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Asynchronous turbogenerator with a massive rotor with short-closed copper cells as a natural damper of electromechanical oscillations and a reliable source of Active Power

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ABSTRACT: The article presents the results of a study of electromechanical oscillations of regime parameters caused by external disturbances, based on existing model asynchronous turbo generators (ATG).Oscillograms of electromechanical oscillations were taken under the same conditions, when operating as part of electric power systems of two identical synchronous turbo generators (STG) and during joint operation of STG and ATG with a massive rotor with short-circuited copper cells.

A comparison of the energy performance of model ATG with various designs of massive rotors is made on the basis of their frequency characteristics obtained by the direct current attenuation method.

Changes in the active and reactive resistance of a massive rotor with different designs against slip are considered.

KEYWORDS: frequency response, asynchronous generator, electric power system.

1. INTRODUCTION

In modern electric power systems (ESS), active power sources are exclusively synchronous generators. These EESs are often subjected to various kinds of perturbations, which cause oscillatory processes in them that require their damping.

Vibration damping in existing EPS is carried out mainly by automatic excitation and frequency controllers (AFC), the setting of which is based on determining the common part of the stability zone and selecting gain factors within this zone that meet certain requirements for the quality of the electromechanical transient process [1].

However, in recent years, in developed EPS, the appearance of excitation and frequencies of low-frequency oscillations not damped by regulators in the range f = 0.2-2 Hz, leading to long-term oscillations and the danger of system accidents, has been observed.

The results of the study conducted to date by well-known scientists headed by Academician of the Academy of Sciences of the Republic of Uzbekistan K.R. Allaev showed that ATG without traditional windings on a rotor with stator excitation (ATG with a massive rotor with squirrel-cage copper cells), in addition to ease of manufacture and high operational reliability have natural damping properties, which will allow them to be used more efficiently as sources of active power, which is extremely important for modern EPS, and it has also been established that the introduction of ATG into the composition of electric power systems leads to an increase in their static and dynamic stability in steady state and transient modes [2].

Prospects for the development of EPS create the necessary conditions for the use of ATG as large sources of active power.

II. EXPERIMENTAL PART

Experimental studies to determine the effect of ATG with massive rotors with squirrel-cage copper cages on the electromechanical oscillations of controlled EPS with a sketch of periodic disturbances were carried out on the

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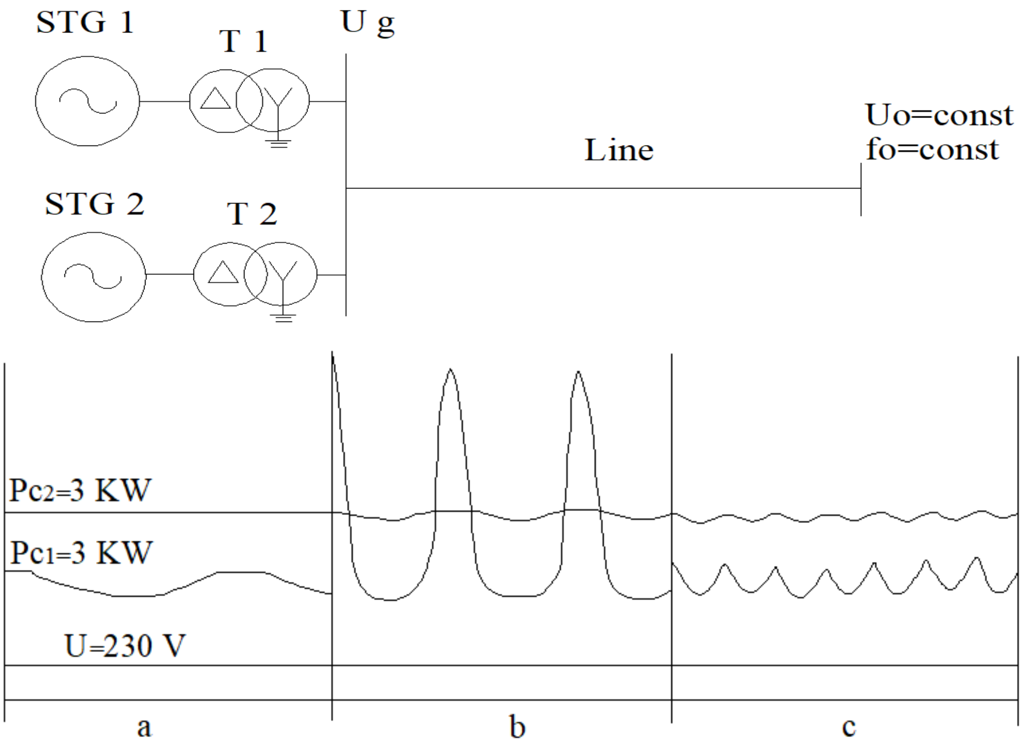
electrodynamic model of the Department of Electrical Networks and Systems of Tashkent State Technical University [3].

