Modelling of autonomous power source for gas distribution station using ASPEN HYSYS

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Annotation. The article is devoted to the study of energy conservation issues in gas transmission and gas distribution systems. In the Aspen HYSYS software package, the authors developed a model of an autonomous power source for gas distribution station (GDS). A brief simulation sequence is described. The dependence of the electric power of the expander-generator unit on the natural gas flow ratio is determined.

1. Introduction

In recent years, due to increased demand for various energy resources, a lot of attention has been attracted to the problem of rational use of energy, which in turn leads to problems related to energy conservation in various areas of energy activity, including transport systems and the distribution of natural gas, as well as the use of non-traditional energy sources. Speaking about energy conservation programs, it should be noted that one of the key energy conservation measures is the rational use of secondary energy resources (SER). Particular attention should be paid to both energy conservation and increasing the energy efficiency of transported natural gas, which is facilitated by the Federal Law “On Energy Saving and Increasing Energy Efficiency, and on Amending Certain Legislative Acts of the Russian Federation” of 23.11.2009 N 261-FZ (latest edition).

Our country has the most extensive and large-scale gas transmission and gas distribution network in the world. PJSC "Gazprom" accounts for about 70% of gas production in the country. The length of the main net-works alone is 160 thousand kilometers, in addition to this, PJSC Gazprom has in aggregate a huge number of gas distribution organizations. When transporting natural gas through trunk pipelines, the pressure in them should be several tens of atmospheres, most often about 7.5 MPa. Consumers, on the other hand, need natural gas with a pressure significantly lower than in the main gas pipeline, so part of the pressure of the transported gas is reduced on the gas distribution system from 7.5 MPa to 1.2 ÷ 1.5 MPa, then the gas pressure decreases again from the hydraulic fracturing 1.2 MPa to 0.2 MPa. Pressure relief on classical hydraulic fracturing and hydraulic fracturing occurs with the help of throttle devices, in which the entire potential of the differential pressure of natural gas is irretrievably lost and not used at all.

One of the solutions to the problem of energy conservation in gas supply systems is the use of an expander generator set (EGU), which is installed instead of throttling devices on hydraulic fracturing or gas distribution system, in which case the expander will be the generator of the so-called fuel-free electric power received in the electric generator.
Expander-generator units, which are utilizers of the excess energy of transported natural gas to gas distribution stations or hydraulic fracturing, can also be used as a gas engine. The possible operation of the EGU is possible not only in the schemes of gas distribution or hydraulic fracturing, but also at compressor stations. An obvious positive aspect of the application of this method of reducing natural gas is that the gas, after passing through the expander, in which it is used only as a working fluid, flows further through pipelines to the consumer, it is not combusted. Consequently, there is a complete absence of harmful emissions into the environment. Each year, expanders are becoming an increasingly promising area for research, but, unfortunately, the market for low-power EGUs (less than 5 kW) is still poorly developed in comparison with powerful units from 1.5–7 MW.

2. Technology of useful pressure difference application using EGU

2.1. Overview of existing methods for reducing natural gas pressure in gas distribution systems with energy generation

In 1947, Academician M.D. Millionshchikov proposed the idea of using high gas pressure in gas pipelines to generate electrical energy. European countries (Germany, Italy, etc.) and the USA have been using this source of almost free energy for several decades, while in Russia this technology began to be developed in the 90s of the last century. Russia's first 10 MW expander-generator unit, consisting of two EGUs, was commissioned in 1994 at Mosenergo thermal power station-21. Similar units are operated today in the Central Urals GDS in Russia, the Dnepropetrovsk GDS-7 in Ukraine. Two 5 MW EGUs (EGU-5000) of the Ryazan GDS (manufactured by Kriokor OJSC) and ETDA-1500 were commissioned at Soda OJSC (Sterlitamak, Bashkiria). The successful experience of using EGU in Russia, Ukraine and Belarus, as well as more than 40 years of experience in their application in Western Europe and America, has revived market interest in this technology. This applies not only to powerful EGUs on gas mains, but also to small units installed on gas distribution and hydraulic fracturing distribution networks, where gas reduction is carried out at low pressure (for example, from 1.8 or 1.2 to 0.3 MPa). Studies conducted by Gazprom Energo LLC have shown that turbogenerators with a total capacity of about 550 MW can be installed on the gas distribution system of PJSC Gazprom. At the same time, the average annual capacity of almost 80% of the total number of installations is in the range from 0.3 to 4.0 MW, 15% from 4.0 to 9.0 MW and 5% from 10.0 to 17.0 MW [1].

