the magnetic devices is modelled as a voltage source U_{WST} . This solution seems to be interesting because the voltage drop on windings are naturally part of the sources of the circuit and the currents through the windings are naturally the sources of the electromagnetic field. Thus, the currents in the windings are obtained by the relations:

$$\{I_{WST}\} = [F_{WST}]\{X_c\} + [G_{WST}]\{U\} \quad (4)$$

A resistor and inductor in series with each winding can be added to the circuit to model the parts of the magnetic device which are not taken into account by 2D FEM. Equations (2) and (3) are linked together with equation (4) to form the global system:

$$[M]\{A\} + [N]\frac{d}{dt}\{A\} + [P_{ST}][F_{WST}]\{X_c\} + [P_{ST}][G_{WST}]\{U\} = \{0\} \quad (5a)$$

$$[B_{WST}][Q']\frac{d}{dt}\{A\} + [A_c]\{X_c\} + [B_c]\{U\} + [E_c]\frac{d}{dt}\{U\} = \{0\} \quad (5b)$$

The system is solved by a step by step method knowing the real sources U to get the magnetic vector potential A on each node of the mesh and the state variables X_c . The PECs like diodes, transistors or thyristors are modelled as two values resistors : a very high value when it is off and a very low one when on. The states of the PECs are not known a priori. Their states are managed by a coloured Petri net representation [4]. Up to this point, to simulate the dynamic operation of the whole system, the control signals of PECs are defined all for once at the beginning of the simulation [3].

Taking into account of the feedback control

In order to take into account feedback control, we have implemented the method of control loops in the software developed from the coupled field circuit model [5-6, 8]. We have adopted a formalism intimately related to the sampled control model. The method consists to interrupt the main program every sampling time. Communications between the coupled system and the control block occur only at these sampling moments. Between two sampling instants, the software continues to search for natural commutations of PECs, by looking at the voltages across these components. Precisely at each sampling moment, the control block receives its inputs sent by the main program. These inputs are defined as voltage drops across resistors placed in the circuit. The control block computes the internal variables to elaborate the control laws and sends back to the main program the gating orders of the PECs. From this model, a software called MagCvs has been elaborated. As the main program, the code for the controls law is written by the user in FORTRAN and can be written also in C.

Application: Multi-windings transformer in a railway traction system

To validate this field circuit model accounting for feedback control, we study the ac to dc power supply of a railway traction drive system (Fig. 1)[7]. Our study consists to model the multi-windings transformer associated to four Ac-Dc converters and takes into account the current regulation needed to satisfy the railway standards. The different features treated here are:

1. The Ac catenary line (25 kV ac rms) feeds the main transformer whose structure is given on Fig. 2. The latter has a single primary winding and four secondary windings. All the conductors forming the windings are modelled as stranded conductors. The primary winding is made with 2828 turns whereas each secondary with 168 turns.
2. Four 4-Quadrant Converters (4QS) (Fig. 1) are connected to the secondary windings of the transformer in order to convert the Ac voltage of the overhead line into Dc voltage ($E_C = 2750$ V). The 4QS converter is made with 4 power transistors (IGBT) and are controlled using synchronous bipolar Pulse Width Modulation (PWM) technique. This technique allows to deliver an output voltage of the 4QS converter with 3 levels ($-E_C, 0, E_C$) and to reduce the harmonics in the overhead line current. The input line frequency is 50 Hz and the triangular carrier frequency is 6 times this frequency. We represent the Dc to Ac converters and the induction motors as a Dc voltage source whose value is equal to E_C .
3. A Unity Power Factor Control ensure a maximum power transfer between the line and the load. A real time current regulation keep the phase shift angle between the Ac supply voltage and its current equal to zero. It can be shown that the leakage inductance of the transformer is a key parameter of this current regulation [7]. The value of this parameter is obtained by simulations made with our software where PEC are removed and the four secondary windings of the transformer short circuited. This value is included in the control block which is compiled with our program and whose diagram is given in Fig. 3.
4. A multi-interlaced phase shift control allows to reduce the undesired current harmonics [7]. This control consists to phase shift by 45° , with respect to each other, the carrier signals of the 4QS converters.

