THE STUDY AND PREVENTION OF ELECTRO-MECHANICAL MODES OF RESONANCE IN POWER SYSTEMS WITH DISTRIBUTED GENERATION

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The relevance of research. In electrical networks, especially recently, the share of the nonlinear load that is a source of distortion of the voltage and current curves has increased significantly, more and more reactive elements appear (capasitor batteries, reactors, etc.). These trends significantly increase the probability of occurrence of resonant interactions both at frequencies greater than the nominal and less. For electric power systems with distributed generation, the problem of electromechanical resonance at the subsynchronous frequencies, the cause of which is the resonant interaction of the mechanical part of the turbine with the electric oscillatory circuit formed by the reactive elements of the capacitive and inductive type network, is rather actual. These modes are characterized by the appearance of vibrations in turbogenerators at certain frequencies causing the protection against vibration and further disabling of the generator. This leads to a stop of the technological process and accelerated wear of the moving parts of the turbogenerator.

The occurrence of Electromechanical resonance in the real power systems

Time traces were obtained for the gas turbine power station in power system in the north of the Tyumen region in Russia at 2014 year.

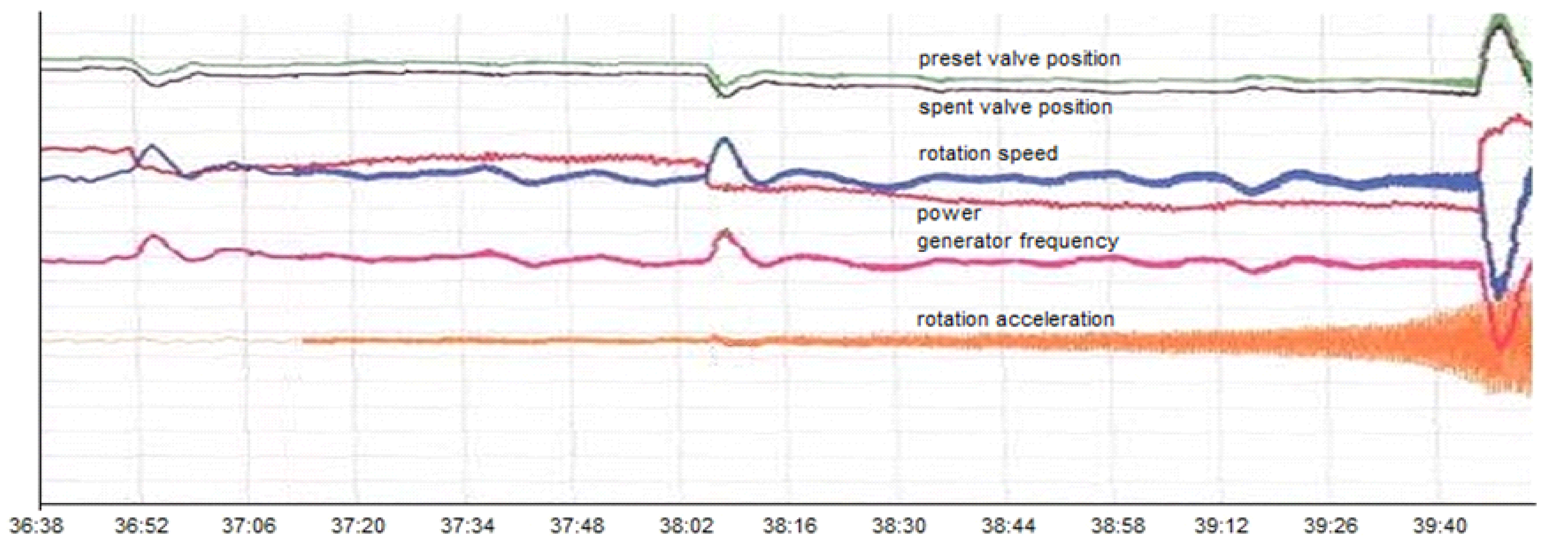

Fig.1. Time traces of different parameters during accident on the gas turbine power station

