

New generation of turbogenerators for regulation of voltage of power grids in conditions of developing power market

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JSC "Electrosila", jointly with JSC "VNIIE", developed unique turbogenerators of new type - so-called asynchronous turbogenerators with power rating of 110, 220 and 350 MW of type TZVA with full water cooling and power rating of 110 MW of type TZFA with full air cooling. These generators represent the most radical and economical means for solution of the problems associated with compensation of excessive reactive power in the power grids and allow stepless regulation and prevention of rise of voltage in the power grids above the rated level. The asynchronous turbogenerator power plant allows significant improvement of the static and dynamic stability of the power grids and quality of the generated electric power.

Over the past decade the problems of maintaining the required norms of levels of voltage in the superhigh-voltage power grids in Russia became very acute, which is attributed to the overall reduction in power consumption in the country and consequently generation of reactive power by under-loaded power transmission lines rated for 220-500 kV due to insufficient number of installed reactive power compensation facilities.

Regulation of voltage (reactive power) in the system-forming power grids of EES of Russia is provided by the following:

- automatic regulators of excitation of the synchronous turbogenerators (STG) at the power plants;
- synchronous and static thyristor compensators at the substations;
- shunting reactors (SR), transformers with on-load voltage regulation (RPN), static capacitor banks (BSK).

The use of SR, RPN, BSK allows compensation of excessive reactive power only stepwise. Besides such regulation is applied in practice, as a rule, on a seasonal basis due to shortage of the switching reserve of the air circuit-breakers, and also due to lower reliability of RPN.

As stated above, to secure continuous regulation and maintenance of the normal levels of voltage at the power plants the use is made of synchronous generators. On instruction from the dispatcher the operating personal changes some of the turbogenerators into the mode of consumption of reactive power which helps somewhat reduce the excessive levels of voltage.

However, lengthy operation of the STG in the mode of consumption of reactive power results in the following:

- accelerated wear of the active steel of the end zone of such generators and later on in failure of these zones;
- drop in limits of static and dynamic stability.

Operation of STG in modes of consumption of reactive power results in a shorter service life in average by 16.5% (or 5 years), and respectively in their premature full or partial (stator) replacement.

This situation is further aggravated by the fact that with total power rating of 150 GW of the turbogenerators installed at the fossil-fuel power plants (1200 units) about 55% of the turbogenerators practically exceeded the regulatory minimal service life limit (25-30 years).

It should be noted that in STG of new designs, such as TZV manufactured by JSC “Electrosila”, the problems with heating restrictions of the end zones are partially resolved, in principle the generators may operate in modes of consumption of reactive power, but the area of this operation is small, since it is limited by the conditions of static and dynamic stability. That is why these generators cannot exert any significant effect on the magnitude of voltage, i.e. normalization of levels of voltage in the power grids.

Thus, involvement of the turbogenerators rated at 100 MW and higher in the process of normalization of the levels of voltage in the power grids, while considering their age and technical condition does not solve the problems and results in their accelerated wear, and consequently in significant economic losses.

Much more efficiently this problem can be solved by the use of the turbogenerators of the principally new type - so-called asynchronous turbogenerators (ASTG)[1].

In contrast to the synchronous generators, ASTG are capable of:

- operation in modes of high consumption of reactive power, which is impossible for STG;
- they feature higher limits of static and dynamic stability, i.e. they are more reliable in operation.

The above mentioned advantages of ASTG are achieved at expense of:

- new design of the rotor which features not one as in STG, but two excitation coils mounted with bias over the circumference of the rotor in respect to each other of 90 electrical degrees;
- unique system of automatic regulation of excitation.

The excitation system of ASTG contains two sets of reversible exciters capable of changing excitation current in each of the coils both by magnitude and sign.

The automatic regulation system allows, in contrast to the turbogenerators of traditional make, to control simultaneously and independently of currents of two excitation coils, and consequently separately of two variables of the mode: voltage across the bus bars of the power plant (reactive power) and electromagnetic torque of the turbogenerators which secures operation of the turbogenerators in modes of high consumption of reactive power without loss of stability.

In principle, the ASTG stator does not differ by design from the STG stator, but incorporates measures for improvement of reliability of the end zones.

Moreover ASTG, as compared with STG, features:

- higher speed of response of voltage regulation which in particular helps maintain stability of generators operating in parallel at the power plant;
- possibility of lengthy operation with loss of excitation (with restriction of power rating to 70-80% of the nominal). Meanwhile the standard synchronous turbogenerator (STG) in case of loss of excitation should be unloaded by 40-60% and should be shut down in 15-30 minutes;
- when installed at the power plant in parallel with the synchronous turbogenerators, ASTG operating in the mode of consumption of reactive power secure unloading of such STG by consumption of reactive power, i.e. significantly improve their reliability.

Besides, the above mentioned generators operate with biggest (nominal) values of efficiency (with ASTG the highest efficiency corresponds to the modes of consumption of reactive power, and with STG - to the modes of output) which improves efficiency of the power plant as a whole.

ASTG are installed on the same foundations as STG of the same power rating.

It should be noted that interest to the asynchronous generators at present is very high in the whole world. Japanese companies “Hitachi”, “Toshiba” fabricated and installed similar hydrogenerators at a number of hydropower plants with unit capacity from 80 to 440 MW, asynchronous compensators with rating 60 MVA for regulation of reactive power in the

power grid. High interest to the turbogenerators was shown by “General Electric” and “Alstom” companies.

The world first ASTG rated for 200 MW fabricated by NPO “Elektrotyazhmash” was installed in 1985 at the Bushtyn fossil-fuel power plant (Ukraine). In 1990 the same power plant commissioned the second turbogenerator of this type. The generators securely operate in the modes of output and high consumption of reactive power while ensuring optimum voltage parameters.

