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METHODS FOR TESTING THE STABILITY OF THE AUTOMATIC GENERATOR VOLTAGE ADJUSTMENT SYSTEM

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Abstract

The article deals with the issue of stability analysis of synchronous generators. A mathematical model of a synchronous generator, power transmission, and constant voltage electrical system has been constructed. Various approaches to constructing the angular characteristics of the active power of synchronous generators are presented. A computer program that implements various approaches to constructing the power characteristics of a synchronous generator is developed. Computer modeling allows analyzing the degree of influence of system parameters on the stability of a synchronous generator.

Keywords

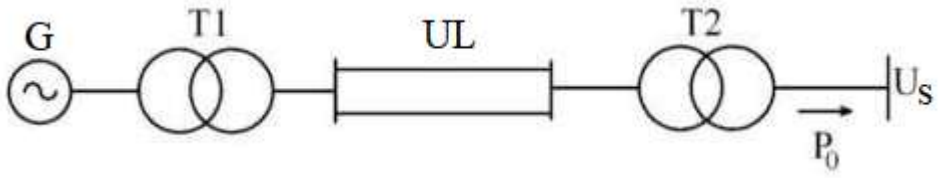
angular characteristic, power transmission angle, active power, automatic control, relative motion excitation, power limit, stability reserve.

The development of modern electric power is carried out by increasing the capacity of units - not only those that produce electricity, but also those that consume it. In the recent past, the largest domestic turbogenerator had a capacity of 1200 MW, which determined the size of the imbalance in the energy system. Currently, the most powerful synchronous generator in China is a synchronous generator with a capacity of 1750 MW and is designed to operate at the Taishan NPP. produced.

modern automatic control systems (A BT) allows you to implement many system and protection functions: stable operation of a group of synchronous generators and equal distribution of reactive power between them; absorption (damping) of post-major accident oscillations and small fluctuations occurring in the power system; ensuring a high level of dynamic stability through excitation amplification; stabilization of the network - not only in terms of voltage frequency, but also in terms of its derivative, etc.

Currently, there are many software packages for analyzing power system regimes and calculating electromechanical transients, such as RastrWin, EUROSTAG, DAKAR. However, there is a need for a simple software product to study the stability of synchronous generators and the influence of various automatic excitation control systems on it, the results of which and the algorithms of their operation should be accessible to a wide range of users.

Stability analysis of synchronous generators is carried out on the basis of the angular characteristics of active power . Angular characteristic of active power Consider **a classical power supply scheme , which includes: a synchronous generator, an electrical system with unlimited power, which are interconnected by a power transmission system with transformers and power lines.**



1. Diagram of the network being analyzed

To study the stability of synchronous generators, a program has been developed that implements various approaches to constructing angular characteristics of active power , and it allows analyzing the stability of the power transmission system shown in Figure 1 [4].

The analysis can be performed for different values of the power system parameters, which allows assessing the impact of active power on the angular characteristic and on the quantitative indicators of the static stability reserve (Figure 2).

The calculation is carried out on the basis of pre-selected basic conditions in a system of relative units. The basic conditions can be selected by the exact displacement method in a system of relative units or by an approximate method; that is, the average nominal stresses of the floors are taken as the basic stresses.

