Coupled Three Dimensional Numerical Calculation of Forces and Stresses on the End Windings of Large Turbo Generators via integral formulation

*R. Albanese, *F. Calvano, †G. Dalmut, †F. Ferraioli, °A. Formisano, +F. Marignetti, °R. Martone, *G. Rubinacci, +A. Tamburrino and +S. Ventre
*Dip. Di Ingegneria Elettrica, Univ. di Napoli "Federico II", Via Claudio 25, I-80124, Naples, Italy
+DAEIMI, Univ. di Cassino, Via G. Di Biasio 43, I-03043, Cassino, Italy
°Dip. di Ingegneria dell'Informazione, Seconda Università di Napoli, Via Roma 29, I-81031, Aversa (CE), Italy
†Ansaldo Energia, Via N. Lorenzi 8, I-16152, Genova, Italy
E-mail: Raffaele.Martone@unina2.it

Abstract — A novel numerical approach to calculate the time evolution of the three dimensional distribution of the magnetic field in the end winding regions of large turbine generators is presented. The proposed approach is based on an integral formulation for non linear magnetostatic problems within the frame of the finite element analysis. The integral formulation compute the eddy current and the magnetization and, therefore, its main advantage is the reduction of the discretization only to the part of the domain made by conductors and magnetic materials. In this paper the solution of a coupled magnetostructural problem consisting in the calculation of the mechanical stresses and deformations caused by the electrodynamic forces during a short circuit transient is presented. The currents used in the magnetostatic model are derived from the integration of a lumped parameter model. A specific parallel implementation customized for the proposed application makes of practical application the proposed technique.

I. Introduction

The evolution of electrical machines design has led to the increase of both power density and electrical loading. Among the other implications of such evolution, the influence of the mechanical stresses caused by electromagnetic forces and acting on the end windings has acquired a significant role both in machine design and in the performances assessment. Electrodynamic stresses and vibrations can severely damage winding insulations, end bracings and support rings both at steady state [1-2] and during transients [3]. As high-power high-pressure hydrogen-cooled turbo-generators are subject to large load variations, modeling the end winding electro-mechanical behavior is crucial. The analysis of the forces on the end windings is based on the computation of the local three dimensional flux density distribution. Although the older models date back to the '30s [4-5] and have been used up to recent years [6], the most widely used analytical models to study the end winding fields were those envisaged by Tegopoulos [7-8]. Old numerical models are based typically on Biot-Savart's law [4] and cannot account for iron saturation as well as for many geometrical details. Recently, three dimensional numerical approaches have been proposed. Concerning this field of research, a notable paper was proposed by Kim, Lee and others to analyze the end windings of a 900 kW 6.6kV induction motor at startup [9]. The model used in [9] is based on a quasi-static linear analysis. Each coil is energized separately and the contributions of all coils are finally added. This paper, indeed, illustrates a method to compute forces and mechanical stresses on the end windings of a large turbo generator, taking into account rotor and stator currents, rotation, iron saturation and external shielding by the generator case virtually in any operating condition including the most critical ones i.e. the three phase short circuit transient. The finite element model based on the integral formulation [10-11], if compared to the differential ones implemented in commercial codes, on one hand is characterized by managing less unknowns to describe the solution domain because no free space discretization is required and, on the other hand, is characterized by the needed of managing dense matrices instead of sparse ones. Therefore, a customized parallel implementation, unavoidable even in case of differential formulations, has been developed [12] to allow the practical application of the numerical procedure. In this paper, the proposed method is used to compute stresses and deformations in the end windings of a turbo generator during a short circuit transient. The procedure used is as follows: generator currents are computed from a lumped parameter model and form the input in the magnetostatic FEM model. Finally, the elemental forces calculated in the electromagnetic FEM analysis is given as input to a commercial code used for the stress analysis.

II. Calculations of Forces and Stresses in a Turbo Generator End Windings During Short Circuits

The outline of the magnetostructural analysis for an air cooled 330 MVA turbo generator is presented hereafter.

