Gas transmission services with the combined drive as managed load consumers in regions with the high share of NPP

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Abstract. In this article we consider the questions connected with efficiency of equipment of gas transmission services of gas-compressor stations with the combined drive: with electrical one in addition to the existing gas turbine drive. In our research we consider geological and geographical regional features of the European part of Russia in coordination with an arrangement of large gas trunk pipelines, the existing boosting compressor stations (BCSs), the NPP, high-voltage transmission lines and saliferous basins suitable for creation of underground storage tanks for accumulation of stored air for needs of the gas turbine drive of gas transmission services. The following possible benefits of the schemes offered by authors are researched: the advantage of the additional charge of nuclear power plant units with increase in their capability utilization index during the off-peak periods account of transition to the electrical drive of superchargers; the advantage of use of stored air during the separate periods for partial unloading of the gas turbine drive; replacement of fuel gas as a valuable export resource; the advantage of improvements of the ecological indicators of already operating and expansions of layout opportunities of again constructing BCSs under the terms of acceptable concentration of emissions and to noise indicators. We provided the technique and results of calculation of technical-and-economic efficiency of re-equipment of BCSs under the offered scheme. In the offered method of application are considered: the mean effective performance factor of the NPP, the increase in the capability utilization index due to growth of gross generation and economy of nuclear fuel. We have considered questions of rationalization of configurations of residential settlements adjacent to BCSs under the terms of improvement of ecological indicators and to noise impact of BCSs by various number of working hours of the electrical drive in a year. The offered technique in combination with the specified starting base of data, which bases are provided in this article, will allow to perform the zoned optimization of a profile and the equipment of the compressor yard with BCSs taking into account already existing background and noise pollution Method for calculating the noise level from compressor stations.

The experience of using of off-peak night electricity for an electric drive on gas transmission services with a basic drive from a gas turbine of a compressor station is available in Europe, where
electricity tariffs are differentiated by the hour. This prompts to consider the effectiveness of using a combined drive on gas transmission services at booster compressor stations in Russian conditions too, primarily for the growth of the capability utilization index of nuclear power plants, their gross revenue, the growth in efficiency with the decrease in the depth of load failures, and also the “displacement” of gas as a valuable export resource. Let us consider these issues in more detail.

Figure 1 shows the situational location of the main trunk gas pipelines, of compressor stations of main gas pipelines, of underground gas storage stations, of booster compressor station and also the location of NPPs and of power transmission lines (PTL-500).

The objective data of Figure 1 currently show the development of trunk gas pipelines with a combined construction of underground gas storages in the European part of the Russian Federation, a significant (and increasing) number of NPP power units with the already high (and further developed) demand for high-power transmission lines. Under these conditions, there is an urgent need within the declared “Union of Atom and Gas” [1] to consider the advantages of combining gas consumption and gas supply schedules close to the basic ones. They are provided by numerous energy-intensive compressor stations, mainly with a gas turbine drive, with relatively flattened graphs of electric load of integrated power systems (in the region under consideration) with a tendency to daily, weekly and seasonal unevenness. Numerous booster compressor stations equipped with combined electric drive of transport gas superchargers of transport gas, can become consumers – regulators with high added power (in deficit-free hours and periods for integrated power systems (including taking into account the shift of the “zone” time up to 4 hours for the European part the Russian Federation).

This will contribute to a more complete loading (increase of capability utilization index) of nuclear power plants, saving gas as a valuable export resource in the domestic market, and will also
significantly eliminate the modes of forced throttling of fresh steam at the CHPP (via a reduction-cooling unit to a heat supply unit with insufficient night load of generators).

The basic technological scheme of the operation of a gas transmission service with a combined drive was proposed by the authors [2] and in Fig. 2a. A mandatory element of such circuits is a reversible motor-generator [2].

The proposed method of operation allows to drive the main equipment of compressor stations of main gas pipelines in combination (Figure 2a):
- from a gas turbine plant in the period of electric load deficit;
- from the reversible engine-generator operating in the electric drive mode of the gas transmission service during the load failure periods (at night, on weekends and holidays).

The proposed scheme also allows the generation of electricity through a gas turbine plant and an engine-generator operating in the power generation mode.

