Operation analysis of expander-generator unit at a gas distribution station

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Abstract. The article touches upon the urgent problem of deploying secondary energy resources in the system of transportation and distribution of natural gas. Excessive gas pressure as the main component of secondary energy resources for technological processes is practically not used at gas distribution stations, where throttle devices are deployed. The proposal to utilize excess gas pressure in turboexpander both at gas distribution stations and at compressor stations of gas pipelines without preheating has not yet been widely applied, and therefore the replacement of throttle devices with turboexpander units will be determined by energy and economic efficiency. One of the effective technologies to reduce the consumption of fuel and energy resources is the expander-generator technology. In combination with heat pump units, expander-generator units allow you to create highly efficient energy-generating complexes that can generate electricity without burning fuel. The possibility of generating electricity without burning fuel by expanding high-pressure natural gas at gas distribution stations is being considered. An analytical dependence has been obtained to determine the proportion of electric energy supplied to the electric network based on the expander-generator unit in the gas supply system.

1. Introduction
The problem of energy conservation, being one of the most important in all developed countries, is becoming especially acute in Uzbekistan.

With the growth of the economy and the standard of living of the population, the need for energy has also increased. Thus, lately, the generating capacities of the country's system have noticeably increased. A 300 MW power unit at Novo-Angren thermal power plant (TPP), a 800 MW unit at Talimarjan TPP were commissioned, a project to expand Navoi TPP with the construction of a combined cycle gas turbine unit (CCGT) with a capacity of 478 MW was implemented, and a cogeneration gas turbine unit was installed at Tashkent CHPP with a capacity of 27 MW.

One of the promising ways to save energy is the use of expander-generator units (EGU) for generation of electricity through the use of technological pressure difference of transported natural gas.

However, to date, no practical measures have been taken for large-scale and effective practical use of this technology in the Central Asian republics, including Uzbekistan. Thus, for uninterrupted power supply on the linear part of gas pipelines, gas metering devices at gas distribution stations (GDS), gas
regulation points (GRP) and other gas supply facilities, the authors consider it appropriate to use EGU to generate clean electricity by utilizing compressed natural gas energy.

The effectiveness of EGU depends on the method of heating the gas before the expander.

In [1-4], various methods of gas heating using EGU and the issues of determining the energy efficiency of using EGU are considered. It is shown that when choosing a gas heating system, it is necessary to take into account how gas is used after expansion in the expander, as well as how changing the gas parameters affects the performance of gas-consuming equipment.

In [5–8], the use of EGU in industry is considered and the distinguishing characteristics of kinetic and volumetric machines are given.

In [9–11], the possibility of using EGU in boiler plants is described. Various options for heating the gas before EGU are considered: using direct network water, flue gases, or using a heat pump unit, to ensure the operation of which part of the electricity generated by EGU is utilized. The advantages and disadvantages of each of the considered methods of gas heating are shown, an exergy analysis of the proposed schemes is carried out. The influence of EGU on energy efficiency of boiler plants under variable operating modes is analyzed and an economic assessment of the use of EGU in boiler plants is given.

This article discusses the main parameters of the unit, in which the gas is heated using a heat pump [12–16].

2. Research methods and the received results

Operation and parameters of EGU are considered in two options:

1) the start-up of EGU without changing the gas flow to gas-consuming equipment;

2) the start-up of EGU affects the gas flow to gas consuming equipment and varies in proportion to the change in the available heat of the gas, taken equal to:

\[ Q^W_0 = Q^W_L + h_G - h^0_G, \]

where \( Q^W_L \) - lower calorific value of the gas, \( h_G, h^0_G \) – gas enthalpy at given temperature and pressure and at 0°C and pressure 0.1 MPa, respectively.

In option 2), the specific change in the gas flow rate \( q_{SP} \) to the gas-consuming unit at EGU start-up is also determined:

\[ q_{SP} = \frac{\Delta G_G}{N_{UNIT}}, \]

where: \( N_{UNIT} \) - net power delivered to the power grid; \( \Delta G_G \) - change in gas flow.

In figure 1 the scheme of gas heating before EGU by low-grade heat using a heat-pumping unit (HPU) is shown. A part of the energy generated by EGU is used to drive the HPU compressor.

The performance parameters of this unit are determined by selection of a refrigerant which provides the required gas temperature.

Let’s investigate the case when a change in the enthalpy of gas at the inlet to a gas-consuming installation does not cause a change in gas flow.

