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NUMERICAL SIMULATION OF THE STABILISATION OF THE STEADY STATE OPERATION OF AN ALTERNATOR FEEDING AN INFINITE BUSBAR BY A CIRCUIT FIELD COUPLED MODEL

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Abstract – In this paper, the authors present a study of the stabilisation of the steady state operation of an alternator by means of a time stepped 2D finite element field circuit coupled model. The results of the study show that it can be very difficult to stabilise the global quantities of the alternator. Ripples of numerical origin are observed on these quantities. The studies presented in this paper are intended to explain these difficulties and show that these ripples are due to the famous backward Euler algorithm commonly used in this kind of model.

Introduction

By the recent advent of two-dimensional, time-stepped, finite-element, field circuit coupled model, it is now possible to simulate the dynamic operations of electrical machines with very few assumptions [1]. This type of model takes into account naturally in their formulations the eddy currents, the saturation of the magnetic circuit. These models can be applied to simulate the transient response of alternators after system faults [2]. Our long term goal is to study the capability of these models to be applied in the diagnostics of faults occurring on a very high power (1GW) alternator feeding an infinite bus bar behind an appropriate transmission line.

In this paper, we present the difficulties we have met with this kind of model during the simulations of the stabilisation of the steady state operation. First, we explain why this kind of simulation is important for the study of transient response after system faults. Then, to show the problems we have met, we present the results we have obtained. Finally, in order to explain the ripples of numerical origin observed on the global quantities that we have obtained from simulations, a simplified model has been implemented in MATLAB. Conclusions are made on the common use of the backward Euler algorithm.

Procedure of simulation of the transient response of an alternator

Before simulating the transient response of an alternator after systems faults, it is necessary to put the alternator in the steady state in which it was just before the faults. Assuming that eddy currents in conductors can be neglected and that we have a sinusoidal distribution of flux density in the air-gap, we can apply the two axes model of alternator based on Park's transformation. From this, a specific procedure has been established and combined to a finite element code to calculate the currents in the windings knowing the operating point before faults [3]. This specific procedure allows to calculate a first approximation of the steady state: the magnetic field inside the alternator, the currents in the inductor and in the stator windings. Before simulating the actual transient response, one must proceed to the simulation of the stabilisation of the steady state. This stage allows to make sure that the operating point before faults is achieved. It is necessary because assumptions are needed to calculate this first approximation of the steady state. To simulate this stabilisation we use the very same finite element code we use for transient response. The code employed can take into account eddy currents, saturation of magnetic material, the movement of the rotor and the circuit supplied by the alternator [4][5][6].

Simulation of the stabilisation of the steady states

The alternator studied here has four poles and a power of about 1.3 GW. In order to make clear the problems we met, we assume that there are no eddy currents, the magnetic circuit is not saturated and there are no damper

windings. With the two reactions models based on Park's transformation and knowing the measured currents in the stator windings for the operating point just before the faults, the voltages on stator windings and the current in the inductor have been calculated. Then, by means of a 2D magnetostatic finite element code, the field inside the alternator has been computed.

From this first approximation of the steady state, several simulations of the stabilisation of the steady state have been undertaken with different time steps (1ms, 385 μ s and 100 μ s). The results are given on Fig. 1 which shows the current I_{ex} in the inductor.

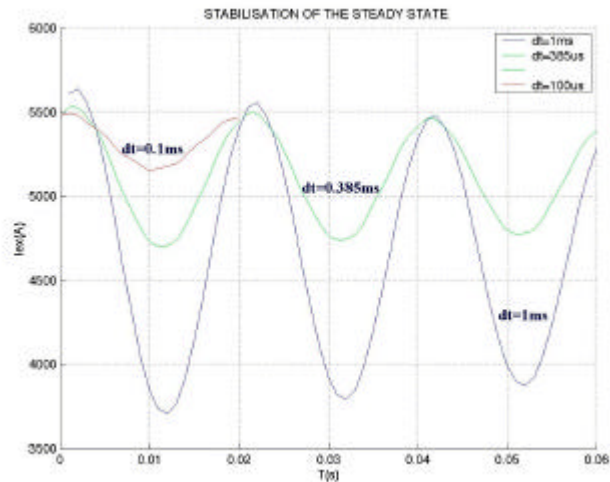


Fig. 1: Current I_{ex} in the inductor obtained from a field circuit coupled model with different time step δt .