In the USSR, turbo-expanders have been used since 1985 at large gas distribution stations and compressor stations [1], and in Russia since 1994.

The advantages of high-power turboexpander generators are: low unit cost of installed capacity in comparison with gas and steam-turbine power plants; gas savings of up to 60% per 1.0 kW of generated electricity; high efficiency of the flow part from 70% to 80%; absence of harmful emissions into the atmosphere and short payback periods from 2.5 to 5.0 years.

The disadvantages are: high gas consumption EGU (from 20,000 nm³ / h); strong cooling of the gas at the outlet of the expander (at 45 ... 70 ° C); high operating costs due to the complexity of the equipment; the need to stabilize the frequency of generated electricity in the face of fluctuations in pressure and gas flow through EGU [2]. These features make it possible to use EGU in fields [3], where the temperature of the gas leaving the well is high enough, and gas supercooling in EGU is used as one of the operations of low-temperature separation, or in thermal power plants where gas consumption is quite stable and there are sources of cheap heat for heating it [4].

Currently, the development of turboexpander with power up to 50 kW is being carried out, as the most suitable for powering the power consumers of GRS, however, examples of their widespread use are practically absent [5]. The disadvantages of turboexpander with power up to 50 kW are: relatively high cost and complexity of designs; high rotor speeds; sensitivity to possible condensation; The need for a stable flow rate through an expander and high pressure [6].

There are developments of expanders with rarer types of rotary-piston volumetric machines, which were developed in 1980-1990. at the institutes of NAMI, VNIIMotoprom, at the special design bureau of rotary piston engines of AVTOVAZ OJSC [7]. The use of such expanders as a generator drive in a
EGU for power supply to gas industry facilities is impractical due to the high complexity and cost of manufacture.

The examples discussed above imply the priority use of volumetric expansion machines as a drive in an EGU, in particular rotary expanders.

2.2 The relevance of the use of EGU in gas distribution systems

The Russian Federation ranks first in the world among countries in terms of an area of 17 125 191 km$^2$, and is also on the list of world leaders in natural gas production. Russia is rich in deposits of mineral resources, including natural gas. Western Siberia is especially rich in them; it contains about 90% of the natural gas reserves. According to statistics from the Ministry of Energy of the Russian Federation, in 2018 the total production of natural and associated petroleum gas increased by 5% and thereby became a record for the entire history of gas production in the Russian Federation (725.5 billion m$^3$).

For the transport of "blue fuel" to a particular consumer there are gas distribution stations (GDS), gas distribution points (GDP), compressor stations (CS) etc., which together form a single gas transmission system (GTS). At the moment, you can see that the level of consumption and production of natural gas in our country is growing from year to year, this fact negatively affects the cost of energy and funds allocated for the preparation of gas, as well as its transportation. Consequently, there is a need to increase not only energy efficiency, but also the efficiency of gas transmission and gas consumption systems. Scientists predict that by 2030, gas consumption in the world will increase by 2 or more times, compared with the current value.

Many gas distribution facilities are located in different parts of our country. For their stable functioning, they need electricity, which in most cases is delivered through the usual overhead power transmission lines (OPTL). Depending on the distance GDP and the area of its connection to a stationary electrical network, the cost of constructing a high-voltage power line will increase with every kilometer. The cost of 1 km of OPTL is estimated at 10 million rubles, but the final price may be higher. Additional financial costs are incurred for connection to the electric grid, which vary from technical feasibility and amount to about 1 million rubles per kW of installed capacity. For the operation of electrical equipment located on GDP, it is also necessary to purchase electricity. At GDP, the main consumers of electric energy are:

1. lighting and electrical heating systems;
2. security and fire safety systems;
3. control devices for shut-off and control valves.

In total, the above-listed electrical receivers consume less than 5 kW of power in total, their rated voltage does not exceed 28 V. When powering the electrical receivers from an alternating current electrical outlet with a phase voltage of 220 V and linear 380 V, various step-down converters necessary for their operation are used. Excess energy is dissipated in them in the form of heat.

Due to various factors, technical or natural, the supply of electricity (for example, GDP) may be interrupted or the electric power will be of a low level of quality. GDP that consumes electricity from an autonomous power source will have several advantages. When creating this kind of power supply system, it is necessary to create a list of requirements to which it would comply:

1. ease of maintenance;
2. autonomy;
3. work resource more than 5 years without interruptions;
4. independence of the quality of the received electric energy from external environmental conditions.

