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Voltage Deviations Influence on Asynchronous Characteristics of Powerful Asynchronized Turbogenerator

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Abstract

The widespread applying of electrical grids with voltage classes 330 and 750 kV with powerful units of nuclear and heat power plants creates a set of problems with normal modes ensuring in the Ukrainian energy system. Due to sufficiently great transverse capacitance of such overhead lines, significant amounts of reactive power excess are possible in the system. This phenomenon manifests itself especially in the load reduction hours in the power system through the visible voltage levels deviation at the energy-generating nodes in an upward direction. The application of asynchronized turbogenerators with the ability to work in asynchronous mode could solve the problem of reactive power excesses in the energy-generating nodes during load reduction hours in the power system due to their possibility of deep reactive power consumption. The paper presents the calculated results of the asynchronous modes coordinates for an asynchronized turbogenerator with a capacity 1000 MW based on the parameters of the equivalent circuit, taking into account possible generator stator voltage deviations within ±10%. The influence of voltage deviations on the asynchronous modes coordinates is shown. Due to the obtained characteristics, it is possible to perform engineering estimations of the possible asynchronous mode applying for the asynchronized generator under conditions of nuclear and thermal power plants and taking into account possible voltage deviations.

Keywords: asynchronized generator; asynchronous mode; reactive power; generator mode.

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1. Definition of the problem to be solved

The electrical grids with voltage classes 330 and 750 kV with powerful units of nuclear and heat power plants play a significant role in Ukrainian energy system. Huge capacity of such elements, on the one hand, allows increasing power flow volumes and on another hand causes a set of problems with ensuring normal modes. Particularly, the large amounts of reactive power excess are possible because of the sufficiently great transverse capacitance of overhead lines. The reactive power excess appearance is especially notable during load reduction hours through the visible voltage levels deviation at the energy-generating nodes in an upward direction [1]. The existing compensation means of excess reactive power like shunt reactors are not always able to perform their functions under such conditions due to their relatively low reliability [2]. An additional factor that exacerbates the problem of reactive power excess manifestations is the narrowing of the control range by automatic excitation regulators of synchronous generators. The influence of voltage levels increasing in energy generating nodes on synchronous generator mode manifests in generators transition to the modes which are close to the reactive power consumption. In such mode, the synchronous generator stock to generate reactive power becomes redundant while the possibility to consume reactive power is limited. Such synchronous generator modes are undesirable and restricted with protection equipment both on stator core ends heating and on ensuring the generators operation stability [1], [3].

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2. Analysis of the recent publications and research works on the problem

The application of asynchronized turbogenerators (ASTG) with the ability to operate in asynchronous mode with deep reactive power consumption could solve the problem of reactive power excess in power generating nodes during load reduction hours due to the capability to resorb the reactive power without restrictions on both stator core ends heating and ensuring the generators operation stability [1-5, 7]. To analyze possible asynchronous modes of powerful ASTG (with the excitation winding disconnected) in real schemes it is necessary to take into account its asynchronous characteristics depending on voltage level deviation at stator winding. Only such characteristics could help us extend the ASTG 1000 MW using areas under conditions of voltage deviations at high-power units.

3. Formulation of the goal of the paper

According to the research results of similar generator operation modes, the deep reactive power consumption under real conditions leads to significant voltage deviations at the generator stator terminals [3,4]. The investigation's purpose is to obtain the calculated asynchronous modes coordinates of asynchronized generator 1000 MW and its asynchronous characteristics based on equivalent circuit parameters taking into account possible stator winding voltage deviations within ±10%. Such characteristics serve as the basis for engineering estimation of the possibility to apply ASTG asynchronous mode under conditions of possible voltage deviations.

4. Presentation and discussion of the research results

There are some important features of ASTG asynchronous mode as compared to ordinal modes. Having been in asynchronous mode with short-circuited excitation windings the asynchronized turbine generator is capable to carry active power simultaneously consuming reactive power with restrictions related only to stator currents and turbine power [7]. There are no mode coordinates fluctuations inherent in all types of synchronous machines, so asynchronous modes improve the stability of power plant operation as a whole. Considering rotor lobe symmetry on the *d*,*q*-axes, as well as equivalent contour of the circular array of the rotor, the traditional equations set of the generalized electromechanical converter is used to design the ASTG mathematical model (1).