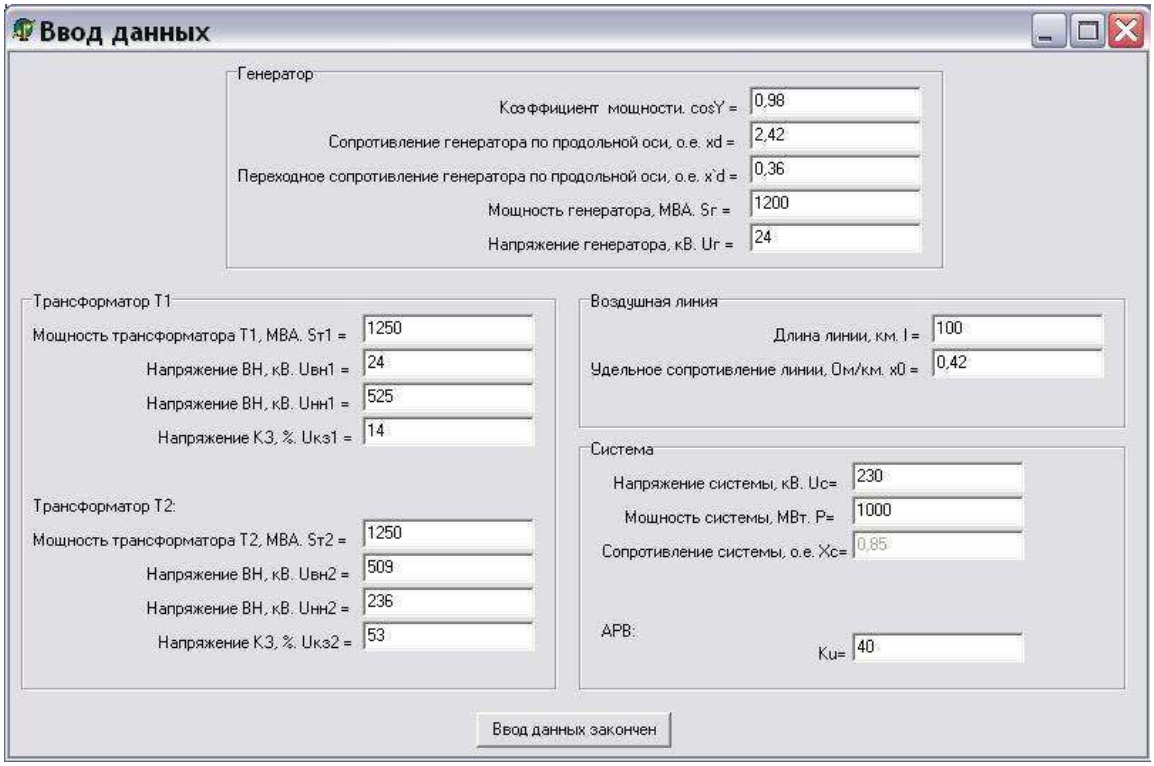


Figure 2. System settings input window

The chosen approach to building the program structure allows you to assess the degree of influence of the applied detection method (exact or approximate) on the result.

characteristic of the active power of an uncontrolled generator is described by the following expression:

$$P = \frac{E_q U_s}{X_{d\Sigma}} sin\delta \qquad (1)$$

Here: E_q– projection of the generator electromotive force (EMF) vector qalong the axis $E_q \approx \sqrt{\left(U_s + \frac{Q_0 X_{d\Sigma}}{U_s}\right)^2 + \left(\frac{P_0 X_{d\Sigma}}{U_s}\right)^2}$;

U_s– voltage of the electrical system;

$X_{d\Sigma}$– resistance between the synchronous generator (SG) and the electrical system $X_{d\Sigma} = X_d + X_0 = X_d + X_{T1} + \frac{1}{2}X_l + X_{T2}$;

δ– power transmission angle.

The angular characteristics of the active power of an uncontrolled generator , which has a sinusoidal shape, are shown in Figure 3.

The presence of an automatic excitation control device in synchronous generators changes the angular characteristic of the synchronous generator.

