Applying Independent Power Sources
Based on Small-Capacity Micro Turbo-Expander Generators

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As the total and specific demand for in energy of various kinds for industrial production and municipal increases the new generating facilities are consistently put into operation. Meanwhile the main kind of energy, used by mankind, is the electric energy that is pre-determined by a number of its advantages – long-term generation, convenience of delivery to end users, universality, convenience and simplicity of transforming into other kinds of energy.

Electric power is mainly generated by thermal power stations using the organic fuel – solid (mainly coal), liquid (petroleum derivatives) and gaseous (mainly, natural gas). Meanwhile the consumption of natural gas by power stations continuously grows, that gives an opportunity to decrease the harmful environmental impact.

In Russia, that appears to be the world leader in gas production, for delivery of such fuel to power stations and other facilities the unified gas transmission system comprising an advanced network of trunk gas pipelines (TGP) and compressor stations (CS) has been constructed. Open Joint-Stock Company "Gazprom" operates the most extended network in the world gas transmission network comprising about 170 thousand kilometers of trunk gas pipelines, and their length is increased each year.

Mechanical energy required for creation for energy of gas pressure and for compensation of hydraulic losses in TGP, is generated, mainly, in gas turbine units. To get such energy 0.2-0.3 % of the flow pumped through the gas station is incinerated in turbine combustion chambers of each CS. During gas transfer from locations of its production (for example, in Western Siberia) to the end user (EC countries) up to 6-7 % from total amount of pumped gas is incinerated in combustion chambers. In each of subsequent CSs fuel gas is throttled (reduced) from the pressure in TGP 5.4-9.8 MPa down to the pressure of fuel gas 2-3.6 MPa. Meanwhile the gas pressure energy is completely lost, i.e., the energy of the fuel gas, burnt in the previous stations, is actually lost.

To supply the natural gas to end household or industrial user the gas pressure shall be also decreased in gas distribution stations (GDS), i.e., reduce gas pressure from the trunk gas pipeline pressure down to the user pressure (0.3-1.2 MPa). Meanwhile, in existing technologies the gas pressure energy is also completely lost, i.e., the energy, transmitted to gas on previous CSs, is lost.

The offered concept of turbine generators utilizing the energy of gas pressure reduction, allows to create the sources, generating electric energy, without incineration of additional fuel. The implementation of the concept will allow to solve the problems of increase of energy efficiency of operation of gas transmission system, efficiency of utilization of potential of organic sources of thermal energy – natural gas.

One of the largest gas transmission enterprises in Russia, Gazprom transgaz Saint Petersburg LLC is 100 % affiliated organization of OJSC "Gazprom", operates more than 10.7 thousand kilometers of gas pipelines (Fig. 1), 240 gas distribution stations and 32 compressor shops, where 192 gas transfer units with cumulative power 1795 MW are installed.

Fig. 1. Extent of trunk gas pipelines of Gazprom transgaz Saint Petersburg LLC, km

The annual volume of gas transfer in 2013 has exceeded 130 billion cubic meters (Fig. 2), while 74 % of gas was intended to cover the export programs of gas transfer to foreign consumers. The most part of gas is transferred at the expense of operation GPU with a gas turbine drive.