In the gas industry, a wide range of technical equipment can act as an autonomous source of power supply.
One of the areas of energy conservation, as well as improving the reliability of gas supply systems, which is becoming increasingly relevant and interesting for research, is the use of autonomous power sources in the GTS. The role of such a source can be an expander-generator unit mounted on GDP instead of a throttling device. The gas temperature and pressure decrease in the expander-generator unit, its kinetic energy is converted into the mechanical energy of rotation of the rotor connected to the generator shaft, in which electric energy is generated. After EGU, the gas continues on to the consumer. It is important to note that gas is not burned at the same time, which completely eliminates the possibility of environmental pollution by harmful emissions.

Despite the positive aspects of the possible operation of the DGA instead of the throttling device, it is important to understand the disadvantages of this expansion machine, which impose the impossibility of its use in certain conditions. Weather conditions in summer and winter are different due to the geographical location of our country. At different times of the year, the values of the gas pressure parameters in the gas pipeline, as well as its flow rate and temperature differ significantly. Variability of gas parameters depending on the time of the year encourages the use of low power expanders (0.5 ÷ 5 kW) on GDP to cover the building's own needs.

2.3. Innovation of EGU application in gas distribution systems and analysis of market trends in this area

Unlike turbine units, a EGU driven by a rotary ex-pander can be used to generate electricity when it is used on a gas pipeline with insignificant gas extraction ≈ 100÷200 nm3/h and with a gas pressure at the inlet of about 0.08 MPa. To reduce energy losses in the process of its conversion and increase the reliability of the entire system, it is advisable to use a low-voltage generator, which will provide power to consumers of electricity on DGP with a constant voltage of 12 to 24 V (since almost all power receivers are low-voltage), which will allow abandon step-down converters and other auxiliary equipment. If necessary, the low-voltage generator can be combined in parallel operation with rechargeable batteries.

Currently, developments are being carried out in the field of autonomous power supply in the GTS based on various devices of the same power. The most common options for power supply to the expander power generating units with a generator drive from a turbine or from microturbine. But there is no serial application in gas distribution systems. At the facility where it is necessary to supply low-voltage equipment with insignificant energy consumption (telemetry and ATPCS) as an autonomous source of electric energy, unconventional energy sources are used:

- a) solar panels;
- b) installations powered by wind energy;
- c) the joint use of solar panels and wind turbines.

These sources of electricity, which were operated at various facilities with fairly low energy consumption (most often road infrastructure), have not established themselves as a reliable and uninterrupted autonomous source of electric energy, since their efficiency directly depends on geographic and climatic factors, which leads us to conclude that it is inappropriate to use these technological solutions for their use in transport and natural gas distribution facilities. Of the above possible solutions to the problem of introducing autonomous sources of electricity in the GTS, the greatest attention is paid to expander-generator aggregates, which makes this area relevant today.

Various enterprises are engaged in installations of this kind, including LLC Delta P (Moscow), this company creates and puts into operation expander-generator sets used in hydraulic fracturing with a power range of 0.1 ÷ 5 kW.
3. Development of a principal scheme with EGU

3.1. Overview of EGU schemes for power generation

There are many gas distribution stations and gas distribution points in the gas transmission system of the Russian Federation, which serve to change the parameters of the transported natural gas from the parameters that are inherent to it when located in the trunk network to the parameters required by the consumer. Depending on their geographical location, various power supply sources are used on a particular GDP, most often these are gas turbine plants, but there are also objects on which electrical energy is obtained using both renewable energy sources and autonomous power sources operating on the beneficial use of secondary energy resources. An example of such a source is an expander-generator unit.

The use of the expander-generator unit in a particular circuit at the facility primarily depends on its operating conditions and on the design features of the unit. The choice of the inclusion scheme in the GDP also depends on the goals and objectives for the solution of which it is applied.

The most common options for incorporating EGU into an GDP have a heat exchanger located in front of the EGU, which preheats the gas before it is fed to the expander-generator set. Such gas heating can be realized using fuel energy or using low-grade heat sources, in this case, there is no fuel combustion and therefore expander-generator sets operating according to this scheme are called “fuel-free” [8].

Fuel-free installations based on EGU are described in [9-10]. The study of various circuit solutions showed that there are a sufficient number of standard and modified methods for including EGU in the GDP scheme. In most cases, the expander-generator unit is usually placed in parallel with the throttling device, this method allows you to reduce the pressure of natural gas using both the EGU and the throttling device, which also increases the reliability of the system as a whole. It should be noted that in addition to schemes with the use of a heat exchanger in front of the EGU, there are also technical solutions that exclude the preliminary heating of the gas at the entrance to the EGU. The schematic diagram of one of these installations is shown in Fig. 1.