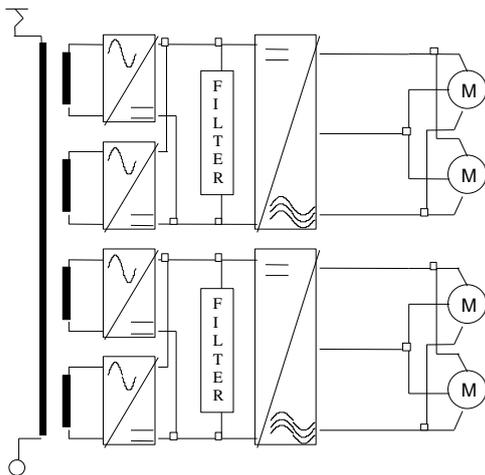


Fig.1: Induction motor traction drive system

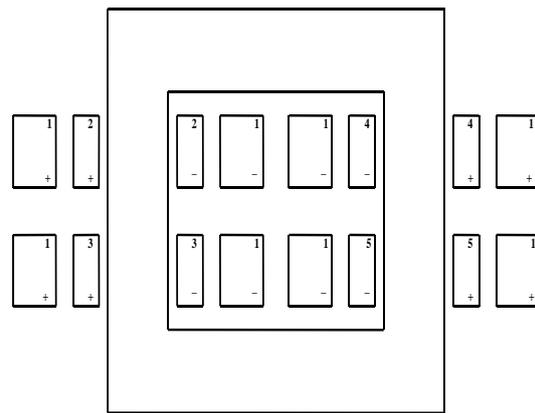


Fig.2: The main transformer with one primary and four secondary windings

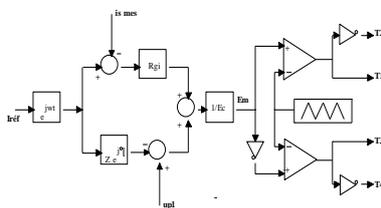


Fig.3: Block diagram of the current regulator

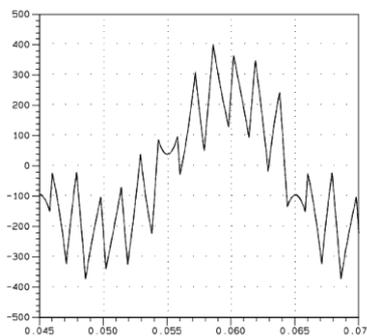


Fig.4: The current in the primary winding of the transformer without multi interlaced phase shift control obtained from a circuit model and the field circuit model.

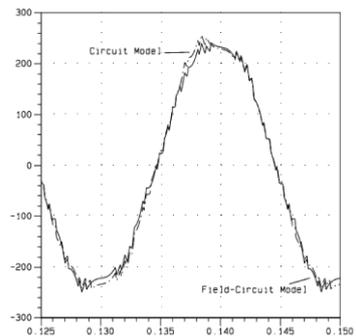


Fig.5: The current in the primary winding of the transformer with multi interlaced phase shift control obtained from a circuit model and the field circuit model.

We have simulated the operation of the power system constituted with the multi-windings transformer associated to the four 4QS converters. This power system is supplying a Dc voltage source and the current regulation described before is taken into account. We consider two cases: a current regulation with and without Multi-Interlaced Phase Shift Control. We present results in a case where the RMS of the fundamental of the currents in secondary windings are assigned to 707 A. We compare them with results obtained from simulations made with a purely circuit model software [5]. Fig. 4 and Fig. 5 show the currents in the primary winding of the transformer. We can observe the good agreement of the results obtained from the two models with a quite complete feedback control, mainly in the case without phase shift control (Fig. 4). On Fig. 5, we can see that the phase shift control allow to reduce harmonics of the current in the primary winding of the transformer. In this case, according to the simulation results obtained from both models, we find 8° phase shift between the voltage and the current of the Ac supply which corresponds to a power factor close to unity as desired.

Conclusion

In this paper, a method taking into account the feedback control in a time stepped coupled field circuit model is presented. This method is based on the formalism of sampling mode. It allows the simulation of complex system involving a strong interactions between power converters associated with electromagnetic devices and their controls. An industrial high power application , used in railway traction system is studied. We can model a very large number of windings feeding various converters made of PEC (diodes, power transistors, thyristors). Complex and useful feedback controls can be implemented in a discrete version without altering the codes of the software. The comparison of simulation with a circuit model validates our general field circuit formulation using 2D FEM. Further works are going on to validate this coupled model with feedback control in power systems where the saturation of ferromagnetic material is significant.

References

- [1] I. A. Tsukerman and al., "Coupled field circuit problems: trends and accomplishments", *IEEE Trans. On Magnetics*, vol. 29, N°2, pp.1701-1704, March 1993.
- [2] F. Piriou and A. Razek, "Finite element analysis in electromagnetic systems accounting for electric circuit", *IEEE Trans. On Magnetics*, vol. 29, pp.1669-1675, March 1993.
- [3] N. Sadowski and al., "Finite element simulation of electrical motors fed by current inverters", *IEEE Trans. On Magnetics*, vol. 29, N°2, pp.1683-1688, March 1993.
- [4] J.F. Charpentier, Y. Lefèvre and H. Piquet., "Une méthode générale pour modéliser les convertisseurs statiques associés à des dispositifs magnétiques", *J. Phys. III, France 7*, pp 2225-2237, November 1997.
- [5] Louisnard O., Meynard T., and Piquet H., "Simulation program for the design of static power converter", *PCIM-Nuremberg*, 1992.
- [6] P. Kuo-Peng and al., "Analysis of a combined converter electromagnetic device by taking into account its control loop", *IEEE Trans. On Energy Conversion*, , February 1998.
- [7] A.D.Cheok and al, "High power AC/DC converter and DC/AC inverter for high speed train applications", *TENCON 2000 Proceedings*, Vol 1, pp. 423-428, 2000
- [8] G.Manot, Y.Lefèvre, H.Piquet and F.Richardeau., "Integration of control loops in field circuit model to study magnetic devices supplied by power electronic converter and their control", *TEAM Whorshop and Application Forum*, ICS, Evian, July 2001.