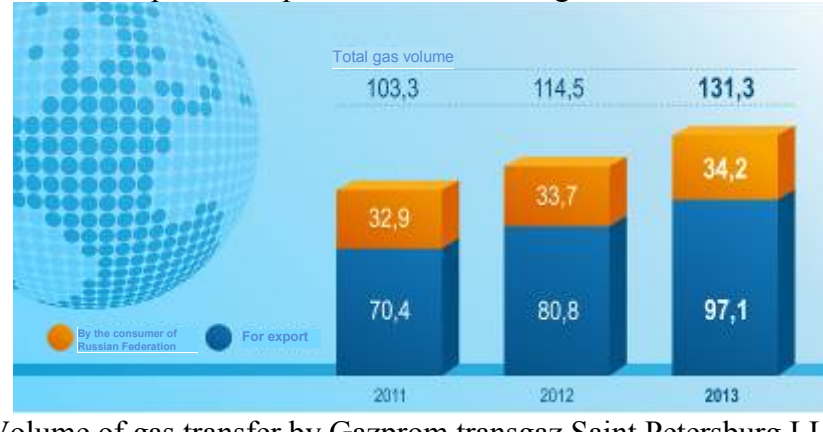

Fig. 2. Volume of gas transfer by Gazprom transgaz Saint Petersburg LLC, bln m^3

Expansion of automation and supervisory control system, and also implementation of new power consuming systems requires the increase of power loading of facilities, especially of gas distribution stations (GDS), located on vast territory. Traditional network solutions for connecting electric power of GDS mean rather high cost of construction and operation, require much time for design and survey, and civil and erection works.

To solve the problem of power supply for GDS own needs, and also to increase of energy efficiency of gas transmission system in general, micro-turboexpander generator with the electric power 20 kW (MDG-20) has been developed. The development has been performed by the specialists of Gazprom transgaz Saint Petersburg LLC in cooperation with the St. Petersburg State Polytechnical University and "Scientific and Technical Center “Microturbine technologies” LLC. On the basis of MDG-20 the independent block-type power sources for installation in gas distribution stations have been developed.

The capacity of MDG-20 has been selected after the thorough analysis of operating modes of all GDSs of Gazprom transgaz Saint Petersburg LLC. Main power consumers in GDSs are: power supply of instrumentation and automation, pumps for forced water circulation in a heating system (or electric heating of premises), internal and external lighting, and cathodic protection systems for anti-corrosion protection of metal pipes of gas pipelines.

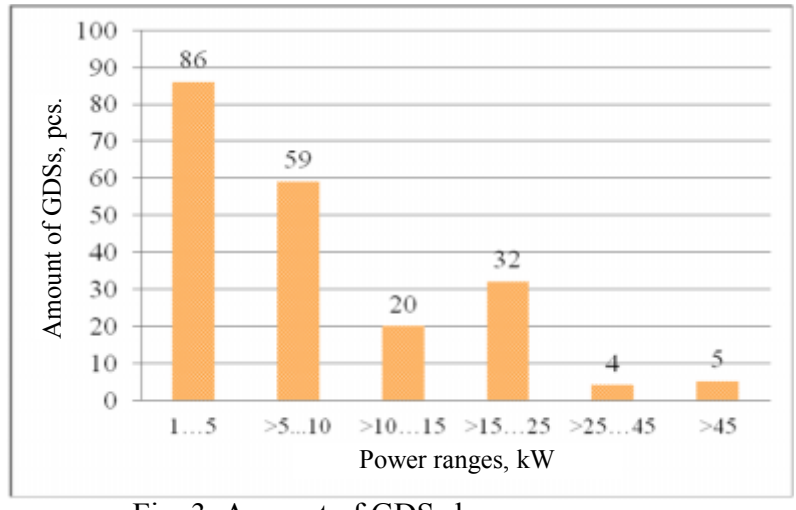

Fig. 3. Amount of GDSs by power ranges

In Figure 3 it is seen, that in most cases the power consumption for own needs does not exceed the level 20 kW and only in nine large GDSs it exceeds 25 kW. In general, in 93 % GDSs the power consumption falls within 20 kw.

On the basis of the conducted analysis the electric power of turboexpander generator 20 kW has been selected.

MDG-20 is an advanced unique and unparalleled technology. Its operating principle consists in the use of potential energy of reduced natural gas in gas distribution stations and gas control stations in locations of natural gas supply from the trunk gas pipeline to the consumer.