In this scheme, the throttling device 7 is necessary for preliminary throttling of the gas flow at the inlet to the expander, since if it is absent, the gas temperature at the end of the expansion process can reach a value of -80°C, which is unacceptable according to the operating standards of the equipment. Due to the preliminary throttling, the gas pressure and temperature difference in the EGU are reduced. The achievement of the required gas temperature after EGU of -30°C is carried out using a heat exchanger 5, heating natural gas, with its help it is provided to obtain cold for the consumer. The use of such a EGU inclusion circuit is advisable for GDS or GDP with a negligible ratio of input and

![Figure 1](image-url)
output pressures. However, such a solution is inefficient from an economic point of view, which prompted the development of schemes in which gas is heated before EGU.

3.2. Development of the scheme for the inclusion of the expander in the GDP

Typical design solutions for fuel-free systems based on EGU include gas heating systems, additional circuits for producing cold, auxiliary equipment in the form of air turbines and air compressors, heat exchangers. Such technological solutions adversely affect the cost of both the equipment separately and the system as a whole. The use of a large number of equipment in the circuit complicates the operation and maintenance. Together, the reliability of the system is reduced. It should also be noted that such installations are designed for high power. Similar schemes also require a rather large area for their location. In this regard, it is relevant to develop a conceptual scheme for incorporating low-power EGU in the GDP, which would completely solve all the tasks, was as simple, economical as possible, and effective.

Since the study aims at studying the possibility of incorporating low-power EGU into the GDP circuit, the following prerequisites were formulated to develop the circuit diagram: the low-power EGU is included in the GDP circuit; that allows you to abandon the various schemes of gas heating, in which there are various auxiliary units and installations.

Often used is the EGU turn-on circuit in parallel with the standard pressure regulator. Such a scheme implies the use of EGU in conditions of low unevenness of gas sampling by consumers, and also includes all the disadvantages inherent in traditional pressure regulators. A EGU switching circuit is also used after a traditional taxiway, but before the discharge of the pulse tube of the regulator's command pressure (Fig. 2).

![Figure 2. Circuit for turning on the EGU sequentially behind the gas pressure regulator: 1 - turboexpander; 2 - pressure regulator; 3 - safety shutoff valve; 4 - safety relief valve](image)

This approach allows us to reduce the negative impact of low temperature on the taxiway, however, it implies the use of low power EGU [11]. This circuit also has all the disadvantages associated with the use of traditional RP. In addition, there is no possibility of mechanical stabilization of the expander speed in case of significant irregularities in gas extraction by consumers [12, 13].

There are various automatic EGU control systems based on, one way or another, the principles of separation and switching of flows. However, such systems are more complex and have significant dimensions, determined by the use of turbine expansion machines and high gas flow rates. To include a sample of low-power rotary EGU in the GDP circuit, the solution shown in Fig. 3. Based on this circuit solution, a mathematical model of the EGU block is created in the Aspen HYSYS environment.
Figure 3. The mathematical model of EGU

In fig. 3 shows that the expander is connected via a bypass line, the supply of natural gas to one is regulated by two valves. The main gas flow goes through the main line. When the battery is fully charged, automatic control is triggered, the supply of natural gas to the expander is shut off, and it stops.

4. Creating a mathematical model of a EGU block in aspen HYSYS

4.1. The static model of the block EGU, working in the summer

Aspen HYSYS medium is used to assess the theoretical possibility of the beneficial use of the pressure drop of natural gas in order to obtain electricity using a low-power EGU. Aspen HYSYS is a software package that allows you to simulate processes in stationary and dynamic modes, which is widely used in both domestic and world science to solve a wide range of problems.

This software product determines its popularity by the convenience and simplicity of creating technological circuits of any orientation, as well as their automated calculation. For the calculation of technological schemes and processes occurring inside a particular apparatus, HYSYS contains a wide range of thermo-dynamic packages, the choice of which depends on the working fluid used at a certain stage of the technological process. The circuit shown in Fig. 3, was adapted for the HYSYS medium and is shown in Fig. 4.

Figure 4. Power unit based on a low-power rotary EGU in Aspen HYSYS
The constituent scheme in Fig. 4 with their description are summarized in table 1.