During these simulations, the speed of the rotor is assumed to be constant and equal to 1500 revolutions per minute. The electric frequency is then equal to 50 hz. The alternator supplies an infinite bus bar which represents the electric network. The inductor is supplied by a dc voltage. On Fig. 1, it can be noticed that the current I_{ex} in the inductor has ripples whose amplitudes diminished when the time step is reduced. Note that, theoretically, during these simulations the current I_{ex} in the inductor has a constant value. Further examinations of the results obtained show also that as the time step δt increases the final value of the current I_{ex} actually obtained by simulation diminishes. It seems then that, besides generating ripples of numerical origin, the simulation of the stabilisation of the alternator by a time stepped finite element code leads to a steady state which depends on the time step δt chosen.

Simulation of the stabilisation of the steady state by a simplified model

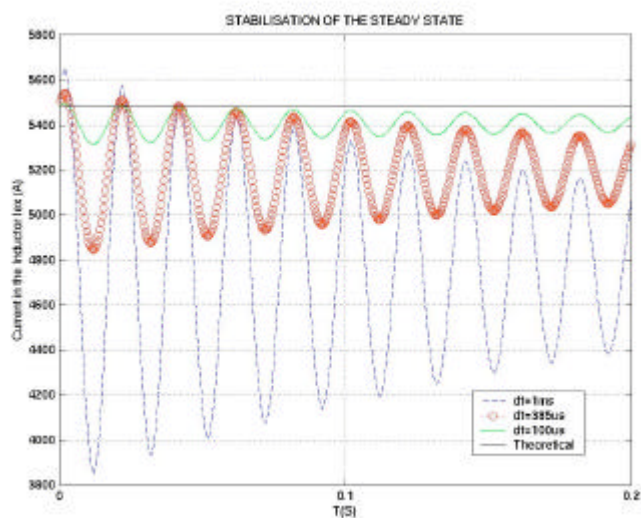


Fig. 2: Current I_{ex} in the inductor obtained from a simplified model with different time step δt and theoretically.

In order to understand the origin of the oscillations observed, a simplified model of the alternator supplying an infinite bus bar was implemented in MATLAB. This simplified model is based on the two axis model and Park's transformation. We have to precise that this model is only used here to represent the flux currents relations. The dynamic response is calculated by a circuit model taking into account the three windings of the stator and the inductor supplied by a dc voltage. In this model, theoretically, the stator currents, I_{sd} and I_{sq} , calculated in the DQ axes, the current I_{ex} in the inductor and the torque have all constant values during steady state.

For this step by step simulation, we use the backward Euler algorithm. Results are shown on Fig. 2 which represents the current in the inductor for different time steps. We notice the same behaviour concerning the ripples and the final value of the current I_{ex} . These observations are more evident here because the final time t_f reached is larger than in the former simulations ($t_f=0.2s$ in Fig. 2 besides $t_f=0.06s$ in Fig. 1).

We have reported in Fig. 2 the theoretical value obtained by the two axes model. Theoretically, the current I_{ex} is constant. In fact, as it is shown in the next section, the ripples are due to the use of the backward Euler algorithm which is now commonly used in time stepped finite element code. By the way, these results show also that the behaviour of the time stepped algorithm doesn't change with the number of degrees of freedom. In the finite element coupled to circuit model, the number of unknowns is about 10000 and in the simplified model we have only 8 unknowns, the flux and the current in the three stator windings and the flux and the current in the inductor.

Comparisons of different step by step integration algorithms

The previous simulations in MATLAB show that a simplified model based on the two axis model is enough to analyse the problems we met. By means of this model, we compare here the use of different algorithms to simulate the stabilisation of the steady state: the backward Euler algorithm, the Cranck Nicholson algorithm, the Gear's second order algorithm and backward-differentiation formula (BDF) of order 2 [7].

Fig 3. shows the comparison of the results obtained from the backward Euler and the Cranck Nicholson algorithms for a time step Δt of 1 ms. It is remarkable that the ripples are considerably reduced with Cranck Nicholson.