(a) (b) (c)

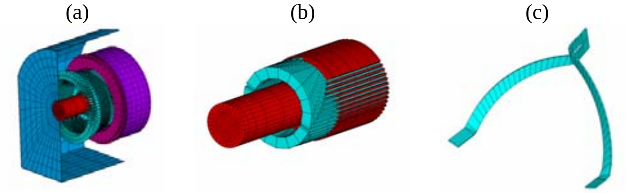

Fig. 1. Some details of the FE model: (a) ensemble, rotor iron and field coil, (c) stator end winding bar

Full results will be presented in the final conference paper. Almost all the geometrical details have been taken into account concerning the stator end windings as well as the rotor. Less details have been taken into account in modeling stator and rotor teeth geometrical profiles as well as the machine enclosure. An example of the FE mesh used in the simulations is shown in Fig. 1. The integral formulation allows to provide fine accuracies with limited number of unknowns. In the present case the mesh capable to model this complex geometry includes 22.000 nodes and 11.300 elements, except for 1100 nodes and 600 elements for the external casing. It should be noticed that only a portion of the active length of the generator has been modeled; the effect of the remaining part has been simulated by applying a symmetry boundary condition on the cut plane (see fig. 1). The length of the active part of the machine that need to be modeled has been calculated by varying it and comparing the air gap radial magnetic at rated load with the same quantity obtained by a 2D FE model. Such a 2D model has been thoroughly assessed by comparisons with terminal measurements. Despite the above mentioned simplification of the teeth profile, an excellent agreement has been obtained between the air gap radial magnetic flux density computed in 3D with the 2D model [12].

(a) (b) (c)

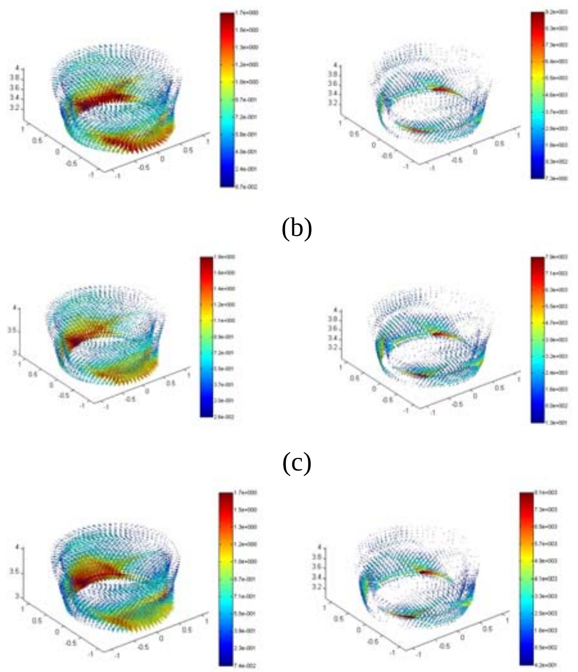

Fig. 2. Flux density distribution in the end windings (left) and forces (right) for various stator and rotor MMF relative position: (a) aligned, (b) quadrature, (c) opposition

A worst case analysis has been performed in the evaluation of the electrodynamic stress on the stator end windings. A three phase short circuit transient has been simulated by using a lumped parameters model, then the computed field and armature currents have been applied in the 3D FE (integral formulation) model. For the sake of simplicity massive rotor iron (including the rotor end winding retaining ring) and damper reaction have been neglected. Furthermore during the transient the rotor oscillates, therefore several relative positions between rotor and stator magnetomotive force (MMF) space vectors have been examined (see fig. 2).

In such a way the end winding magnetic flux density distribution and, consequently, magnetic forces can be calculate by using a non linear magnetostatic approach.

Finally a sketch of the filamentary mechanical model is shown in fig. 3.

III. Conclusion

A technique based on an integral formulation of the non-linear magnetostatic equation to compute stator end winding forces on large turbine generators with high space and time resolution is proposed in this paper. By using those forces as input for a stress analysis a three dimensional magnetostructural tool have been developed. Comparison with terminal measurements assesses the correctness of the electromagnetic computation. The described tool appears to be very useful one in the modern design of large turbine generators.

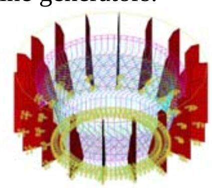

Fig. 3. Stator end winding FE mechanical model

IV. References

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