Table 1. Symbols for scheme elements in Aspen HYSYS

| №  | Designation of the element in the circuit | Item Description                                                                                                                                 |
|----|------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------|
| 1  | Methane Flow                             | The material flow of the working fluid (natural gas, hydrocarbons, air, flue gases, water, etc.) with the name assigned to it                      |
| 2  | Valve Component (Gate Valve), Position: open/closed |                                                                                                                                                |
| 3  | Mix1                                     | The mixer intended for separation/mixing of material streams                                                                                  |
| 4  | Control Valve Component (Control Valve)  |                                                                                                                                                |
| 5  | Expander                                | Expansion machine. The pressure differential in the unit is set, its adiabatic/polytropic efficiency or the required received power.          |
| 6  | Ratio CNTRL                              | A tool called ADJUST, which allows you to determine the value of a given parameter using any second parameter, taking into account their relationship. |

The inlet pressure \( P \) of natural gas at the inlet to the hydraulic fracturing is 0.3 MPa, the temperature \( t=15^\circ C \) and the volumetric flow rate \( V \) is 5000 \( m^3/h \). Since natural gas consists mainly of methane, the following assumption was made in the model: methane (CH4), is chosen as the working fluid, then used the formula for determining the gas mass flow rate: \( G=V\cdot \rho \), where \( \rho =0,72 \) \( kg/m^3 \) – methane density. Then: \( G=V\cdot \rho =5000\cdot0,72=3600 \) \( kg/h \).

In this circuit, it is also assumed that the pressure \( P \) of the two streams included in Mix2 is 0.11 MPa (the value of the gas pressure in residential waiting). Relative to this value, the hydrodynamic resistance in the Valve4 gate valve and Flap1 regulator is calculated.

The modeling process consists of a series of sequentially performed operations. To create the necessary model, you first need to select the specific composition of the material flow in a special component window. This window is located on the left of the initial screen when the program starts and is called the "Component List". Methane is selected from the list.

After the user selects the necessary substance in the corresponding window, the next step is to select the thermodynamic package in the Fluid Package section, with which the HYSYS environment will perform a full range of calculations. Each thermodynamic package or group thereof is designed to calculate certain substances. Since methane was chosen as the working fluid for constructing the model under study, the Peng-Robinson package is selected from the set of thermodynamic packages. This thermodynamic package is one of the recommended for calculating hydrocarbons.

At the end of the selection phase of the thermodynamic package, the user is given access to the working area of the HYSYS environment. The work area is a plain background, on which it is necessary to place all the necessary elements and material/energy flows. (Fig. 4).

Within the framework of the created model, the required DGA power is 1.1 kW. Regarding this value, the RatioCNTRL element allows you to determine what proportion of the main gas stream with
The appropriate parameters should be directed to the line to the EGU. As seen in fig. 5, the fraction of the flow directed to the EGU is 0.04891, which is 4.891% of the main. With the help of the created model, one can see how the ratio of the fractions of the gas flow separated in Mix2 will change, depending on the required amount of electric power generated in the EGU. In fig. 5 shows a graph of the dependence of the power N generated in the EGU on the fraction of the main flow directed to the line to the EGU, created using the Case Studies tool built into HYSYS.

![Graph of the power N generated in the EGU on the main stream ratio directed to the line to the EGU](image)

**Figure 5.** Graph of the power N generated in the EGU on the main stream ratio directed to the line to the EGU

From fig. 5 it is seen that with an increase in the amount of gas directed to the EGU, the power generated by it increases in a linear relationship. The value of the fraction of the main gas flow directed to the EGU obtained from the graph corresponds to the value obtained by the ADJUST tool. This shows that to solve one specific problem, HYSYS provides several options for its solution, since the Aspen HYSYS environment has on board a huge number of different tools designed to solve a wide range of problems.

5. Conclusion

The results of the work are new knowledge of the use of the Aspen HYSYS medium, with the help of which a mathematical model of the low-power EGU block included in the hydraulic fracturing scheme has been created. For the given gas parameters using the ADJUST and Case Studies tools, a part of the flow equal to 4.891% was determined, which must be supplied to the EGU to generate the required amount of electricity.
List of designations

GDP – gas regulatory point;
GRS – gas distribution station;
CS – compressor station;
GTS – gas transport system;
EGU – expander–generating unit;
RP – pressure regulator;
OPL – overhead power line;
ATPCS – automation of thermal process control systems;
P – natural gas pressure, MPa;
t – natural gas temperature, °С.
V – natural gas volume flow, m³/h;
G – natural gas mass flow, kg/h

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