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TORSIONAL TORQUES IN TURBINE-GENERATOR SHAFTS DURING DISTURBANCES

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Calculations of torsional torque values can be useful for finding out a reason for shaft damage.

The mechanical data of turbines and a generator of 1000 MW reference unit, working at overcritical parameters, were established. Using the modal method, the characteristic frequencies of torsional oscillations in shafts of rotating masses were calculated. The values of torsional torques in shafts which can arise during faults in electrical networks, like close distance short-circuits, the action of automatic reclosing, synchronization, as well influence of electromagnetic torques from the network side causing the resonance oscillations of unit were investigated.

Introduction. Planned in nearest future implementation of 1000 MW unit working with overcritical parameters (program 50+) into the National Power System poses new problems in the area of cooperation between the unit and the power system [1].

The issues of the rotating set of turbines and generator masses modeling are presented. The aim of the modeling is to calculate torsional torques in shafts between the individual masses during faults appearing in the power network. Calculations were performed using the EMTP/ATP program.

The elements of the turbine - generator unit are connected with shafts (Fig. 1), with limited mechanical endurance which can be exceeded during some faults.

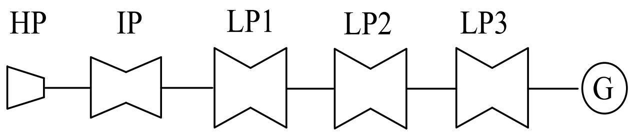

Figure1 - Structure of 1000 MW reference unit

The EMTP/ATP [2] program enables us to simulate dynamics of the synchronous generator with any number of turbines fixed on the common shaft. The mechanical system is considered as linear, therefore spring-connected rotating masses can be described by the second Newton law:

$$\mathbf{J} \cdot \frac{d^2}{dt^2} д + \mathbf{D} \cdot \frac{d}{dt} д + \mathbf{K} \cdot д = \mathbf{T}_{turb} - \mathbf{T}_{gen} \qquad (1)$$

where: д - angular positions,

J - moments of inertia,

D - damping coefficients,

K - stiffness coefficients of shafts between rotating masses,

$\mathbf{T}_{turb}$ - torques applied to turbines,

$\mathbf{T}_{gen}$ - electromagnetic torque of a generator.

To determine the expected mechanical data of a similar power unit, the review of literature describing these problems was presented. On the basis of many publications, for example [3÷7], the mechanical parameters of units were established.

Parameters of the 1000 MW referent unit were set as: **Inertia constants** (p.u.*s): HP=0.17, IP=0.4, LP1=0.6, LP2=0.6, LP3=0.6, GEN=0.8, **Stiffness coefficients** (p.u./rad): HP-IP=150, IP-LP1=200, LP1-LP2=250, LP2-LP3=300, LP3-GEN=350.

Using the transformation modal matrix **Q** with columns being eigenvectors of expression $\mathbf{J}^{-1} \cdot \mathbf{K}$, the equation (1) can be transformed to the modal formula. Its solution enables to find the modal frequencies of system oscillations [2, 3, 5]. For the considered unit these frequencies are: **f** = [1.44 13.37 23.77 32.98 38.17 44.9] Hz.

Calculations of torsional torques. Influence of network on generator rotor. Susceptibility of rotating masses to the influence of a disturbing signal with the close to natural frequency was examined. Such a disturbance can come from the network side as the generator current with this frequency component. More and more power electronic devices in the network encourage to such a situation. The modeled generator-transformer-line unit power lead is shown in Fig. 2.

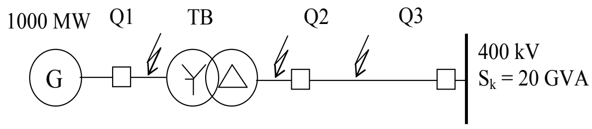

Figure 2 - Scheme of the generator - transformer unit for calculations of mechanical shaft torques during selected faults

Fig. 3 presents the dependence of maximal values of torsional torques T_i (related to nominal torques of shafts) in individual shafts on frequency of the sinusoidal external input torque with amplitude 1% of nominal electromagnetic torque T_{n_gen}, affecting on the generator rotor.

It should be noticed that even this small effect of the network disturbance on the rotor at some resonance frequencies results in the torsional torques exceeding nominal values for these shafts.

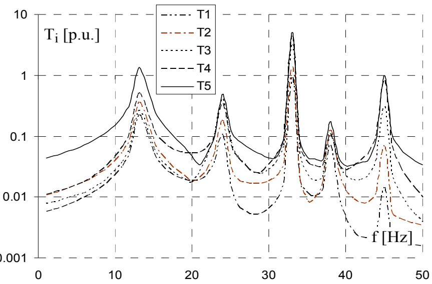

Figure 3 - Dependence of maximal values of torsional torques in individual shafts on frequency of the sinusoidal external input torque with amplitude 1% T_{n_gen}, affecting a generator rotor

Short-circuits in power network. Fig. 4 presents the maximal values of torques in shafts of the rotating unit at some faults in the network:

- 3-phase short-circuit on generator voltage bus bars for a rated loaded (A) and unloaded generator (B).
- 3-phase short-circuit on HV side of the unit transformer for a rated loaded generator (C) and unloaded generator (D).
- 1-phase short-circuit in 400 kV unit line. 1-phase effective automatic reclosing with time 0.4 s (E).

The calculations show that values of torques significantly exceed permissible limits.