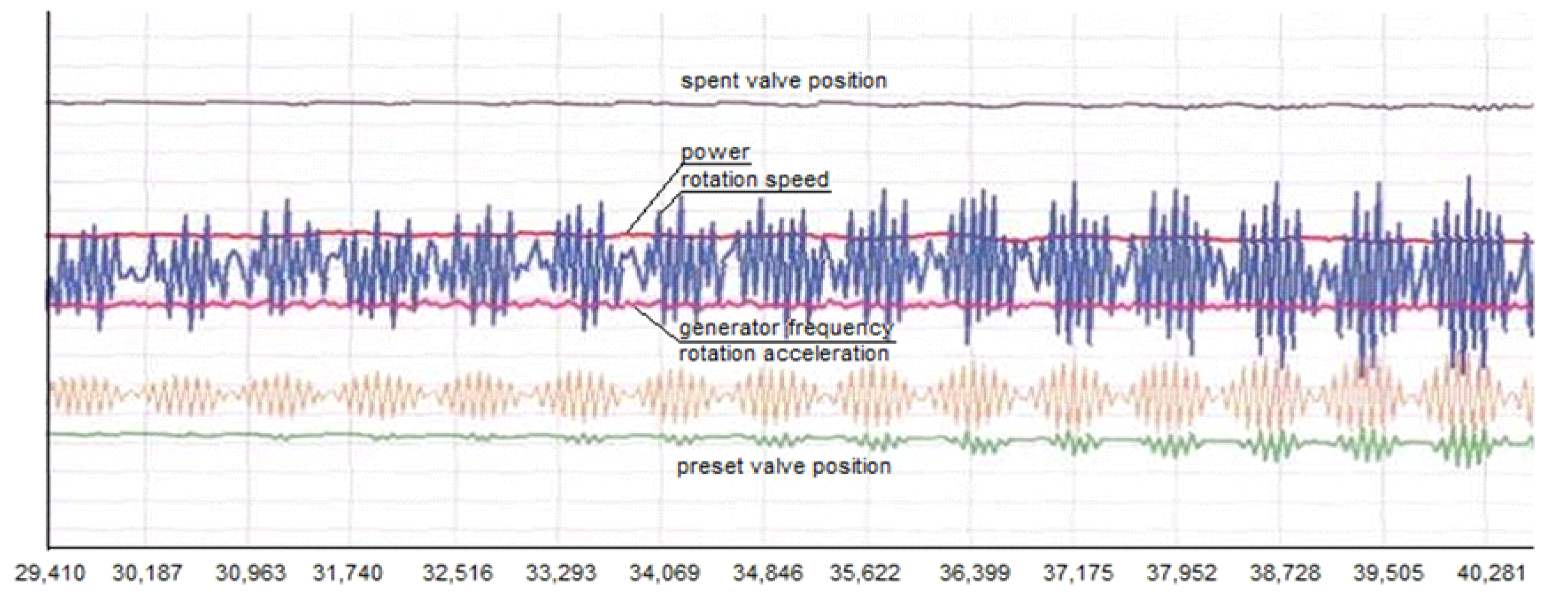

Fig.2. Accident's progress on the gas turbine power station

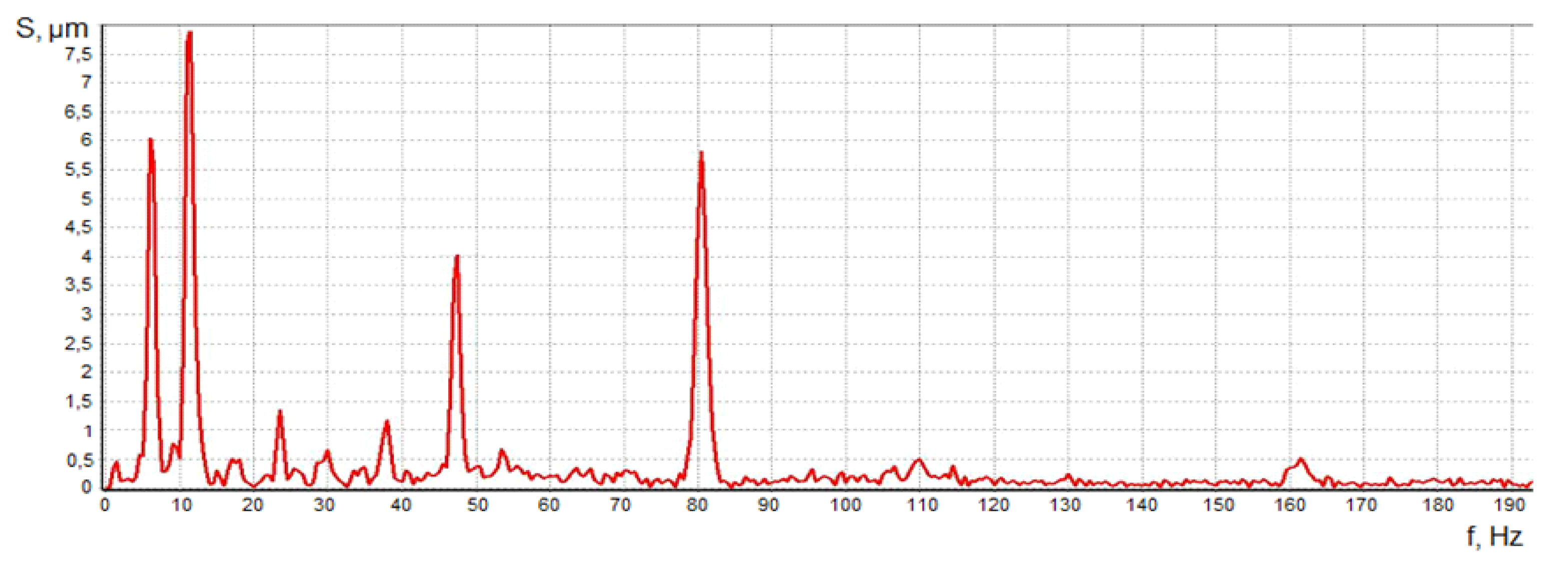

Fig.3. FFT of the gear vibration

It can be seen from the presented figures that the amplitude of the oscillations increases, while the control system was unable to suppress the increase in the amplitude of the oscillations.

Methods of performing the work

In this work, we used methods of numerical integration, bifurcation analysis.

When compiling a mathematical model for the study of electromechanical resonance, it is necessary to take into account both the electrical part and the mechanical one. Equations describing the electrical part of a synchronous turbogenerator are represented as

(1)

where ψ_d , ψ_q – flux linkages of the stator in the direct and quadrature axes;
ψ_f – flux linkage of the field winding;
ψ_{1d} , ..., ψ_{nd} , ψ_{1q} , ..., ψ_{mq} – flux linkages of the n direct and m quadrature damper windings;
i_d, i_q – stator currents in the d-q axes;
i_f – field winding current;
i_{1d} , ..., i_{nd} , i_{1q} , ..., i_{mq} – currents of the n direct and m quadrature damper windings;
r_a – stator resistance;
r_f – field winding resistance;
r_{1d} , ..., r_{nd} , r_{1q} , ..., r_{mq} –resistances of the n direct and m quadrature damper windings;
u_d, u_q – stator voltages in the d-q axes;
u_f – field winding voltage;
M_T – momentum;
T_J – mechanical time constant;
s – motor slip;
δ – angle between q-axis of the rotor and voltage vector of the infinite bus power system;
ω_c – synchronous velocity;
M_e – electromagnetic torque, Me=ψdiq–ψqid;
p – derivation operator, p = d/dt.

Electromechanical resonance is a power system condition, where an electrical network and a turbine rotor have the energy exchange supporting oscillations on one or more frequencies. At the same time the oscillations frequency ω_k interact with the rotation frequency ω_c and form stator voltage components at the frequency $\omega_{er} = \omega_c - \omega_k$. When the stator voltage frequency becomes close to the power system eigenfrequency, the stator current component at this frequency creates electromagnetic moment component sustaining rotor vibrations.

Goals and objectives

To determine values of the power system with distributed generation parameters, which will have modes of electromechanical resonance; to define the settings for the ARV of the generators, preventing the electromechanical resonance.

Description of the work done

In the work, the electric power system with distributed generation was investigated, which is shown in a simplified manner in Fig. 4. Computer modeling of electromechanical resonance modes was carried out, the parameters of the system under which resonance phenomena occur were determined. The action of an ARV generator and its effect on electromechanical resonance modes are considered. The ARV controller settings that prevent electromechanical resonance are determined.