$$\begin{cases} -u_d = (r+px)i_d + px_{ad}\left(i_{fd}+i_{rd}\right) + xi_q + x_{ad}\left(i_{fq}+i_{rq}\right); \\ -u_d = (r+px)i_d + px_{ad}\left(i_{fd}+i_{rd}\right) + xi_q + x_{ad}\left(i_{fq}+i_{rq}\right); \\ -u_{fq} = \left(r_f+px_f\right)i_{fq} + px_{ad}\left(i_q+i_{rq}\right) - s\left(x_f i_{fd} + x_{ad}\left(i_d+i_{rd}\right)\right); \\ -u_{fd} = \left(r_f+px_f\right)i_{fd} + px_{ad}\left(i_d+i_{rd}\right) - s\left(x_f i_{fq} + x_{ad}\left(i_q+i_{rq}\right)\right); \\ 0 = \left(r_r(s)+px_r(s)\right)i_{rq} + px_{ad}\left(i_q+i_{fq}\right) - s\left(x_r(s)i_{rd} + x_{ad}\left(i_d+i_{fd}\right)\right); \\ 0 = \left(r_r(s)+px_r(s)\right)i_{rd} + px_{ad}\left(i_d+i_{fd}\right) - s\left(x_r(s)i_{rq} + x_{ad}\left(i_q+i_{fq}\right)\right); \\ T_j ps = M_t - M, \end{cases} \tag{1}$$

where u_d, u_q are the projections of stator winding voltage on *d*-axis and *q*-axis; i_d, i_q are the projections of stator winding current on *d*-axis and *q*-axis; i_{fd}, i_{fq} are the projections of exciting current on *d*-axis and *q*-axis; i_{rd}, i_{rq} are the projections of rotor array current on *d*-axis and *q*-axis; *s* is the generator slip; T_j is the inertia time constant of turbine-generator block mass; *M* is the generator electromagnetic torque; M_t is the turbine mechanical torque; *r* is the stator winding active resistance; $r_r=f(s)$ is the active resistance of rotor array in the function of generator slip; r_f is the exciting winding active resistance; x_{ad} is the mutual inductance between two inductive reactance of stator and rotor windings; $x_r=f(s)$ is the inductive reactance of rotor array in the function of generator slip; $x=x_s+x_{ad}$; x_{fs} is the scattering inductive reactance of rotor windings; *p* is the differentiation operator.

One of the possible approaches to obtain the rotor contours parameters in the function of generator slip is to approximate the table dependencies [6]. Due to the [7] such expressions for resistance and reactance are obtained

$$r_r(s) = A_r + B_r/s\,; \quad x_r(s) = A_x + B_x/s\,, \tag{2}$$

where r_r, x_r are the rotor array resistance and rotor array reactance, pu; A_r, B_r, A_x, B_x are the constant coefficients of approximation table dependencies.

To analyze the ASTG asynchronous mode, the transition to complex plane is done considering p=0 and taking that $u_{fd}=u_{fq}=0$ in case of short-circuited terminals for excitation winding. After the equations (1) and (2) transformations, the equations set (3) is obtained

$$\begin{cases} -\bar{\mathbf{U}} = r\bar{\mathbf{I}} + j\left(x\bar{\mathbf{I}} + x_{af}\left(\bar{\mathbf{I}}_f + \bar{\mathbf{I}}_r\right)\right); \\ 0 = r_f\bar{\mathbf{I}}_f - js(x_f\bar{\mathbf{I}} + x_{af}(\bar{\mathbf{I}} + \bar{\mathbf{I}}_r)); \\ 0 = \left(A_r + \dfrac{B_r}{s}\right)\bar{\mathbf{I}}_r - js\left(A_x + \dfrac{B_x}{s}\right)\bar{\mathbf{I}} + x_{af}(\bar{\mathbf{I}}_f + \bar{\mathbf{I}})), \end{cases} \tag{3}$$

where $\bar{\mathbf{U}}$ is the vector of the stator voltage for turbine generator; $\bar{\mathbf{I}}$, $\bar{\mathbf{I}}_r$ are the currents vectors of stator and rotor array; $\bar{\mathbf{I}}_f$ is the vector of currents induced in exciting winding (all voltages and currents are in complex coordinates).

The calculated results of asynchronous mode coordinate at rated stator voltage for ASTG 1000 MW is shown in Fig.1, where P_g, Q_g are the active and reactive powers respectively; I_g is the total stator current; cos φ is cosine phi; s is the generator rotor slip.