In the course of the experiment, near the initial steady state operation of the station, which consists of two STGs, artificially forced periodic oscillations of the transmitted power with different (from 0 to 5 Hz) frequencies were created by creating such oscillations only on one of the STGs. In the course of the experiment, disturbances were applied to the input of the ARV adder c. the same STG from the sensor. The magnitude of the perturbation was determined by the permissible mode of operation of the STG and the desire not to take them out of synchronism [4].

In the second case, the experiment was repeated by replacing one STG with an ATG under the same periodic perturbations. Figure 1 shows the oscillograms of the generator powers: before, during and after resonance in the compared EPS. The transmitted power in both cases was 3 kW.

It has been established that when STG and ATG work together, the amplitude of periodic forced power oscillations before, during and after resonance is much less than with the traditional layout of the power plant, and the resonant frequency becomes higher than in the first case. ATG power fluctuations are in antiphase with STG power, which is positive influences the damping of fluctuations in the parameters of the EPS mode. Figure 1 shows oscillograms of periodic power fluctuations of STG and ATG [5].

Thus, the conducted experimental studies confirmed the theoretical conclusions that the jointly operating STG and ATG are a self-regulating system, the damping of oscillations of the mode parameters of which occurs very intensively.



a) f=0.35 Hz b) f=fres=0.54 Hz c) f=1.67 Hz

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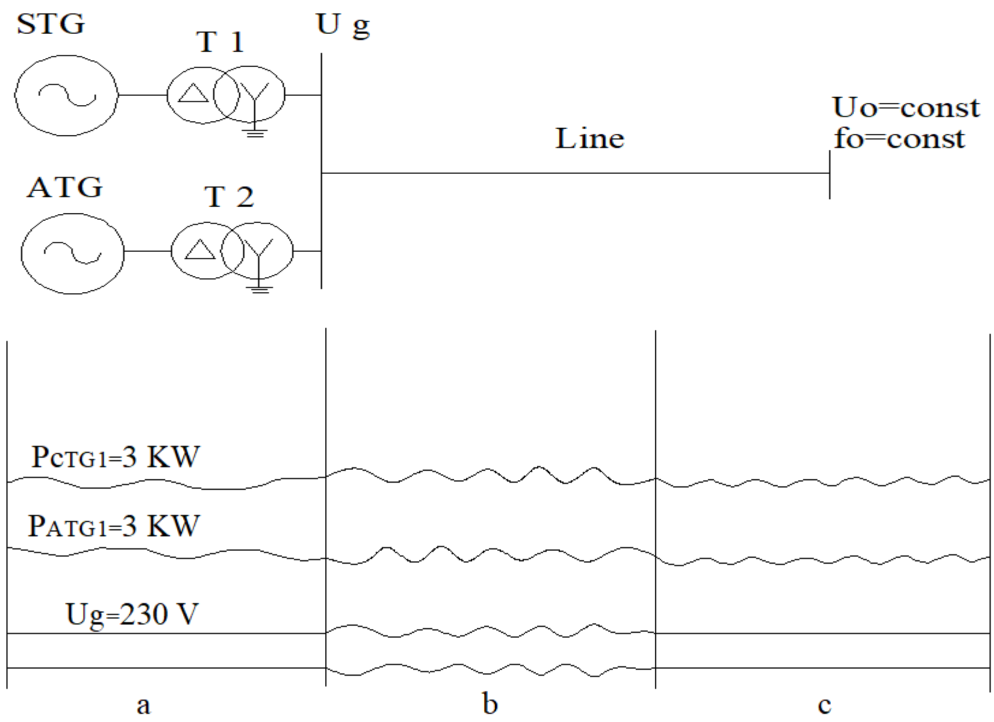

