Axi-periodic analysis for end region of large turbine generator

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***Abstract*-- Axi-periodic analysis for end region of large turbine generator is developed and verified by 3D FEA in this paper. Flux distributions in stator end region, eddy current loss in flux shield for load conditions, and force distributions in stator coil region are estimated. In addition, current distribution in end windings are studied and applied. With developed analysis method, the field analysis of end region of large turbine generator will be rapidly performed with precise results and can be practically applied to the design of stator end region of large turbine generator.**

I. Introduction

In large turbine generator, the flux saturation in the stator end region is the major design limitation of capacity of large turbine generator due to the thermal effect caused by eddy current. Therefore, for the design minimizing thermal damages, field analysis on the stator end region is essential, and this leads to the several times of field analysis on the end region. In addition, transient force distribution on the end winding is also important design factor to design the supporting structure of end winding and this force is calculated by the field distribution and current distribution.

As a quasi-3dimensional analysis, axi-periodic analysis method is introduced and developed in [1-3]. The results from previous paper are verified only by measurements in some regions of end region, because measurement of flux density in the end region is limited in practical aspects. Therefore, 3-dimensional flux distribution in end region of large turbine generator is studied by 3D FEA and axi-periodic analysis is verified by 3D FEA in this paper.

Current distribution in the end windings are studied and applied to the axi-periodic anlaysis. Magnetic vector potential is used as a field variables and force distribution on the end windings and eddy current loss in the flux shield are calculated in this paper.

II. Analysis Theory

A. Axi-periodic analysis

In order to apply the finite element method to an axi-periodic model, following assumptions are made:[3]

a) Slot effects are not considered
b) Displacement current is ignored.
c) Magnetic material is isotropic with infinite permeability.
d) The analysis model is axi-symmetric.

Current density in rotor and stator windings are assumed to be consist of axial and circumferential components in cylindrical coordinates and to be sinusoidal along axial and circumstantial directions.[1]

B. Formulations

Governing equations using vector potential for time harmonic field are (1) and (2). Currents distributions in end windings are assumed to be sinusoidal and current phase angle of top and bottom coils are off phase.

$$\nabla \times (\nu \nabla \times \vec{A}) = -\sigma\left(\frac{\partial \vec{A}}{\partial t} + \nabla\phi\right) + \vec{J}_o \quad (1)$$

$$\nabla \cdot \left(\sigma \frac{\partial \vec{A}}{\partial t} + \sigma \nabla \phi\right) = 0 \quad (2)$$

where, ν, $\vec{A}$, σ, ϕ, and $\vec{J}_o$ is magnetic reluctivity, magnetic vector potential, conductivity, electric scalar potential, and current density respectively.

Shape function and weighting function for Galerkin method are (3) and (4) respectively.

$$N_k^*(r,\theta,z) = N_k(r,z)e^{jp\theta} \quad (3)$$

$$N_i(r,z)\, e^{jp\theta} \quad (4)$$

C. *Eddy current loss in flux shield*

Eddy current loss at the flux shield is calculated using (5), where, p_e^k, k, J_e^k, and σ^k are the eddy current loss in flux shield, harmonic order, eddy current density, conductivity in flux shield respectively. Only fundamental component of eddy current density is considered, and it is proved that high order harmonics do not affect to total eddy current loss of flux shield significantly in this paper.[4]

$$p_e^k = \frac{1}{2}\mathrm{Re}\left[\int_v \frac{J_e^k \cdot J_e^{k*}}{\sigma^k}\right] \qquad P_e = \sum_k p_e^k \ \mathrm{[W]} \quad (5)$$

D. Force density in stator windings

Time varying force on the stator windings is another important design consideration. Force distribution in stator end windings using vector potential is calculated straightforwardly by (6).

$$\vec{f}^k = \vec{J}^k \times \vec{B}^k \text{ [N/m}^3\text{]} \quad (6)$$

where, $\vec{f}^k, \vec{J}^k$, and $\vec{B}^k$ are force density in end winding, current density, and flux density in end winding respectively.