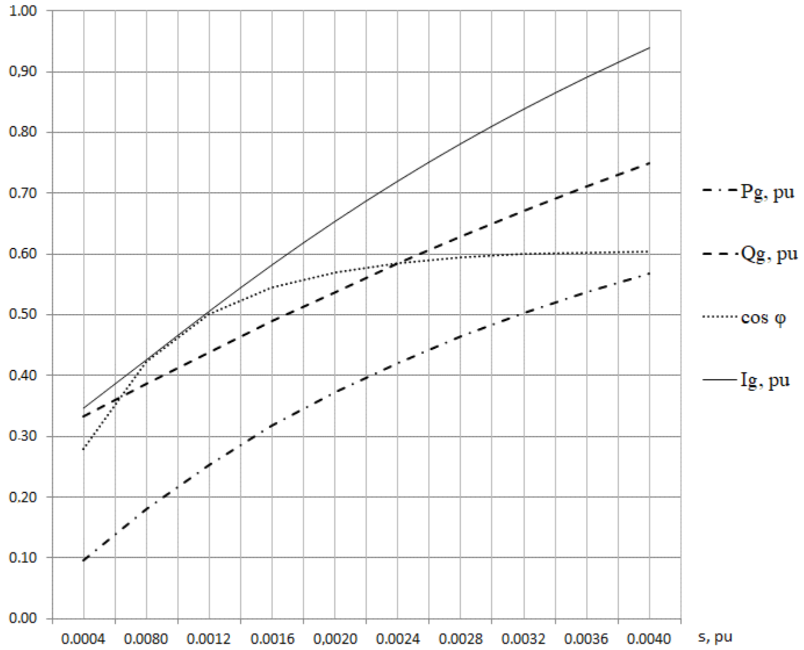

Fig.1. Asynchronous characteristics of ASTG 1000 MW at rated stator voltage.

The obtained results of calculated asynchronous mode coordinates for ASTG 1000 MW prove the asynchronized generator capability to consume deep reactive power at rated stator voltage. The reactive power generation in such mode could reach up to Q_g=0.75÷0.8 pu while the level of active power generation is P_g=0.46÷0.58 pu. There are two more benefits. Firstly, the excitation system is in an off-state, which provides additional opportunities for repair and maintenance. Secondly, the mode is not accompanied by coordinates fluctuations due to the symmetry of the generator parameters along the d,q-axes in comparison to the traditional synchronous generator.

However, it should be kept in mind that the voltage level at the generator terminals in practice could significantly differ from the nominal levels. The additional calculations of asynchronous mode coordinates were done subject to voltage levels deviations at the generator terminals within range ±10%. The calculation results are given in Fig.2 – Fig.5.

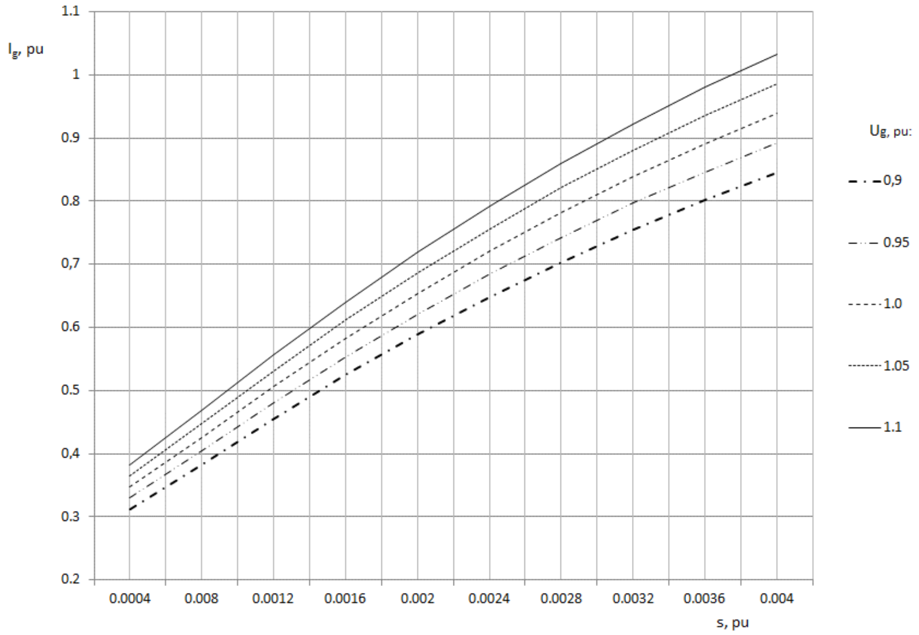

Fig.2. Dependencies of I_g on slip for the voltage change range.

Fig.2 shows total stator current dependencies on the generator slip for the voltage change range 0.9÷1.1 pu. The limiting value for the current is evidently the rated current (I_g=1) due to the thermal state of the stator winding structural elements. In this case, to apply the obtained asynchronous mode characteristics, it is necessary to show the calculated maximum range of the generator rotor slip at the nominal stator current (see in Fig.5).