a) f=0.54 Hz b) f=fres=1 Hz c) f=1.8 Hz

Fig.1. Oscillograms of periodic power fluctuations of SG and AG.

In a massive rotor located in a rotating magnetic field, currents will be induced. These currents will flow along the rotor and close at the ends. As is known, in a smooth massive rotor, currents propagate in the surface layer, the depth of which depends on the frequency of the current. The lower the frequency, the greater the depth of penetration of these currents. Thus, with a decrease in slip, the depth of current penetration will increase, and the active resistance of the rotor will decrease. The leakage reactance of the rotor will increase with decreasing slip [6].

As the slip approaches zero, the active and reactive resistances will approach some constant values. The frequency response of rotating machines is a set of steady-state complex values of stator currents when the rotor slip changes from 0 to $+\infty$.

The actual frequency responses are curves that bear little resemblance to the corresponding calculated circles, for the following reasons:

- in large synchronous hydro generators, for example, it is necessary to use a large copper section in the rotor. In this case, there is a strong displacement of the current in the copper of the rotor with an increase in its rotational speed, which sharply distorts the corresponding geometrical place of the stator currents as a function of frequency.

- in synchronous turbogenerators there is a powerful rotor array with a complex pattern of magnetic flux penetration into steel, slot wedges made of non-ferrous metal, etc., therefore, the equivalent circuit of the machine essentially corresponds to the circuit with distributed constants. The equivalent parameters of the generator strongly depend on the slip.

Ensuring the reliable operation of ATG as part of electric power systems should also be based on their refined calculations of steady-state and transient processes [7].

The solution of these problems is possible with the availability of complete information about the electro-magnetic parameters of the ATG in the form of frequency characteristics or complex equivalent equivalent circuits for all its circuits; existing in the form of closed windings or in the form of contours corresponding to the massive parts of the rotor.

The question of their frequency characteristics is of great practical importance for ATGs with massive rotors, where their parameters, as a result of current displacement in the rotor and saturation of the magnetic paths, especially the tooth zone, usually vary over a wide range compared to the parameters of synchronous turbogenerators [8].

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Experimental studies to determine the frequency characteristics of ATG with various massive rotors were also carried out on the electrodynamic model of the Department of Electrical Networks and Systems of Tashkent State Technical University, containing model ATG with massive rotors of the following configurations: smooth, gear and two squirrel-cage rotors with copper rods in the amount of Z2= 48 and Z2=80 pieces.

The frequency characteristics of model ATGs were determined using the method of DC attenuation in the stator windings by oscillography, with a stationary rotor, then bringing them to a rotating one, that is, a method that has become widespread in the study of the frequency characteristics of large rotating machines.

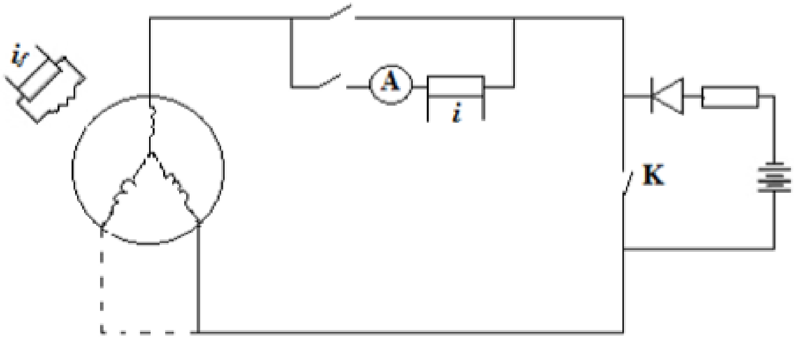

Fig.2. Electric circuit of the experience of attenuation of direct current on a stationary machine.