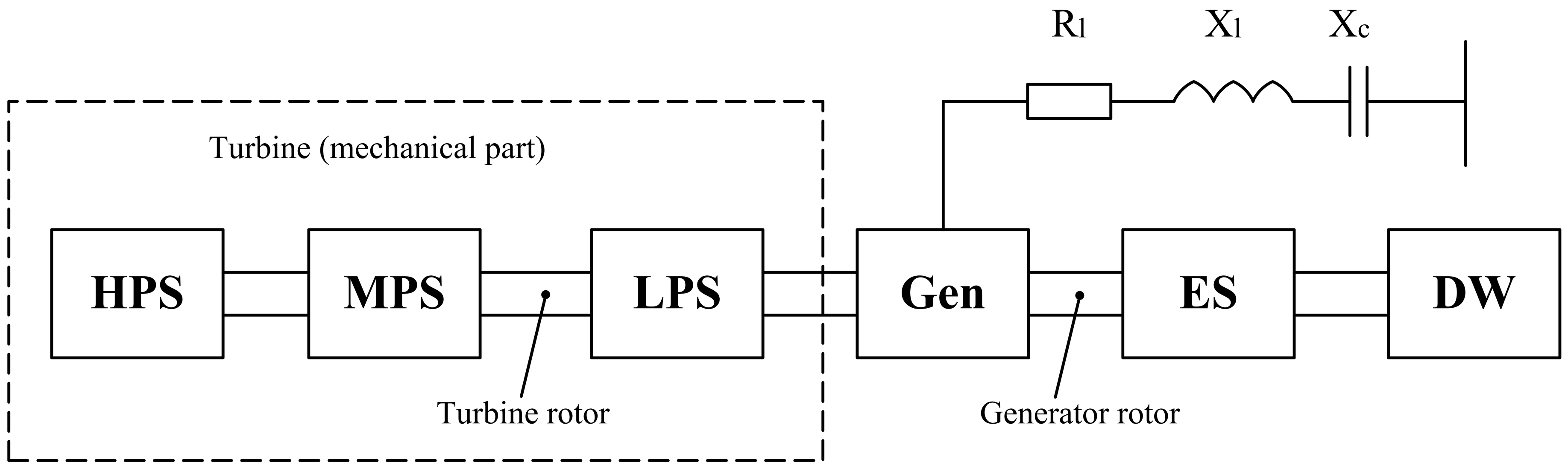

Fig. 4. Power system diagram

In Fig.4. the power system of the turbine - generator – infinite-power bus is presented.

The mechanical part of the power system consists of a turbine with high (HPS), medium (MPS) and low (LPS) pressure stages. The electrical part of the power system consists of a generator (Gen), excitation system (ES), damper winding (DW), power line, longitudinal reactive power compensation system, infinite power buses.

Simulation results

Simulation was performed in the MathCAD package by numerical integration of systems of differential equations (1)