Due to the fact that the change in gas flow rate to a gas-consuming installation \( \Delta G_G = 0 \), then the specific change in gas flow rate to generate electricity at the unit in figure 1 \( q_{SP} = 0 \).

The amount of heat supplied to the gas, \( Q_{SUP} \), is equal to:

\[ Q_{SUP} = G_G \cdot (h_1 - h_0), \]
where: $G_G$ - gas flow; $h_0, h_1$ - gas enthalpy before heat exchanger figure 1 and before expander, respectively.

Figure 1. Diagram of EGU with a heat pump unit: 1 - high pressure pipeline; 2 - low pressure pipeline; 3 - gas heat exchanger; 4 - expander; 5 - throttle; 6 - compressor; 7 - evaporator; 8 - generator; 9 - reducing unit.

Power is required for heat pump installation

$$N_c = \frac{Q_{SUP}}{\varphi} = \frac{G_G \cdot (h_1 - h_0)}{\varphi},$$

where $\varphi$ - heat transfer coefficient.

The fraction of EGU power $\alpha_{DR}$, spent on compressor drive is determined by the following expression:

$$\alpha_{DR} = \frac{N_c}{N_{EGU}} = \frac{(h_1 - h_0)}{(h_1 - h_2) \cdot \varphi},$$

where $h_2$ – gas enthalpy after expander.

Dependence of the fraction of EGU power spent on compressor drive on the temperature of gas heating before the expander at different initial gas pressures is shown in figure 2a and heat transformation coefficients are shown in figure 2b.

The fraction of power $\alpha_{GRID}$ supplied to the power grid will be equal to

$$\alpha_{GRID} = \frac{N_{EGU} - N_C}{N_{EGU}} = \frac{(\varphi - 1)}{\varphi} + \frac{(h_0 - h_2)}{\varphi \cdot (h_1 - h_2)},$$

When $h_0 = h_2$ $\alpha_{GRID} = \frac{(\varphi - 1)}{\varphi}$, i.e. $\alpha_{GRID}$ depends only on the parameters of the heat pump, the useful power $N_{UNIT}$ will be equal to:

$$N_{UNIT} = N_{EGU} - N_C = G_G (h_1 - h_2) \cdot (1 - \alpha_{DR}).$$

If $h_0 \neq h_2$, gas flow to the gas-consuming installation changes, and the formula for determining the useful power of the unit will be as follows:
\[ N_{\text{UNIT}} = G_G \frac{Q_L^w + h_0 - h^0}{Q_L^w + h_2 - h^0} \cdot (h_1 - h_2) \cdot \left[ 1 - \frac{(h_1 - h_5)}{(h_1 - h_2) \cdot \phi} \right] . \]

The change in gas flow can be determined from the following expression:

\[ \Delta G_G = G_G \cdot \frac{h_0 - h_2}{Q_L^w + h_2 - h^0} , \]

and specific change in gas flow for electricity generation:

\[ q_{SP} = \frac{1}{Q_L^w + h_2 - h^0} \cdot \frac{h_0 - h_2}{h_1 - h_2} \cdot \frac{1}{(h_1 - h_5)} \cdot \frac{1}{(h_1 - h_2) \cdot \phi} . \]

The graphs in figure 3 show the results of calculating the dependence of specific change in gas flow on the temperature of gas heating before the expander for various \( \phi \) (figure 3a) and initial gas pressures (figure 3b).

**Figure 2.** Fraction of EGU power spent on HPU compressor drive.

a) for different gas pressures \((\phi=4)\)

b) for different \(\phi\) (\(p=6\) kg/cm²)

**Figure 3.** Dependence of specific change in gas flow on the temperature of gas heating.

a) for different \(\phi\) and \(p=6\) kg/cm²

b) for different \(p\) and \(\phi=4\)
It should be noted that if $h_0 < h_2$, then the gas flow rate to the gas-consuming installation will decrease, and when attributing the change in gas flow rate to EGU, the specific change in gas flow rate will be less than 0.

3. Conclusion

Thus, the obtained dependences make it possible to calculate the useful power of EGU, in which HPU is used to heat the gas before the expander, and the use of a heat pump unit to heat the gas before the expander allows not only to obtain electricity without burning additional gas, but also to reduce gas consumption at the gas-consuming installation due to increase in the physical heat of the gas.

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