During the experiment, a DC voltage is applied to the stator windings through active resistance (to two terminals with the third open or to two phases connected in parallel, and to the third in series with them), as shown in Figure 2. When contactor K closes, the winding is short-circuited, and the current starts to drop. The entire transient process is recorded .

The essence of the direct current attenuation method is to use the connection between the set of steady-state modes when supplying the electromagnetic system with voltages of different frequencies (frequency response) and the transient process that takes place in the system when the constant unit voltage is turned off, set by the Fourier transform, similar to the Laplace transform, after replacing it with the last operator p sliding js.

$$Is(js) = l/X(js) = js\int_0^{\infty} i(t)\, e^{-jst}\ dt$$

where: X(js) - complex inductive reactance

The decaying current is approximated by the sum of the exponents;

$$i(t) = i1e^{-\lambda 1t} + i2e^{-\lambda 2t} \dots + ine^{-\lambda nt}$$

where: i1+i2+ i3+…+ in= i0 - initial value of direct current in, λ`n = 1/Tn - initial value and damping coefficient of the n-th exponential component of the experimental damping curve.

In this case, the frequency response is (js) takes the form:

$$is\ (js) = j\ /(r/s + jx\ (js)) = i1\lambda 1\text{'}js/\ (js + \lambda 1\text{'}) + i2\lambda 2\text{'}js/(js+\lambda 2\text{'}) + \dots = a + jb$$

Here: $a = s^2 (i_1\lambda_1\text{'} / (s^2 + (\lambda_1\text{'})^2) + i_2\lambda_2\text{'} / (s^2 + (\lambda_2\text{'})^2) + \dots)$

$b = s\ (i_1(\lambda\text{'})^2\ (s^2 + (\lambda_1\text{'})^2) + i_2\ (\lambda_2\text{'})^2 / (s^2 + (\lambda_2\text{'})^2) + \dots)$

All quantities in the equation are expressed in relative units.

Calculations and graphical constructions of the frequency characteristics of the considered ATG proceeded from the stator current reduced to the rated voltage. The initial value of the reduced stator current, according to the current decay waveform, is 1/r in fractions of the rated stator current, where the DC resistance of the damping circuit r is expressed in fractions of the base stator resistance, i.e. r=0.01125.

It should be noted that the experiments on the attenuation of direct current in the stator of the ATG with various massive rotors were carried out under the same conditions. As a result of the comparison, the damped currents of the ATG with short-circuit rotors had a steep slope in its initial part compared to the initial part of the damped current of the ATG with smooth and gear rotors, which already testifies to the different electromagnetic properties of these machines [9].

Further, the damping curves were rebuilt on a semi-logarithmic scale, as a result of which two main exponential components were identified from the ATT damping curves with squirrel-cage and gear rotors and three main components from the ATG curve with a smooth rotor, and the corresponding initial values and damping coefficients of these components were also determined.

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As can be seen from the results, the presence of a third circuit with a high attenuation coefficient on the SMR is a consequence of the relatively strong manifestation of the current displacement effect, due to which the kinetic energy stored in the rotor is almost rapidly dissipated. Therefore, electromagnetic and electromechanical fluctuations of the parameters of ATG with a smooth massive rotor are intensively suppressed in comparison with ATG with squirrel-cage rotors.

The presence of a periodic component in the phase currents of the stator of the ATG with SHCMR is due to the fact that the presence of a copper cage provides a directed flow of rotor currents and thereby the equivalent leakage resistance of the rotor circuit decreases, which leads to a slow attenuation of the aperiodic component of the rotor current.

