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Turbogenerator Electromagnetic Analysis with Changing Reactive Load

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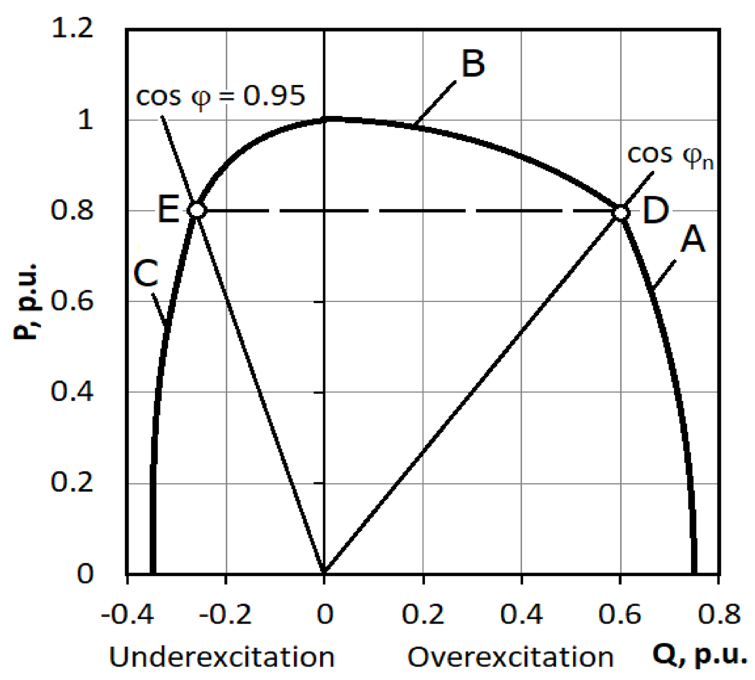
Introduction

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 comparative analysis of the turbogenerator overload capacity when varying operating modes from rated conditions to underexcitation mode.



Turbogenerator P-Q diagram in overexcitation and underexcitation modes

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 allowed obtaining the results of field calculation also in the form of a superposition of rotating waves:

$$X(r,\varphi,z,t) = X_m(r,z)\cdot \exp[j\cdot(\omega\cdot t - v\cdot\varphi + \phi_x)], \quad (1)$$

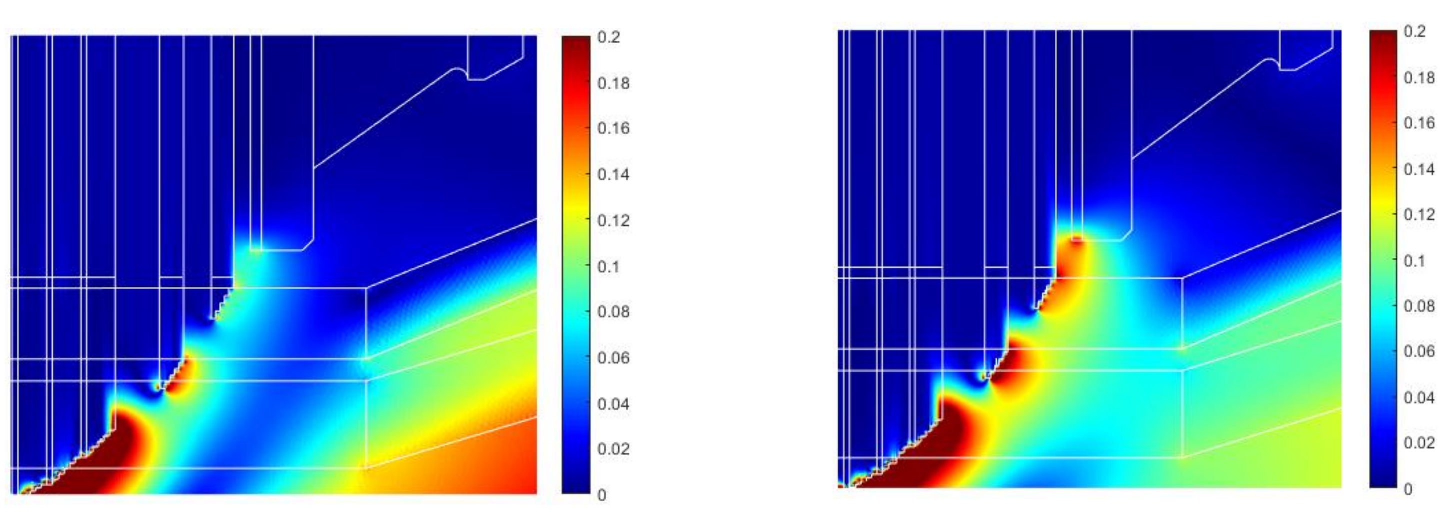
where $X_m(r,z)$ – complex amplitude, v – harmonic number, ϕ_x – initial phase.

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

$$div_2\,\mu\cdot grad_2 U_m - (v^2/r^2)\cdot\mu\cdot U_m = div_2\,\mu\cdot H_{0m}, \quad (2)$$

where H_{0m} is the amplitude of the vector-valued function of the current, μ 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.