The following main requirements to creation of independent local power source MDG-20 have been formulated:

– generation of electric current with standard parameters;
– high reliability and efficiency;
– high explosion and fire proof;
– operational stability in a wide range of load variation;
– minimum volume of maintenance, high maintainability;
– turbine generator with a single rotor, that avoids the use of gear reducer;
– use of gasodynamic bearings, absence of oil systems.

In MGD-20 the following components are implemented:

- high-speed low-consuming turbine;
- high-speed electric generator with gasodynamic bearings.

The working process in GDS is featured by that it requires the turbine operating at high differential pressures, small flow rates and small specific volumes of a working medium (natural gas). To operate in conditions typical for GDS the turbine designed by the Leningrad Polytechnical Institute (LPI) has been selected, the idea was proposed by the professor Ivan Kirillov about 40 years ago. Such turbine allows to avoid the use of admission, that minimizes losses (Fig. 4):

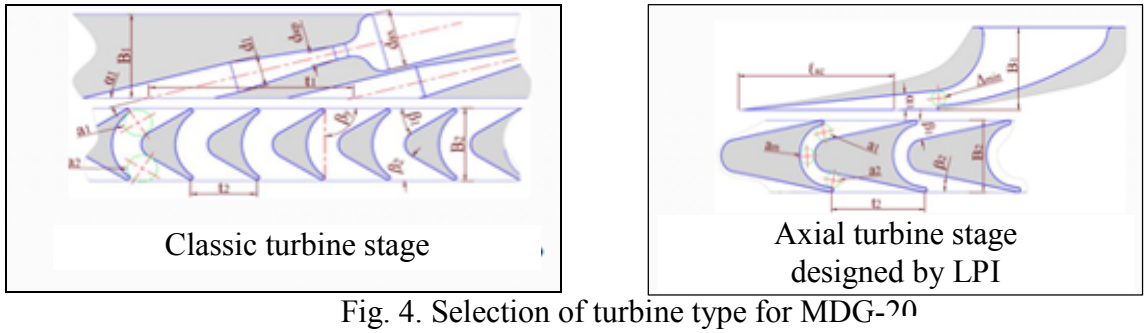

Fig. 4. Selection of turbine type for MDG-20

The turbine designed for MDG-20 is related to a new class of micro-turbines and characterized by the following parameters:

– small angles of outflow from the nozzle assembly (NA), α_1 =3...9°;

– large angles of flow deflection in the runner, θ_2=160…170°;

– small number of nozzle and rotating blades ($z_{CЛ} \geq 2$) *and* ($z_{PK} \geq 6...8$);

– supersonic regimes of working medium flow – Mach criterion: $0.8 \leq M_{C1} \leq 3.0$, $0.8 \leq M_{W2} \leq 1.8$;

– small volume flow rates of working medium with simultaneous possibility of actuation of significant differential pressures at high efficiency;

– increased erosion resistance of nozzle and rotating blades.

For GDS operating conditions the complete cycle of gas dynamic, thermodynamic, strength calculations of the turbine has been performed, that has allowed to pass to the stage of design engineering and complete it successfully.

The turbine has passed experimental test at the specially designed test bench (Fig. 5), having confirmed the calculated paratmeters.

Fig. 5. Test bench for pilot study of the turbine for MGD-20

During design of MDG-20 the spade gasodynamic bearings (Fig. 6) have been selected, because of the following advantages:

- retention of work capacity in a wide range of temperature variation;
- possibility of maintaining of high rotating speed of the shaft;
- large resource due to absence of rubbing parts;
- use of natural gas as a lubrication for working medium of the turbine;
- less friction losses, than in case of liquid lubricant;
- absence of oil system and, therefore, high fire safety and high environment performance.