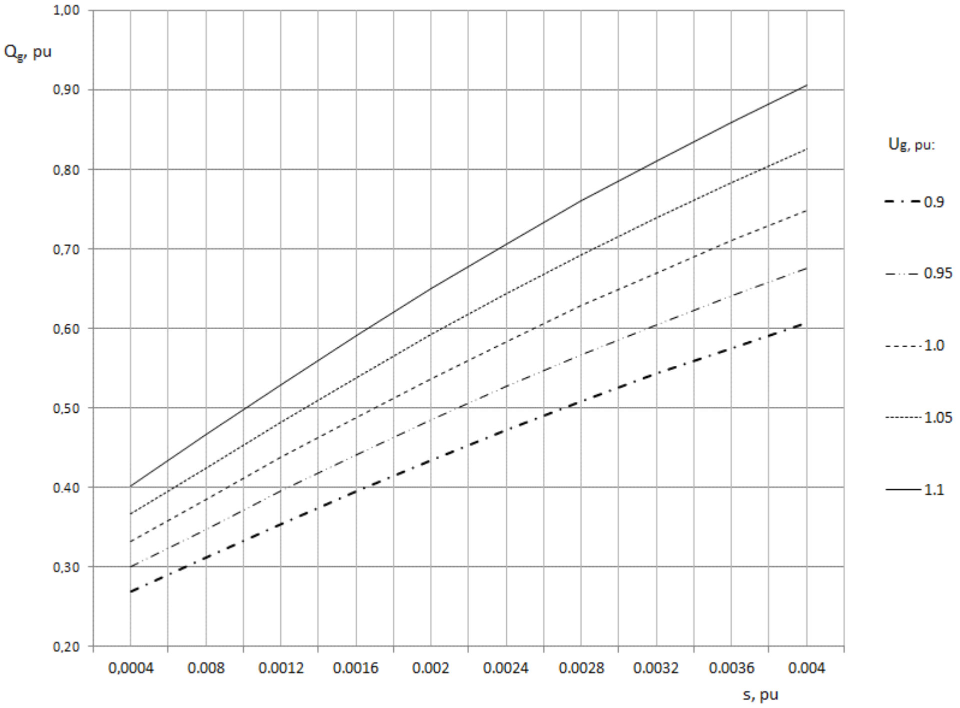

Fig.3. Dependencies of Q_g on slip for the voltage change range.

The consumed reactive power characteristics given in Fig. 3 show the whole range of ASTG 1000 MW for reactive power stock which could be taken in mind under the condition of stable generator operation in terms of technological constraints, in particular in relation to nuclear power plants (NPP). According to [8] the reactive power range is narrowed by 20% at the top of the generator slip change.

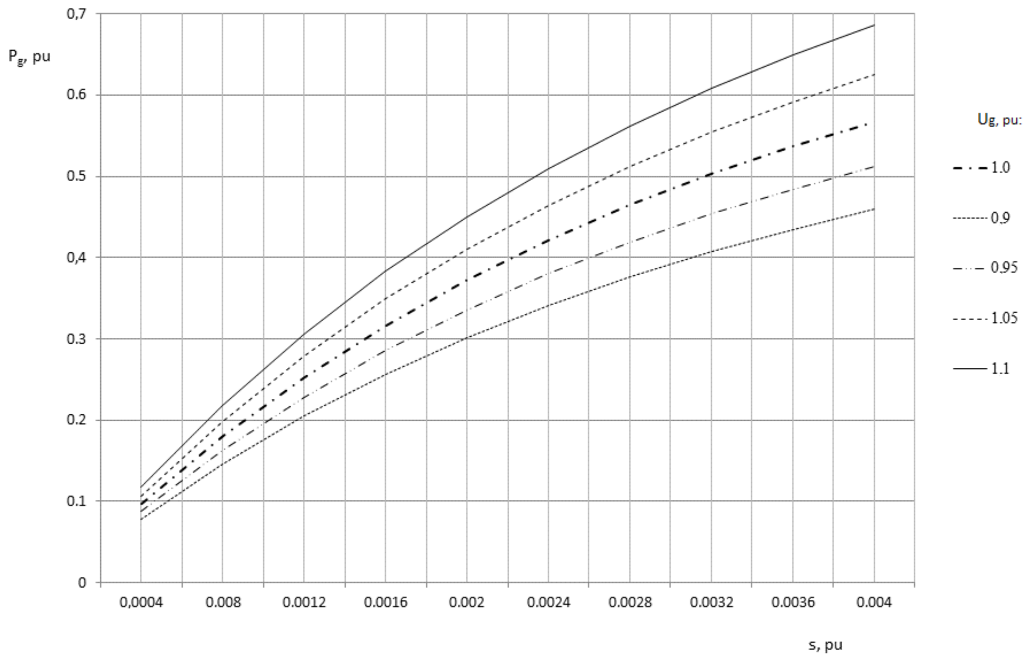

Fig.4. Dependencies of P_g on slip for the voltage change range.