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Axial magnetic field component in the turbogenerator end zone at rated load (a) and at underexcitation (b)

Based on the results of numerical calculations, the effect of a change reactive load on electromagnetic processes in the turbogenerator end zone was analyzed at a unchanged active load.

In the underexcitation mode, a significant increase in the axial component of the resulting magnetic field in this mode was obtained.

Conclusion

Analysis showed that the operation of powerful turbogenerators in underexcitation mode results in increased electromagnetic, thermal, and mechanical loads of structural elements of the end zone of turbogenerators, increasing by 1.5–3 times compared with the rated load mode and resulting in the reduction of the operating life of turbine generators.

On the other hand, the lack of static overload margin of turbogenerators in this mode reduces the reliability of the power system.

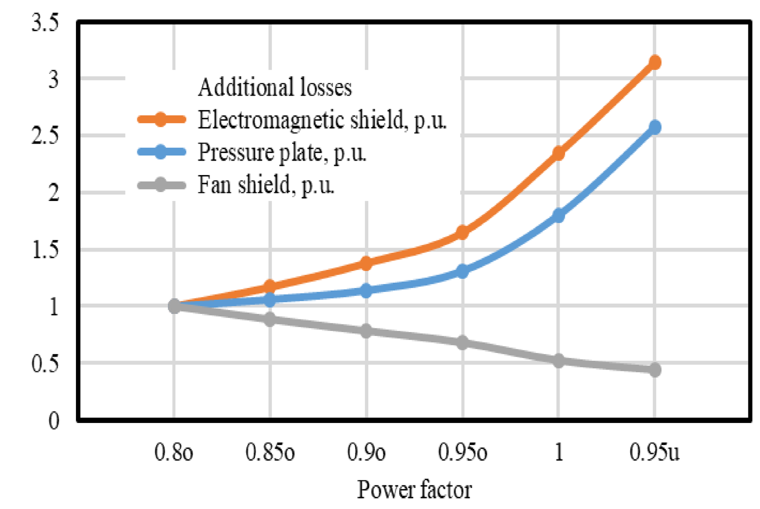
In this regard, it is advisable to limit the operation of conventional turbogenerators in reactive power consumption modes.

To consume reactive power in the network, it is reasonable to use static or electromechanical compensators.

B. End zone in underexcitation mode

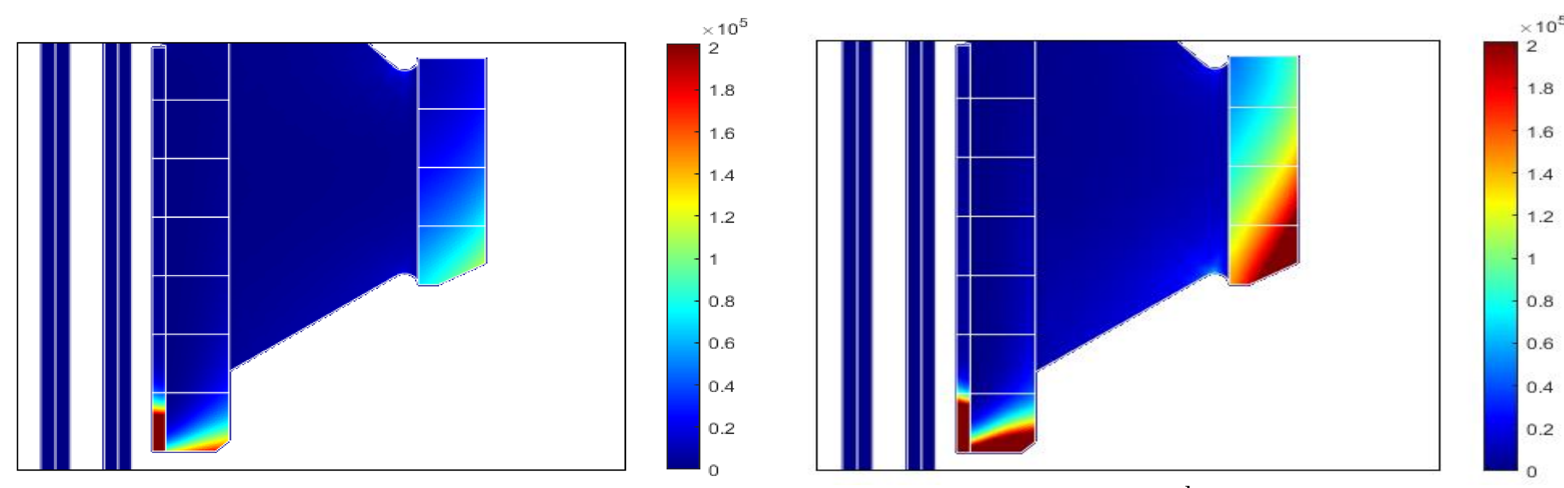
In the underexcitation mode, a significant increase in losses and electromagnetic forces was obtained in the end core packages, the pressure plate and the shield of the turbogenerator end zone, associated with an increase in the axial component magnetic field in this mode.

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.