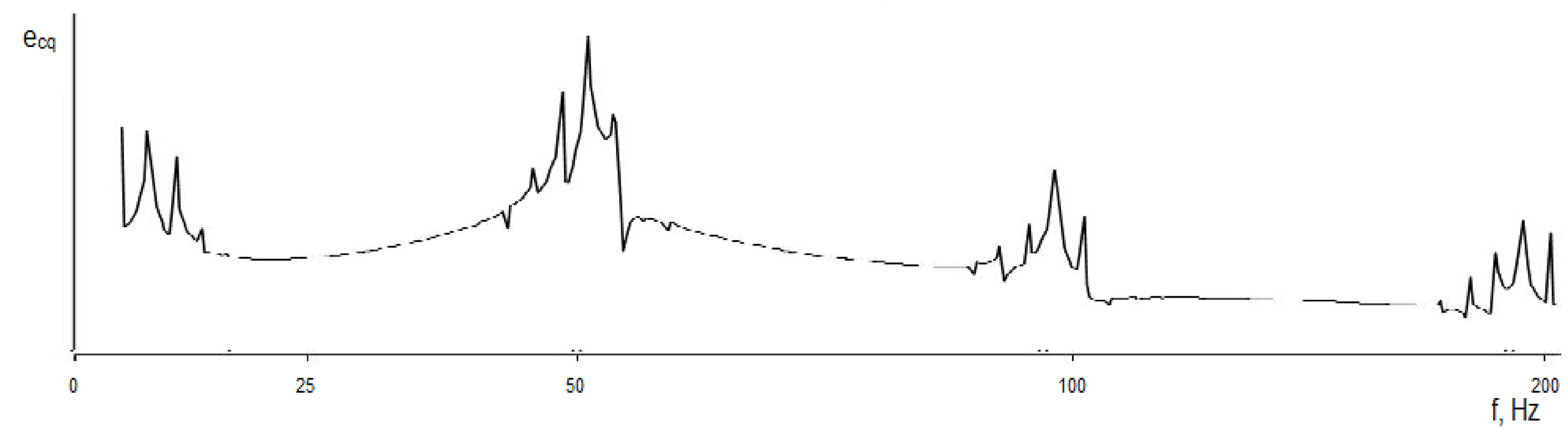

Fig.5. FFT of angular difference between rotor sections

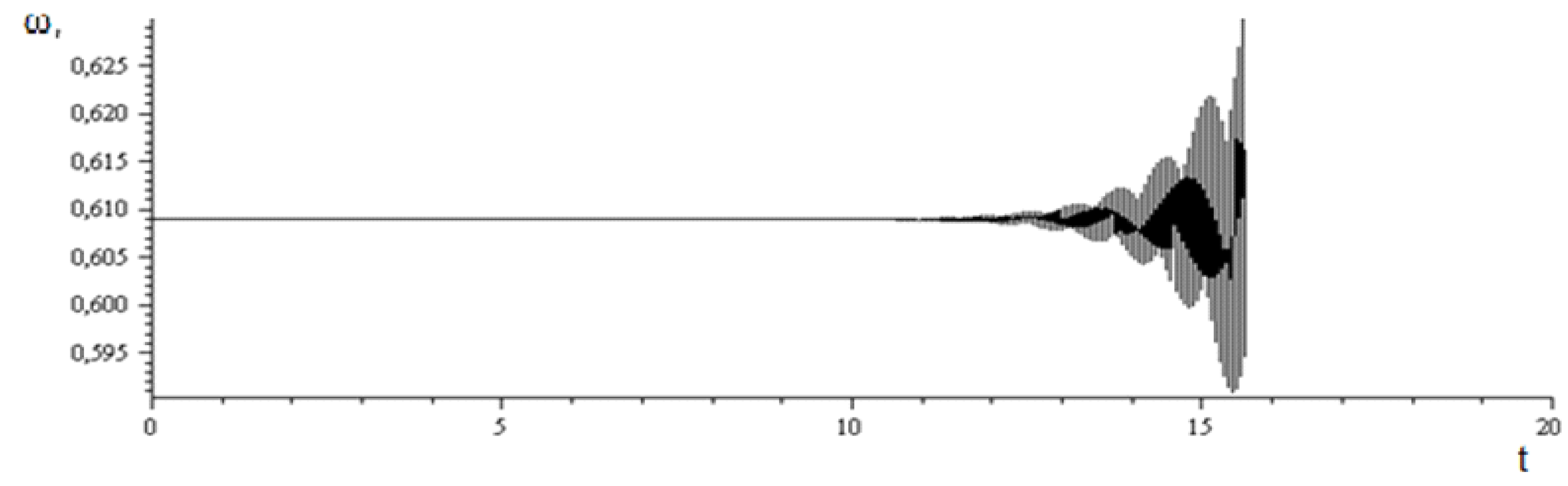

Fig.6. Time variation of rotor speed of generator

In Fig. Figures 5-6 show the results of the system simulation. It is seen from the presented figures that the amplitude of the oscillations increases, while the control system is not taken into account in theoretical calculations. The same thing happens in the real system (Fig. 1). In addition, it is shown that several frequencies arise in the system, on which oscillations occur.