![Schematic diagram of gas transmission service equipped with a combined drive](image)

**Figure 2 a)** Schematic diagram of gas transmission service equipped with a combined drive

1 – air compressor; 2 – combustion chamber; 3 – gas turbine; 4 – gas compressor (supercharger); 5 – reversible motor-generator; 6 – angular reduction gear; 7 – controlled clutch; 8 – turbocompressor shaft; 9 – recycling unit; 10 – flue; 11 – feeding pump; 12 – power shaft; 13 – power take-off shaft; 14 – pheolite battery; 15 – underground air storage.

The systemic effect of the introduction of the proposed scheme for the operation of booster compressor stations in the integrated power systems with a growing share of nuclear power plants, as well as with periodic under-utilization of CHPP generators during periods of dip of load, consists of:

For NPPs: in increasing the efficiency and capability utilization index of nuclear power plants (already in operation), in the growth of the share of nuclear power plants, which can be introduced additionally under the conditions of work in the base part with a high capability utilization index;

For CHPP: in eliminating (restricting) the regimes of forced throttling of fresh steam through the reduction-cooling unit and underloading of generators;

For the gas transportation network: in improving the reliability of both the gas transportation network itself, and the power supply of compressor stations and the adjacent infrastructure of along-route users, as well as reducing harmful emissions into the atmosphere, and, as a result, improving environmental performance;

General social effect: the displacement of the share of fuel gas from the gas transportation network, as a valuable export resource, partial improvement of the environmental situation (noise and emissions).
The block diagram (Fig. 3), which is the resultant, includes an analysis of the environmental damage of long-route users, and it is necessary to take into account the reduction of harmful emissions in the period of time when electric drives are included. In the case of the deficit-free zones of the graphs, as previously noted, the NPP power units are being loaded. Consequently, there is a direct reduction in emissions without a “negative” substitution effect on “other” power plants. Some effect can also be expected from the “noise” impact [3]. In general, given that the permissible distance from settlements to the axis of the pipeline is also regulated, it is often the normative documents that determine the minimum allowable distance from the compressor station to the infrastructure of the long-route settlements [4]. We study these issues separately and they are beyond the scope of this article. Filling of night dips of electric load is especially important in conditions of the planned growth of the share of NPPs in a number of power systems. The efficiency of the additions of power units of nuclear power plants can be estimated by increasing the efficiency of the unit taking into account the change in the configuration (compaction) of the daily load profile.

We take the following notation: \( q_{gas} \), \( q_{uo2} \) – calorific capacity of a unit of gas mass and \( UO_2 \), \( MW/kg_{(gas)} \) and \( MW/kg_{(uo2)} \); \( C_{uo2} \), \( C_{gas} \) – Price for nuclear fuel and natural gas, rubles/kg; \( Z_b \) – number of units with capacity \( N_b \) taken into account, which are loaded during the period \( h_1 \) in a year from the load \( N_{ini} \) to \( N_{for} \) with a corresponding change in specific fuel consumption from \( b_{ini}^{uo2} \) to \( b_{for}^{uo2} \).

With the simplest symmetrical variant of the loading of NPP units and with their identical initial underload (free capacity):

\[
\Delta Z_l = A_0 \cdot \left( \frac{C_{gas}}{q_{gas} \eta_{gtp}} - \frac{C_{uo2}}{q_{uo2} \eta_{NPP}} \right) + Z_b \cdot \frac{N_{ini}^{b}}{N_{ini}^{NCS}} \cdot \left( \frac{1}{\eta_{ini}} - \frac{1}{\eta_{for}} \right) \cdot C_{uo2}
\]

Or: \( \Delta Z_l = A_0 \cdot (A_1 + A_2) \); and \( A_0 = Z_b \cdot N_{cs} \cdot t_e \)

Calculated experiments using formula (1) should be carried out according to the developed algorithm, which is presented in the form of a block diagram in Fig. 3.

The formula (1) has an additive character, which must be taken into account by summing up the fuel economy for all the different “substitutions” of the gas turbine drive by an electric one \( (N_{ini}^{uo2}, N_{for}^{uo2}) \) during the year.