Total additional losses in the turbogenerator end zone structural elements, as function of changing reactive load

Eddy currents in the electromagnetic shield and pressure plate protect the stator core from axial magnetic field component. Additional losses depend on the operating mode.



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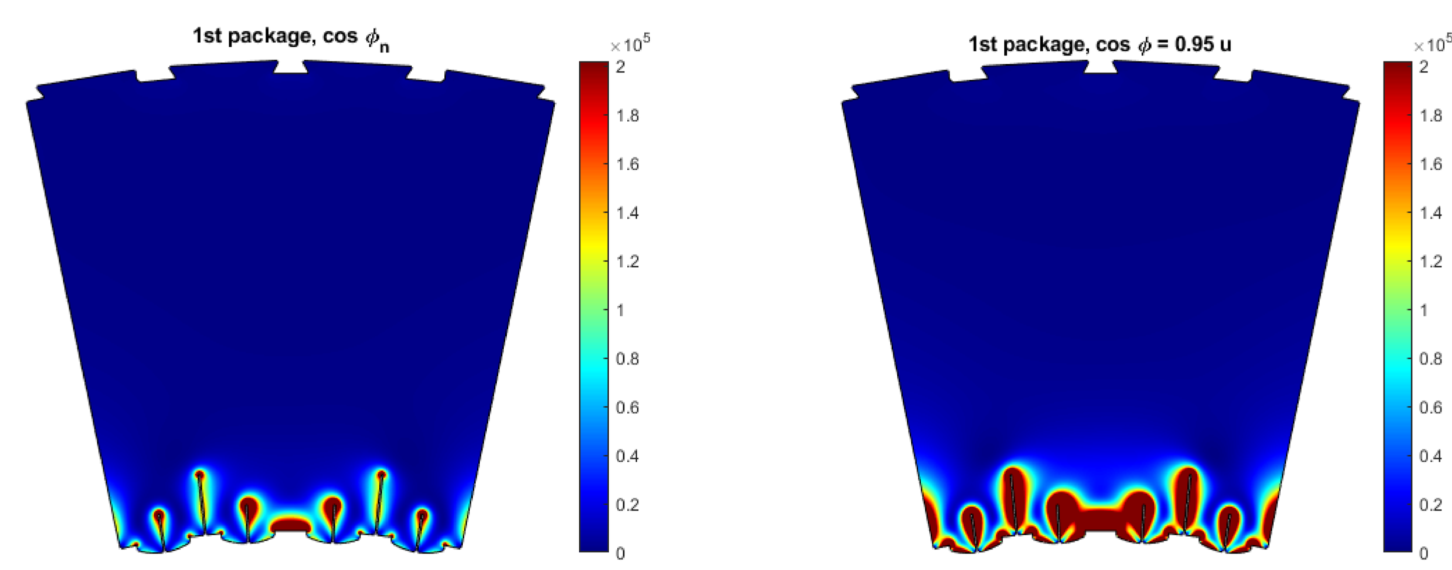
Distribution of losses in the section of the pressure plate and the shield of the turbogenerator end zone at rated load (a) and underexcitation (b)



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Distribution of losses in the stator core end package of the turbogenerator at rated load (a) and underexcitation (b)

Increased losses and heating are common to the by 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 s_n is determined by the ratio of the maximum P_{mn} and rated P_n active powers and is expressed in terms of the load angle Θ_n between the rated excitation electromotive force vector E_{fn} and the voltage of the m-phase machine U_n.

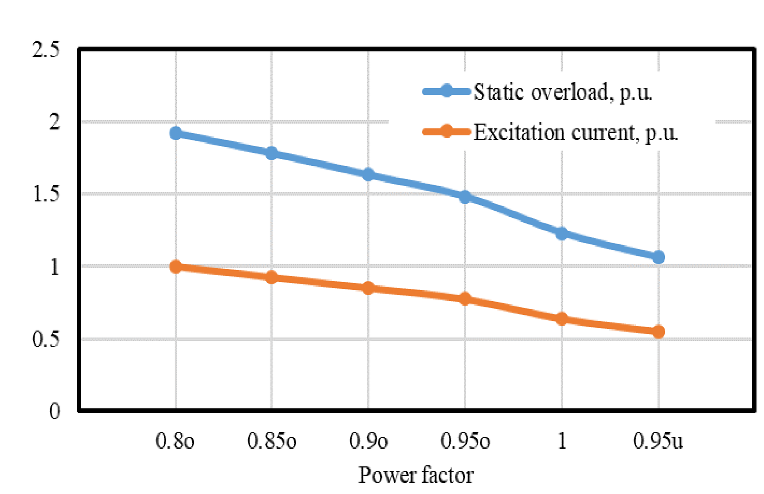
$$s_n = P_{mn} / P_n = 1 / \sin\Theta_n, \quad (3)$$

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):

$$s = (i_f / i_{fn})\cdot(\cos\varphi / \cos\varphi_n)\, s_n = 1 / \sin\Theta, \quad (4)$$

where (i_f / i_{fn}), $(\cos\varphi / \cos\varphi_n)$ is the ratio of excitation currents and power factors in this mode and at rated load, Θ 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.



Excitation current and static overload as function of reactive load

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