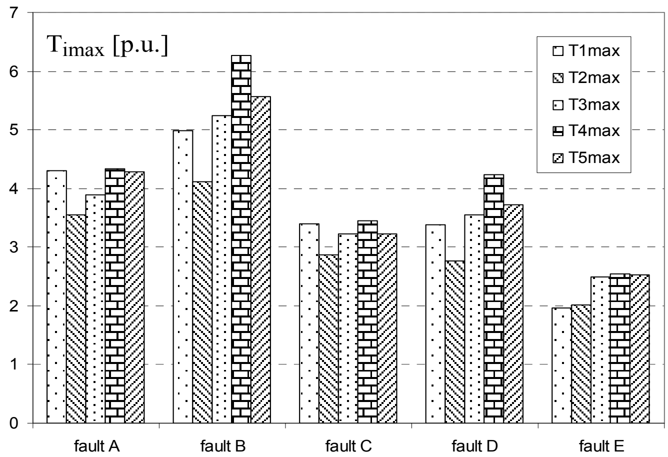

Figure 4 - The maximal values of torques in shafts of the rotating unit at some short-circuits close to generator

The calculations of torsional torques in the turbines -generator unit while carrying out the generator synchronization using a generator breaker Q1 were made. The analysis was performed for the difference in frequencies of the generator and the network $\Delta f = 0.1$ Hz and for differences $\Delta\varphi$ of voltage phases in the range 0°÷180°. The dependence of maximal torque values on differences $\Delta\varphi$ of voltage phases during synchronization is presented in Fig. 5.

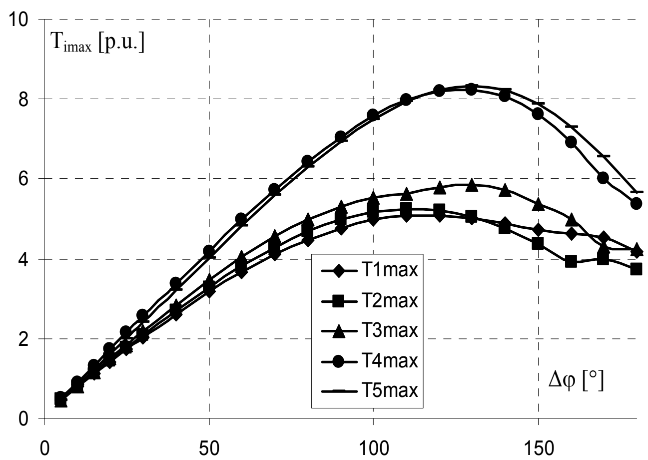

Figure 5 - Dependence of maximal torque values on differences $\Delta\varphi$ of voltage phases during synchronization

The results of the analysis indicate that for the studied unit the maximal values of torques for individual shafts appear at synchronization with the difference $\Delta\varphi$ of voltage phases in the range 110°÷130°.

Calculation of shaft fatigue. The degree of the shaft fatigue caused by the torsional oscillations depends on the amplitude of torsional stress and the number of oscillations. The number of oscillations is influenced by the level of oscillations damping. Figure 6 shows an example of the curves for determining the fatigue caused by torsional oscillations [8].

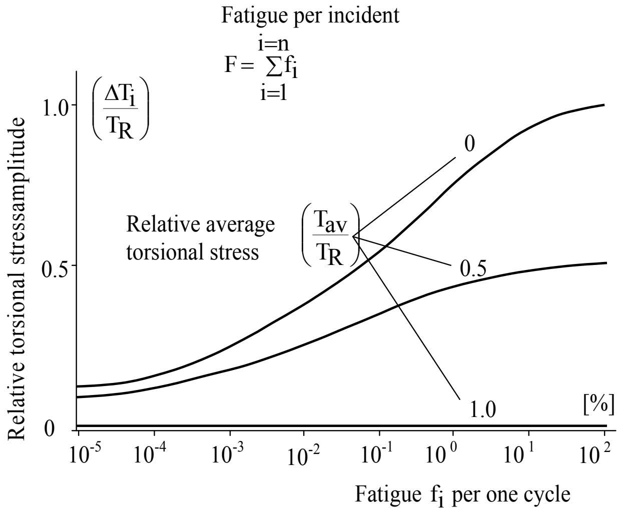

Figure 6 - Example of the curves for determining the fatigue caused by torsional oscillations [8]

This Figure allows to read the value of fatigue f_i [%] caused by one swing (horizontal axis) in relation to the value of the relative torsional stress amplitude ΔT_i / T_R (vertical axis). The value f_i can be read on the curve corresponding to the relative average torsional stress T_{av}/T_R. T_R is the rupture stress causing the destruction of the material, T_{av} means average stress (constant component) and ΔT_i means amplitude of an alternating component of torsional stress.

Conclusions. Calculations of system turbines and generator natural frequencies of oscillation are an important element of the shaft designing process. They allow to avoid working of the unit in conditions of hazard of arising oscillations caused by external influences.

Calculations of torsional torque values can be useful for finding out a reason for shaft damage, applying preventing means and for determining exploitation rules for unit work.

The studied cases of short-circuits, synchronization and the effect of external electromagnetic torque with resonance frequency on a generator rotor were characterized by high values of torsional torques exceeding the permissible values.

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Аннотация

ВЛИЯНИЕ КРУТЯЩЕГО МОМЕНТА НА СОСТОЯНИЕ ВАЛА ТУРБОГЕНЕРАТОРА

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Проведен расчёт крутячих моментов на валу турбогенератора позволяющий выявлять причины его неисправностей.

Анотація

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