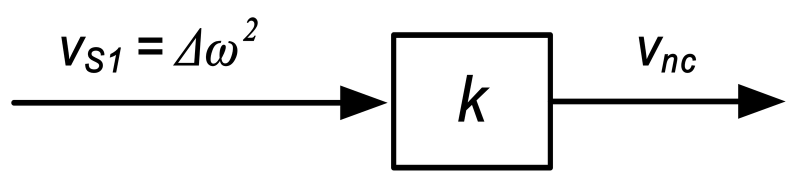

Fig. 7. Simplified circuit of the ARV generator controller

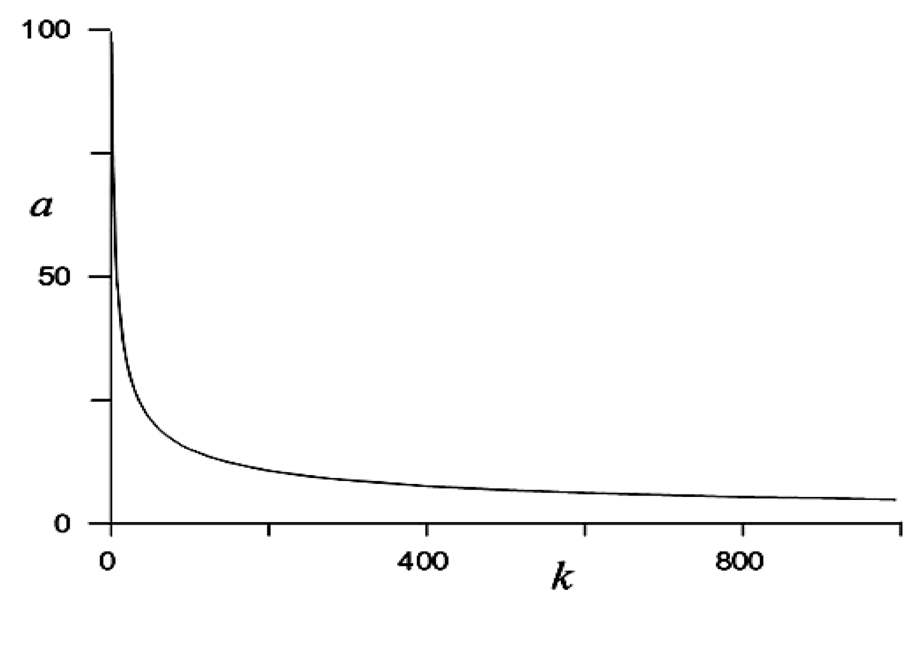

Fig. 8. Dependence of the amplitude *a* of the limit cycle on the gain of the nonlinear controller *k*

Main results

The parameters of the power system with distributed generation are determined, the frequencies at which oscillations in the electromechanical resonance mode occur are specified. The correlation of the gain factor of the nonlinear controller and the amplitude of the limit cycle arising after the Hopf bifurcation is determined. The increase in the gain leads to the suppression of the secondary Hopf bifurcation and, consequently, to the prevention of electromechanical resonance in the power system.

Conclusions

- The research shows that the problem of resonances in electric power systems is quite relevant.
- In the simulation of the power system with distributed generation, the electromechanical resonance modes were considered, and the system parameters at which resonant interactions occur are specified.
- Qualitative coincidence of simulation results and real processes indicates the correctness of the approach to the consideration of electromechanical resonance.
- To suppress the bifurcation and prevent electromechanical resonance, it is highly effective to increase the gain of the controller.

References

1. A.N. Belyaev, S.V. Smolovik, B.T. Kadhem, H.W. Shuhati, Torsional Natural Frequencies and Mode Shapes for Different Turbine-Generator Shaft," IVth International Scientific Symposium Elektroenergetika 2007. Technical University of Kosice, Slovakia.sep. 19-21, 2007-pp.230-234.
2. E.V. Larsen, D.H. Baker, Series Compensation Operating Limits- a New Concept For Subsynchronous Resonance Stability Analysis's," IEEE Transactions on Power Apparatus and Systems, Vol. PAS-99, No.5 Sept/Oct 1980. pp.1855-1863.
3. A.H. Nayfeh, A.M. Harb, C.-M. Chin, A.M.A. Hamdan, L. Mili, Application of Bifurcation Theory to Subsynchronous Resonance in Power Systems, International Journal of Bifurcation and Chaos, 8(1), p. 157–172, 1998.