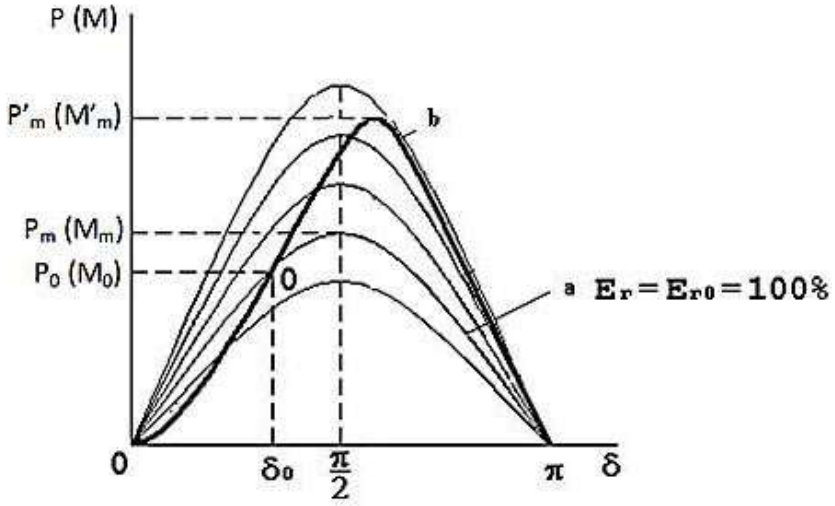


Figure 3. Synchronous generator power characteristic :
a – the generator is not equipped with an automatic excitation control device;
b – the generator is equipped with an automatic excitation control device.

The advantage $P'_m(M'_m)$of a controlled generator's torque (power) characteristic over an uncontrolled generator in terms of stability is that its power (torque) limit $P_m(M_m)$is significantly higher than , which primarily leads to an increase in the static stability reserve coefficient. The maximum of the power characteristic occurs not at $\delta = \pi/2$, as in an uncontrolled generator , but at $\delta > \pi/2$.

In synchronous generators equipped with automatic excitation control (ABT), an increase in the transmitted power leads to an increase in the generator EYUK . With an increase in the power transmission angle δ, this process leads to a transition from the α- angle characteristic , built on the basis of *a* constant EYUK $E_{q,to}$ *the* β- angle characteristic , with a larger transmitted power limit (Fig. 3). In this way, ABT affects the transmitted power limit and, consequently, the stability of the power system.

ABT is important in the calculation of stability . ABT is divided into: automatic excitation regulators with relative motion and automatic excitation regulators with strong motion. The former respond to the deviation of one or more of the mode parameters from the control values, while the latter additionally respond to the rate of change and acceleration of the parameters (i.e., the first and second derivatives).

Therefore, strong motion ABT provides regime stability over a larger range of the power transfer angle δ and the transmitted power P , compared to relative motion ABT .

Relative motion excitation regulators ensure the maintenance of the transition $E'_q = const$EYUK , while strong motion regulators ensure the maintenance of the generator terminal voltage U $_{г = const}$ [2, 5, 6].

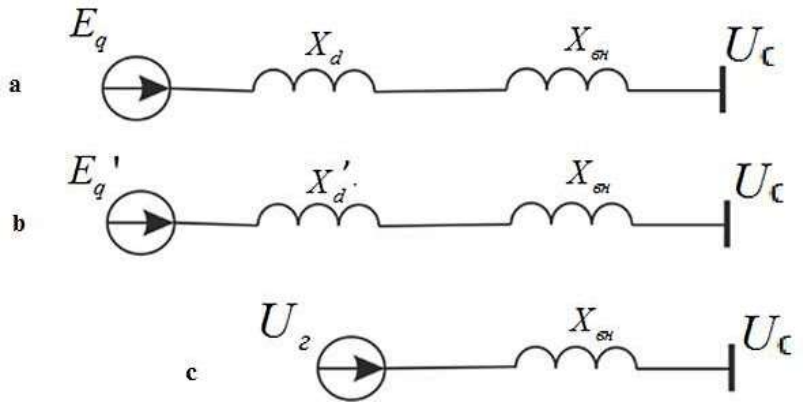


Figure 4. Switching schemes of the network under analysis:
a – the synchronous generator is not equipped with an automatic excitation control device;
b – the synchronous generator is equipped with an automatic excitation control device with relative motion;
c – The synchronous generator is equipped with a powerful automatic excitation control device.

characteristic of a synchronous generator equipped with relative motion automatic excitation control (ABT) (Figure 4, scheme b) can be determined by the following expression:

$$P = \frac{E'_q U_s}{X'_{d\Sigma}} sin\delta - \frac{U_s^2 (X_{d\Sigma} - X'_{d\Sigma})}{2X_{d\Sigma} X'_{d\Sigma}} sin2\delta \qquad (2)$$