JSC “Electrosila” developed a series of ASTG with power rating of 110, 160, 180, 220 and 350 MW of type TZVA with full water cooling and fabricated ASTG with power rating of 110 MW of type TZFA-110 with forced air cooling [2]. These generators, in accordance with the resolutions of RAO “EES of Russia”, JSC “Mosenergo” were recommended for installation at the number of fossil-fuel power plants of Russia.

The main feature of the design of the turbogenerators of type TZVA is a “self-pressure” rotor cooling system which does not have hydraulic connections of the coil of the rotor with the shaft, including a multiplicity of steel and insulating tubes, seals and highly loaded brazed connections causing insufficient reliability of the design of the rotors with water supply through the shaft (“pressure” system).

The stator coil is of bar type made of transposed hollow and solid copper conductors, is cooled in accordance with the traditional method commonly used in the powerful turbogenerators of domestic and foreign companies.

The rotor features two conventional concentric coils (phases) mounted with bias of $\pi/2$. Along axes of each of the coils there are gaps of two tooth divisions required for design considerations. Here, located in some slots (shallow) are coils of one phase only, and in the other slots (deep) - coils associated with different phases. Depending on the number of deep and shallow slots and respectively of the number of coils of each phase per pole, one can achieve a different shape of curve of the overall field of the rotor from currents flowing in the both phases of the excitation coil and different degree of saturation of the entire magnetic circuit of the generator.

All ends of the rotor winding coils wound from copper tubing are fixed beyond the edge of the coil end. To overcome hydraulic resistance of the channels of the coil the use is made of centrifugal force of water supplied as free jets to the rotating pressure header and discharged from the large diameter to the drainage box of the end plate of the stator. Ingress of water to the subshroud space of the rotor and the stator is prevented as their connections with the pressure and drain headers and the headers themselves are removed along the axis of the rotor beyond the shroud rings and all possible leakage of water in these points is thrown by centrifugal force to the common water collector. To secure stable operation with low slippage in the uncontrolled asynchronous mode, and also for compensation of high-frequency fields and fields of reverse sequence in the synchronous mode the rotor is fitted with a full damping winding consisting of copper conductors laid in slots under the slot wedges and end rings of two layers of copper plates located under the shroud rings.

The conductors of the damping coil are made hollow and are cooled with water similar to the excitation coil. Thus, the damping coil is an efficient cooler of the rotor steel, shroud rings and gas in the gap. This precludes necessity to install fans and gas coolers.

A significant feature of the turbogenerators of new series TZFA with full air cooling is the use of high efficiency built-in centrifugal fans fitted with well-designed air supply lines and guide vanes of volute type mounted normal to the longitudinal axis of the frame. Efficiency of such fans measured on the existing turbogenerators is very high - it is in the range of 0.75-0.78. Such values of efficiency are in principle unachievable for the built-in fans of axial type, since there is no room inside the frame of the machine in the axial direction sufficient for location of high quality guide vanes.

Proposed as the basis the master design features a welded, horizontally split frame which houses the stator with coil wound and fitted with minimal number of accessories for

reduction of weight, supporting the action of weight and electromagnetic torque. Provided in the end parts of the frame are borings intended for installation of the split end plates, welded in the inner spacings are guide vanes of volute type.

Analysis of the domestic and foreign experience in development of the air cooled turbogenerators indicates that the following is required for improvement of efficiency of the air cooling system:

- 1) to preclude effect of air heated in the rotor and in the gap on the active part of the stator;
- 2) to arrange such air circulation at which temperature field of the active part of the machine is uniform in nature;
- 3) to avoid inter-braking of air streams in the gap of the machine.

In the generators of series TZFA the air stream used for cooling the stator does not get into the gap. Air is supplied to the core over the U-shaped ventilation channels provided in the number multiple of the number of slots of the core and located between the above mentioned slots; inlet and outlet of the channels are located over the periphery of the core [2]. In such system air circulates over the tooth and trailing edge with counterflow which secures equalization of the temperature field of the stator.

The methods for formation of the U-shaped channels may differ. Commercialized is production of the cores in which the U-shaped channels are formed with the help of specially stamped plates of electrical steel mounted in stacks with a certain spacing at assembly of the core. Each above mentioned stack is divided into two parts one of which is rotated 180 deg. in respect to the other, which results in formation of extended U-shaped ventilation channels.

Such cores with U-shaped channels formed by assembly of specially stamped plates are readily produced and secure required flow of cooling air with differential pressure in the channel of 250-400 mm w.g. The U-shaped channels formed with the help of conventional spacers fixed by point welding to the plates of electrical steel are even more efficient, they feature significantly larger live section and with the same flow capacity they require 1.5-2 times smaller differential pressure. Application of the spacers also results in some increase in the effective section of the magnetic circuit and reduction of losses during the idle run. Given such circumstances, at present the efforts are underway to change over to the use of the cores with the U-shaped channels formed with the help of the spacers.

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The first asynchronous turbogenerator of type TZFA-110 with power rating of 110 MW was fabricated and should be commissioned at the Steam and Power Plant (SPP-22) of JSC "Mosenergo" by the end of 2003.

In conclusion it should be noted that the Uniform power system of Russia in whose framework the process of structural transformation is at present underway should secure transition to the competitive power market [3]. In this context high significance is given to the international power projects aiming at improvement of efficiency of production and transmission of electric power, solution of ecological problems, power saving, improvement of quality and stability of produced electric power, that is to creation of the system of

measures promoting development of trade in the power sector. In such conditions development and commercialization at fossil-fuel power plants of new unique turbogenerators of asynchronous type would allow considerable efficiency in solution of the above mentioned problems.

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