Fig. 4 shows the comparison of the results obtained from the Cranck Nicholson algorithm and the others algorithms for a time step Δt of 1 ms. With a fixed time step, the BDF second order and Gear second order algorithms give the same results. We notice that the Cranck Nicholson algorithm allows to obtain results with less ripples than the Gear second order algorithm. Only the BDF of second order with a variable time step gives results with less ripples than Cranck Nicholson. But this second order algorithm is very difficult to implement in a time stepped finite element method.

These simulations show that all the studied algorithms give results with ripples. Even second order algorithms may give ripples. Among the different algorithms we tried, the Cranck Nicholson algorithm is the most adapted to simulate the stabilisation of the steady state with time stepped finite element model.

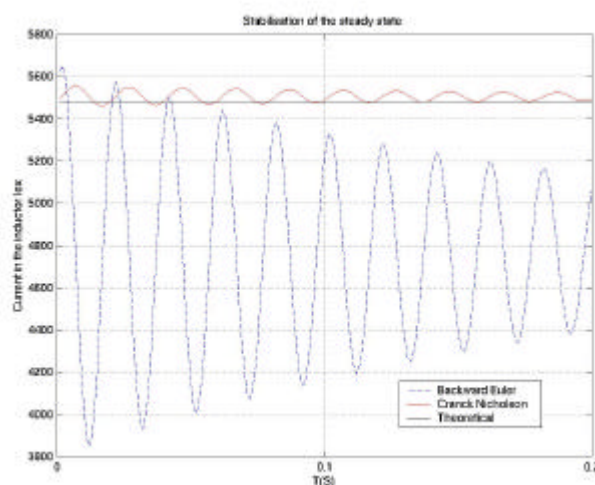


Fig 3: Comparison of the backward Euler and the Cranck Nicholson algorithms for a time step Δt of 1 ms.

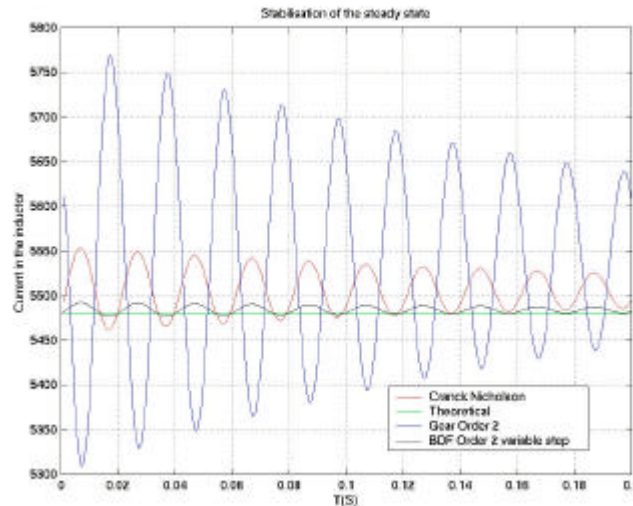


Fig 4: Comparison of the Cranck Nicholson algorithm and some second order algorithms for a time step of 1 ms.

Conclusion

The studies presented in this paper show that the simulation of the stabilisation of the steady state of an alternator by means of a time stepped finite element field circuit model may set some problems. If cares are not taken, for instance for the choice of the time stepped algorithm, results may present ripples of numerical origin. We have shown that these ripples are due to the commonly used backward Euler algorithm in time stepped finite element code. This algorithm is not well suited to the simulation of the stabilisation of the steady state. We have shown that the Cranck Nicholson algorithm is the most adapted to this simulation. For fixed time step, this algorithm is better than some famous second order algorithms.

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] Surgess J.P., Zhu. M., MacDonald D.C., "Finite element simulation of a generator on load during and after a three-phase fault", *IEEE Trans. Energy Conversion*, pp 787-793, vol.7, n°4, 1992.
- [3] S. Bouissou, F. Piriou and P.G. Therond, "Numerical simulation of synchronous generator on steady states", *Electric Machines and Power Systems*, 1993.
- [4] 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.
- [5] Lombard P, Meunier G., "A general method for electric and magnetic coupled problem in 2D and magneto-dynamic domain", *IEEE Trans. On Magnetics*, pp.1291-1294, vol. 28,n°2, 1992.
- [6] 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.
- [7] Leon O. Chua, Pen-Min Lin, "Computer-Aided analysis of electronic circuits: algorithms and computational techniques", Prentice-hall,1975.