To evaluate the effectiveness of the translation of the compressor station of trunk gas pipelines to the combined drive, a reliable database of initial data is needed. The algorithm for estimating the system efficiency of the considered operating modes of the compressor station consists of the following actions (in accordance with the flowchart (Figure 3)):

- forecasting and choosing the configuration of the dipped zones of graphs, summing them for a given region (based on a retrospective analysis of dispatching data) to the nearest calculated horizon;
- determination of power and consumption of fuel gas for the drive of gas turbochargers;
- detection of the possible operating modes of the compressor station according to the schedules of loads of the superchargers of the compressor station, in which it is possible to consume electric power to the drive of the gas transmission service from integrated power systems during the deficit-free period;
- calculating the regime fuel economy for nuclear power plants, gas at the compressor stations and the final saving of fuel costs in the system.

The proposed scheme of operation of the compressor station with combined drive allows:

- to increase the load of nuclear power plants during the night period of working days and on public holidays, to increase the capability utilization index of the installed capacity of nuclear power plants, while increasing their efficiency;
- eliminate the modes of night throttling at the CHPP;
- to receive additional funds from the sale abroad of fuel gas released in the gas transmission system by the partially transferring the gas transmission services to the electric drive and reinvesting the money in the development of energy, and in particular in nuclear power plants;
- to achieve reduction of emissions of NO\(_X\), SO\(_X\) and other ingredients by compressor stations and to improve the air pool in the area of along-route users.

The formula (1) with sequential summation of the effect with a cumulative total with a discount factor by years, as well as taking into account the capital investment, allows us to calculate the real system indicators, the NPV, inflow performance relationship curve (IPR curve), GDP, the payback period of expenses for the reconstruction of the compressor stations and others.

We note that in (1), the third term reflects in the system technical and economic approach the economy of nuclear fuel, in the process of its production with an increase in efficiency in the period \(t_e\) with a capacity \(N_{init}\), but with an efficiency factor higher than by \(N_{fors}\). This is determined by the fact that in the process of loading several NPP units at the expense of a group of compressor stations, switching to work from the electric drive (at the same time or at different time periods), the average weighted value of \(\eta_{UO2}^{init}(N_{init}) < \eta_{UO2}^{fors}(N_{fors})\). In connection with this, the third term is the higher, the higher \(Z_{CS} \cdot N_{CS}\) and the increase in efficiency provided by the loading of several power units of one (or different) nuclear power plants.

**Figure 3.** Flowchart for estimating the system savings of fuel costs from replacement of gas consumed by the gas transmission service upon transition to electric drive gas transmission units during off-peak hours.

It can be seen from Figure (4) that the duration of operation of the electric drive \(t_e\) and the number of compressor stations firstly affect the effect because of the increase in the difference in fuel costs to gas and nuclear fuel during the transfer of the compressor stations to the electric drive; and secondly, because of the fuller loading of more NPP units, loaded on a larger amount of load.

When re-equipping the operating gas transmission services for the combined drive, the technical and economic effect is reduced taking into account the costs of the reconstruction of the compressor stations \(Z_{et}\). Strengthening of power transmission lines with transformers and other equipment is taken into account in enlarged form in total with \(Z_{et}\).
Figure 4. Systemic economic effect by using of the combined drive of transmission services on gas-compressor stations of trunk gas pipelines.

In the computational experiments, the following values are assumed: $Z_{el} = 164;246;328$ mln rubles; $N_{CS} = 37.8$ MW(e), averaged for the duration of work of compressor stations in a year with electric drive $t_e = 8760 \cdot (0.1;0.2;0.3)$ h., that is to 876; 1752; 2628 h/year. In the case of accounting costs in the strengthening of power transmission lines and electro boiler $Z_{el} = 206; 288.4; 370.8$ mln rubles.