The calculation of the frequency characteristics of model ATGs was based on the well-known relation:

$$i_{so}(js) = 1/ X(js) = i_s (js) / (1+ j (r/s)\, i_s(js))$$

$$i_s(js) = a + jb$$

By setting S=0-∞, the desired frequency characteristics of model ATGs with various massive rotors are obtained. Refinements of the frequency characteristics at the points S=0, S=1 and S=∞ were made, respectively, according to the no-load resistance X_0, the short-circuit resistance X_k, and the transient resistance X, obtained from the experiments of idling, short circuit and from the experience of supplying two phases with alternating current equal to 3A. The frequency characteristics of ATG with various massive rotors are shown in Fig.3.

Refinement of the frequency characteristics at the points S=0, S=1 and S. were made, respectively, according to the no-load resistance Xo, the short-circuit resistance Xk, and the transient resistance X, obtained from the experiments of idling, short circuit and for the experience of supplying two phases with alternating current.

From the comparison of the obtained characteristics, it can be seen that the geometrical place of the end of the stator current vector of the ATG with SHCMR varies to a greater extent than the currents of the ATG with TMR and SMR, which means that the ATG with SHCMR is able to generate more active power compared to others with the same structural dimensions of the ATG. The frequency response of ATG with SMR is a complex curve having a flask shape, due to the intensive displacement of the rotor current.As a result of the increased value of the inductive resistance of the rotor, ATG with SMR has a slightly lower power factor and maximum torque compared to other ATGs [10].

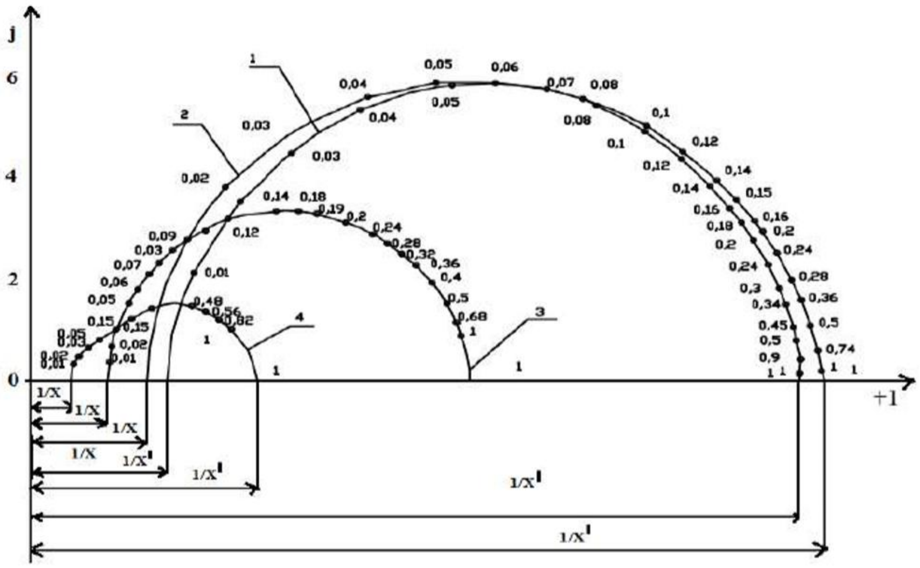

Fig. 3. Frequency responses of model asynchronous Turbogenerators, where: 1 - massive rotor with short-circuited copper cages, Z2=80; 2 - massive rotor with short-circuited copper cages, Z2=48; 3 - massive toothed rotor; 4 - massive smooth rotor.

III. CONCLUSION

Based on the research carried out, the following can be established:

- AG with a massive rotor with squirrel-cage copper cages as a natural damper provides better damping of electromechanical oscillations of regime parameters caused by external periodic disturbances and shocks.

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- Comparison of the frequency characteristics of model AGs with various designs of massive rotors shows that AG with a massive rotor with squirrel-cage copper cells is characterized by high energy performance compared to others.

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