Similarly, to the reactive power Fig.4 shows the asynchronous active power characteristics. The range of its change is determined by the possible characteristics of the turbine torque changing under influence of the primary energy carrier.

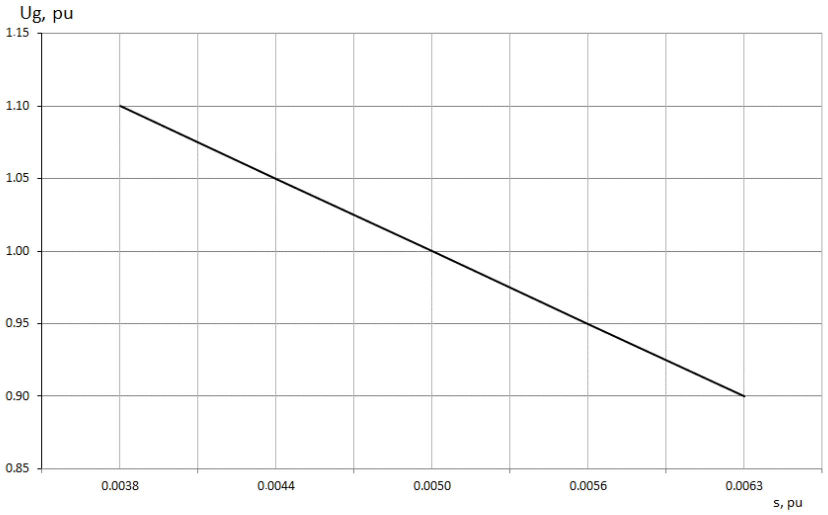

Fig.5. Dependencies of U_g on slip under the condition I_g=1, pu.

The analysis of the obtained data, shown in Fig.1 – Fig.5, allows us to state that the ranges of coordinates deviations in asynchronous modes, taking into account the generator stator voltage deviations from the rated voltage, have the following values (Table 1):

Table 1. The ranges of coordinates deviations in asynchronous modes.

ΔU_g, pu	Δs_g, pu	ΔI_g, pu	ΔP_g, pu	ΔQ_g, pu
±0.1	±0.26	±0.1	±0.21	±0.21

Table 1 was calculated taking I_g=1.0 pu as the base value of the coordinates.

5. Conclusion

Asynchronized turbogenerators 1000 MW together with traditional synchronous generators could take part in covering power system load curve while the first ones operate in the asynchronous mode under conditions of generator stator voltage deviations from the rated voltage. The obtained asynchronous mode characteristics make it possible to evaluate the asynchronous modes acceptability of ASTG 1000 MW in specific connecting schemes taking into account possible generator stator voltage deviations.

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Вплив відхилень напруги на асинхронні характеристики потужного асинхронізованого турбогенератора

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Анотація

Широке застосування мереж класів напруги 330 та 750 кВ з приєднанням до них потужних блоків атомних та теплових електростанцій в енергосистемі України створює ряд проблем із забезпеченням нормального режиму. Поперечна ємність таких повітряних ліній доволі значна через що в мережі виникають значні обсяги надлишків реактивної потужності. Це явище проявляє себе особливо в години зниження навантаження в енергосистемі помітними відхиленнями рівнів напруг у вузлах генерування у бік зростання. Застосування асинхронізованих турбогенераторів з підтриманням асинхронного режимі може розв’язати проблеми надлишків реактивної потужності у вузлах генерування в години зниження навантаження в енергосистемі за рахунок глибокого споживання цих надлишків асинхронізованими генераторами. В роботі представлено результати розрахунків координат асинхронних режимів асинхронізованого турбогенератора потужністю 1000МВт на основі параметрів заступної схеми з урахуванням можливих відхилень напруги статора генератора в межах ±10%. Показано вплив відхилень напруги на координати асинхронних режимів. Отримані характеристики дозволяють реалізувати інженерні оцінки можливостей застосування асинхронного режиму асинхронізованого генератора в умовах атомних та теплових електростанцій з урахуванням можливих відхилень напруги.

Ключові слова: асинхронізований генератор; асинхронний режим; реактивна потужність; режим генератора.