III. Analysis model and results

A. Analysis model

In Fig.1, the analysis models for axi-periodic analysis and 3D FEA are shown. From the study of current distribution in stator windings, it is proved that currents in top and bottom coils have phase difference and this is applied to the analysis model. Commercial software, Flux-3D, is used for 3D FEA, and axi-periodic formulations are coded.

B. Analysis results

Three components of flux density, B_r, B_θ, and B_z from axi-periodic analysis and 3D FEA are compared in Fig. 2. Flux distribution from axi-periodic analysis and eddy current loss in flux shield for load conditions and are shown in Fig. 3.

In Fig. 2, the comparison agrees well in the case of B_r and B_z, however, there are big differences considering B_θ. It is expected that the difference be caused by the fact that circumferential component of current in end windings is not considered. From the comparison, it can be said that 3 dimensional flux distributions in end region of large turbine generator are well demonstrated by axi-periodic analysis.

IV. Conclusions

Axi-periodic analysis for field analysis of end region in large turbine generator is developed and verified by 3D FEA in this paper. Flux distributions in the stator end and winding region and eddy current loss according to load conditions in flux shield, and force distributions in end windings are calculated. Circumferential component of currents will be considered to the following study.

References

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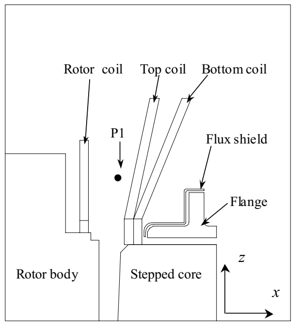
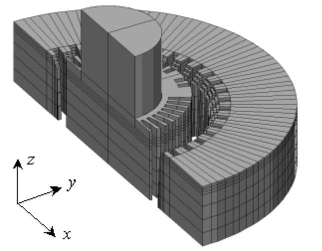
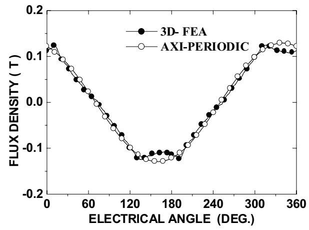


(a) Axi-periodic analysis model

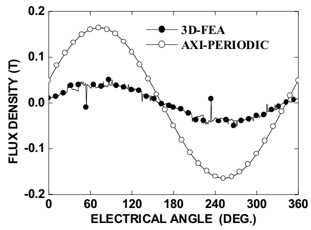


(b) 3D FEA model

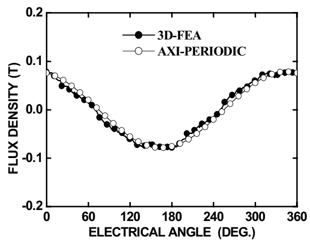
Fig. 1 Axi-periodic analysis and 3D FEA analysis model



(a) B_r at P1

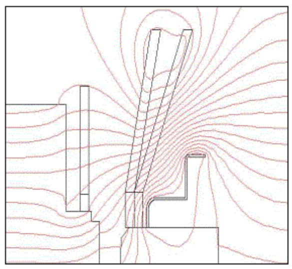


(b) B_θ at P1

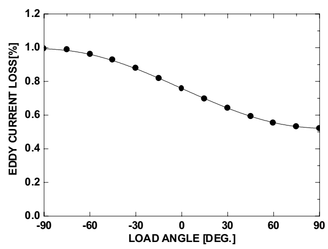


(c) B_z at P1

Fig. 2 Comparison of flux density from axi-periodic analysis and 3D FEA.



(a) Flux distribution from axi-periodic analysis



(b) Eddy current loss in flux shield according to load conditions

Fig. 3 Flux distribution and eddy current loss in flux shield for load conditions