Turbogenerator Electromagnetic Analysis with Changing Reactive Load

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Introduction

In electrical networks with renewable energy sources, conventional generating equipment is periodically switched to reactive power compensation or underexcitation modes to ensure stable operation of the power system.

The underexcitation modes are permissible in accordance with the typical P-Q capability diagram of IEC 60034-3 standard.

The purpose of this paper is to conduct a comparative analysis of the electromagnetic state of a high power turbogenerator end zone, as well as a comparative analysis of the turbogenerator overload capacity when varying operating modes from rated conditions to underexcitation mode.

Electromagnetic analysis

A. Magnetic field in the turbogenerator end zone

When calculating the end-zone field, the rotating magnetic field method was used. Analytical representation of rotating waves of field sources with homogeneous or periodic electromagnetic characteristics of the machine design allows obtaining the results of field calculation also in the form of a superposition of rotating waves:

\[ X_{r,v,\varphi,z}(t) = X_{r,v}\exp(i\omega t) \]

where \( X_{r,v,\varphi,z} \) - complex amplitude, \( v \) - harmonic number, \( \varphi \) - initial phase.

For rotating fields, the three-dimensional magnetic scalar potential, taking into account the results of differentiation with respect to a direction of rotation \( '\varphi' \), is expressed in terms of two-dimensional operators in plane \( \varphi,z \):

\[ \nabla \phi_{r,\varphi,z} = \frac{\omega^2 r^2}{c^2} \nabla \phi_{r,\varphi,z} + \frac{1}{c^2} \frac{\partial \phi_{r,\varphi,z}}{\partial \varphi} \]

where \( \phi_{r,\varphi,z} \) is the amplitude of the vector-valued function of the current, \( \mu \) is the magnetic permeability of the medium.

Numerical calculations derived the distribution of electromagnetic fields, eddy currents, additional losses and electromagnetic forces in the structural components of the end zone of a high power turbogenerator, including the stator winding, end packages of the stator core, pressure plates, electromagnetic shields, ventilation screens, and the generator housing.

B. End zone in underexcitation mode

In the underexcitation mode, a significant increase in losses and electromagnetic forces was obtained in the end core packages, the pressure plate and the shield of the turbogenerator end zone, associated with an increase in the axial component magnetic field in this mode.

At the same time, when the magnetic flux is drawn into the stator core end, there is a slight decrease in losses in the ventilation screen of the turbogenerator.

Increased losses and heating are common to the shield uncovered teeth and slot bottoms of the stator end packages. An appropriate margin shall be provided by the cooling system and the design arrangement of the turbogenerator end zone, including a stepped bevel and slotting of the teeth and the slots bottom of the stator end packages, also by reducing the thickness of these packages. To increase the performance reliability of the stator end zone, the segments of the core end packages are glued together.

C. Static overload

In rated conditions, the static overload capacity \( \alpha_s \) is determined by the ratio of the maximum \( P_{max} \) and rated \( P_r \) active powers and is expressed in terms of the load angle \( \theta \) between the rated excitation electromagnetic force vector \( E_r \) and the voltage of the n-phase machine \( \phi_{n} \):

\[ \alpha_s = P_{max} / P_r = 1 / \sin \theta \]

Static overload capacity with changing reactive power and maintaining active power, rated voltage and frequency changes proportionally to the excitation current and is related to static overload capacity for rated conditions (3) by formula (4):

\[ s = (\sqrt{1 - \cos \phi} / \cos^2 \phi) \]

where \( (\sqrt{1 - \cos \phi}) \) is the ratio of excitation currents and power factors in this mode and at rated load, \( \phi \) is the load angle in this mode.

In the underexcitation mode, the static overload factor decreases to values close to unity, and the load angle approaches 90 degrees, that is, this mode lacks stability margin for synchronous operation.

References