Here: E'_q – projection of the generator's EMU $E'_q \approx \sqrt{\left(U_s + \frac{Q_0 X'_{d\Sigma}}{U_s}\right)^2 + \left(\frac{P_0 X'_{d\Sigma}}{U_s}\right)^2}$ vector on the right axis during the transition period ;

$X'_{d\Sigma}$– resistance between the synchronous generator (SG) and the electrical system $X'_{d\Sigma} = X'_d + X_0 = X_d + X_{T1} + \frac{1}{2}X_l + X_{T2}$;

characteristic of a synchronous generator equipped with a powerful automatic excitation control (ABT) (Fig. 4, scheme c) is described by the following expression.

$$P = \frac{U_g U_s}{X_0} sin\delta - \frac{U_s^2(X_{d\Sigma} - X_0)}{2X_{d\Sigma}X_0} sin2\delta \qquad (3)$$

Here: U_g– projection of the voltage vector at the generator output poles onto the left axis $U_g \approx \sqrt{\left(\mathrm{U_s} + \frac{\mathrm{Q_0}X_0}{\mathrm{U_s}}\right)^2 + \left(\frac{\mathrm{P_0}X_0}{\mathrm{U_s}}\right)^2}$;

X_0– external resistance between the synchronous generator and the electrical system $X_0 = X_{T1} + \frac{1}{2}X_l + X_{T2}$.

an ABT , it is necessary to find the value of the power transmission angle, for which the specific product of the active power with respect to the power transmission angle (2), (3) is set to zero.

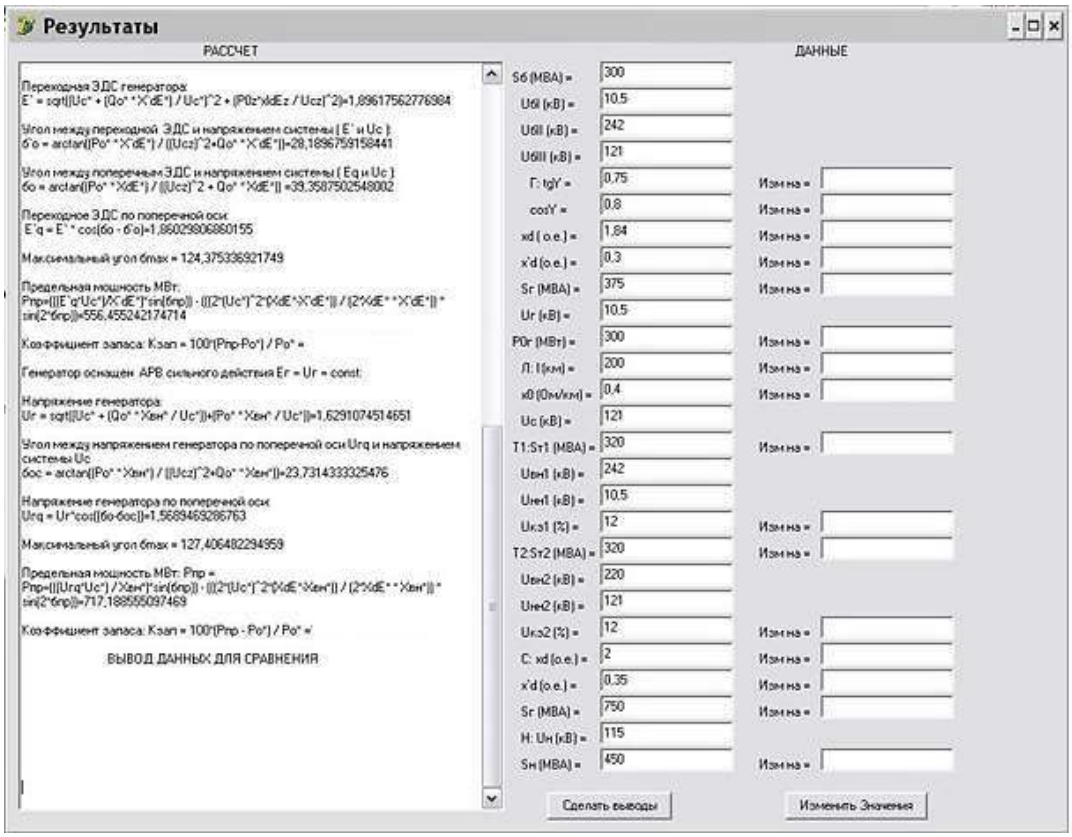


Figure 5. Window for analyzing the angular characteristics of a synchronous generator