For the above-mentioned cost estimates, the most effective way to compensate for heat energy is primarily to increase the capacity of the base boiler houses of the along-route settlements with high boiler efficiency. It should be noted that when using gas transmission services with a combined drive and using an electric drive during the off-peak period, savings are achieved primarily by displacing gas to the external market and using cheaper nighttime electricity, and secondly, by replenishing of the NPP to higher efficiency modes. The size of the system effect depends on the size and duration of the electric drive $t_e$ in a year, the increase of capability utilization index, gross revenues, as well as the ratio of the values of nuclear fuel and gas $C_{uo2}/C_{gas}$ (inside Russia and when exporting abroad) (Figure 4) in a conditional equivalent. Discounted income (NPV), calculated on a conditionally accepted group of 10 compressor stations reaches 52,7 billion rubles during 30 years with an export price of gas of $C_{gas}=40$ rub/kg, at the same time for a price of $C_{gas}=30$ rub/kg this revenue is about 40 billion rubles.

One of the technologies that allows simultaneously adjusting the schedules of electric load of integrated power systems and at the same time ensuring the economic effect on the compressor station by displacing fuel gas, as well as improving the ecology in the vicinity of the compressor station are underground air storages created in rock salt. Analyzing the map of the Russian Federation, we can conclude that in the European part of Russia there are 7 saline basins suitable for the construction of reservoirs of this type [5]. Today, an underground gas storage facility in Kaliningrad has been created in rock salt, a similar storehouse is being built in the Volgograd region; design work on the construction of an underground gas storage facility in rock salt is conducted in the Moscow region.

Figure 2b shows one of the possible schemes of operation of a gas transmission service with a combined drive in the presence of an air storage at compressor stations. Such operation of the equipment is more realistic if at the compressor station of six units in the compressor shop – 2 are in reserve, and for a considerable part of the year the reserve is not under repair or preventive inspection. Also, the proposed scheme of operation of a station with an underground air accumulator can be effective on the basis of underground gas storage facility, where gas-pumping units are idle for 6 months or more, depending on the planned injection volume, and consequently, there is an opportunity of power supply of the station and infrastructure in the autumn-winter period. The advantage of upgrading a number of compressor stations according to the proposed type is in relative low cost. It is necessary to equip the gas-pumping units on the basis of the gas-turbine drive with an additional – reversible engine-generator and to ensure the change of the drive with the help of automatic couplings, depending on the operating mode.

The considered scheme assumes cooling of compressed air before its supply to the storage in the pheolite accumulators, followed by the use of the received heat for heating the air coming from the
storage facility before it enters the combustion chamber of the gas turbine plant. This scheme of operation is necessary to fulfill the thermal and humidity conditions imposed on underground type batteries, but, however, increases the cost of the proposed installation by the value of the land recycling batteries. A detailed description with estimates of the efficiency and cost of the battery is given in [4]. The evaluation technique was suggested by the authors in the Yuri Gagarin State Technical University of Saratov and in the Saratov Scientific Centre of the Russian Academy of Sciences on the basis of taking into account the nonstationary processes of cooling and warming up of the solid heat-accumulating substance by air blowing (in front of the air-storage) or gas blowing (for utilization of the heat of exhaust gases of gas turbine plant).

For air-accumulating power plant in this scheme, air accumulators of constant pressure are selected, which work in combination with the storage of salt water. During the extraction of air from the tank, it is simultaneously filled with salt water in an amount that ensures the constant pressure and temperature of the extruded air [6]. In this case, the heat exchanger for air heating can be excluded from the circuit. During the injection of air into the battery, salt water is forced out from the bottom of the tank into the storage of salt water, which can be placed both underground and on the surface of the earth.

In the operation of such batteries, along with the injection and removal of air from the underground reservoir along the well that connects the air reservoir with the storage of salt water, large amounts of salt water are also necessarily transported, which increases the cost of construction. To ensure the injection and extraction of air from the underground battery, the air and salt water tanks must be located at different levels relative to the ground surface.

For the mining and geological conditions of the air-accumulating power plant construction site at Slavyansk, three different designs of underground constant-pressure air accumulators have been developed by the limited liability company OOO “Podzengazprom”: two batteries with vertical locations of underground reservoirs, a two-well one and a multi-well one, and a tunnel-type tank [5].

With the accumulation of data on the cost of building of batteries of this type and introducing a differentiated on time tariff menu, objective results of technical and economic efficiency can be obtained according to the proposed scheme of operation of the compressor stations with additional generation during the deficit periods of the day. But these studies are still outside the scope of this article.

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