This algorithm is implemented in the software package [4], which allows analyzing the degree of influence of the excitation control algorithm, as well as other parameters of the power transmission, on the stability of the synchronous generator and presents the calculation process and results in the form of (Figure 5).

The calculation approach shown above is approximate and does not take into account the parameters of the excitation regulators.

If the actual no-load characteristic of a synchronous generator is replaced by a corrected (linearized) one, ignoring the saturation of the magnetic system, then the change in the synchronous ESR of a generator equipped with a relative motion automatic excitation control device can be described by the following expression [7]:

$$E_q = E_{q0} + K_{\Delta U}\left(U_{g0} - U_g\right) \qquad (4)$$

Here:

E_{q0}– Initial value of the EYUK ;

U_{g0}– the required voltage value at the generator output poles;

$K_{\Delta U}$ABT amplification coefficient relative to voltage deviation .

The synchronous generator voltage can be described as a function of the synchronous generator EYUK , the power system voltage, and the power transmission parameters by the following expression:

$$U_g = \frac{X_{d\Sigma} - X_0}{X_{d\Sigma}} U_s cos\varphi + E_q \frac{X_0}{X_{d\Sigma}}.$$

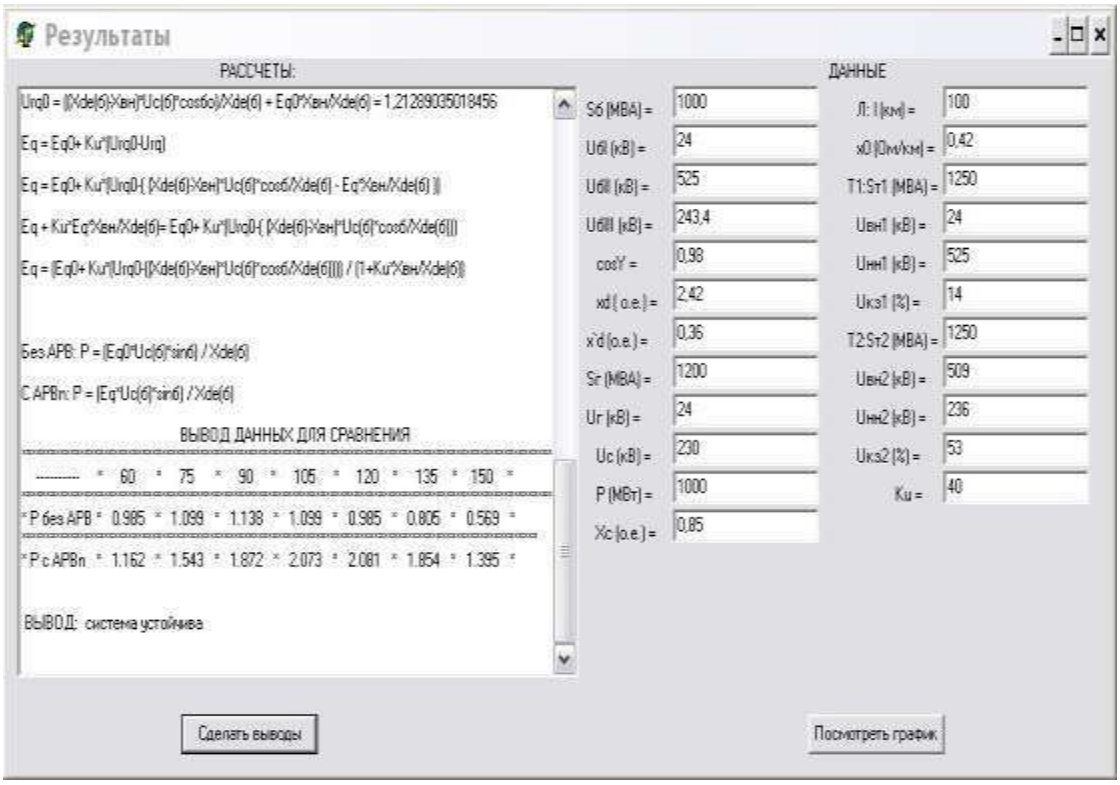
(5) Substituting expression (4) into formula, we determine the dependence of EYUK on the angle δ:

$$E_q = \frac{E_{q0} + K_{\Delta U}\left(U_{g0} - \frac{X_{d\Sigma} - X_0}{X_{d\Sigma}} U_s cos\delta\right)}{1 + K_{\Delta U}\frac{X_0}{X_{d\Sigma}}}$$

Using the obtained relationship together with formula (1), we derive the relationship P = f(δ) of a synchronous generator equipped with an ABT , that is, the dependence of the active power on the power transfer angle, taking into account the value of the amplification coefficient relative to the voltage deviation.

The developed program allows you to analyze the effect of automatic excitation control on the stability of a synchronous generator and to construct the dependence of

active power on the power transmission angle at arbitrary values of the amplification coefficient relative to the voltage deviation (Figures 6, 7).



6-Fig. Analysis window of the effect of the amplification coefficient on the angular characteristics of a synchronous generator relative to the voltage deviation

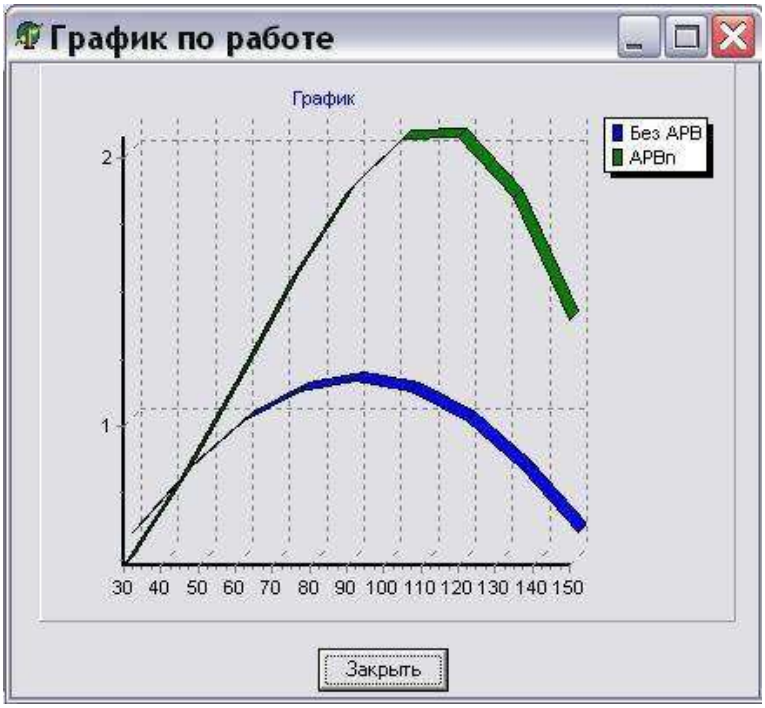


Figure 7. Angular characteristic graphs

The presence of automatic excitation control increases the stability reserve of a synchronous generator. Various approaches, differing in the level of abstraction, to construct the power characteristics of controlled synchronous generators were considered.

A program has been developed that allows for a comparative analysis of the stability reserve for a synchronous generator not equipped with an automatic excitation control device and a controlled generator (based on different approaches to determining their power characteristics).

The program allows you to clearly assess the impact of synchronous generator parameters, automatic excitation regulator parameters, electrical system parameters, and power transmission (transformers, power lines) parameters on stability.

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