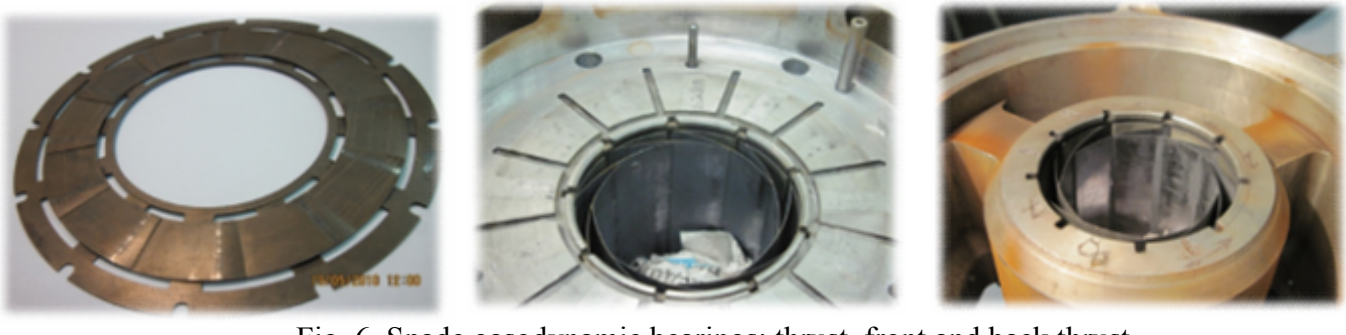

Fig. 6. Spade gasodynamic bearings: thrust, front and back thrust

MDG-20 is featured by the high-speed synchronous generator with permanent-magnet excitation designed in "NTTs " Microturbine Technologies". The generator (Fig. 7) allows to provide the compliance with the following requirements, very important for the facili[illegible] power generation:

– high reliability;
– simple design and service;
– higher, compared with analogues, output, weight and size, noise characteristics;
– simple cooling system using the natural gas, passed through the turbine.

Fig. 7. Generator for MDG-20

For the generator development the complete cycle of estimate and design works, with the subsequent full cycle of tests on benches of the developer, has been performed.

On the basis of the performed studies and available experience of development of similar turbine units the design layout of MDG-20 (Fig. 8) has been developed. The working medium (natural gas) enters the nozzle assembly of the turbine designed by LPI, where it is expanded and sent to the axial runner rotating with the speed in a range n = 0 – 40,000 rpm. The torque from the runner is transmitted to the shaft, where the rotary part of the high speed electric generator is installed. The working medium after the runner enters the outlet and is used in further for cooling of electric generator stator, and is also used for lubrication of gas dynamic supports.

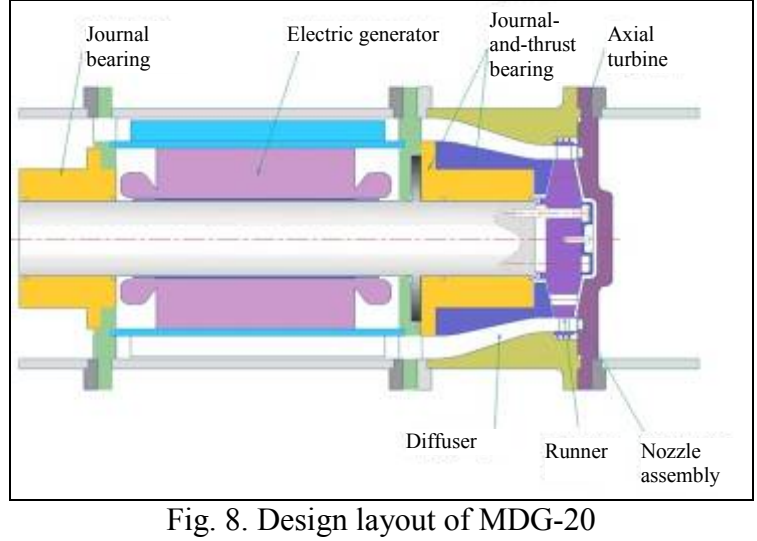

Fig. 8. Design layout of MDG-20

As a result of the performed work the pilot sample of high-speed micro-turboexpander power generator for GDS own needs with the power at the generator terminals 20 kw MDG-20 has been created.

To control its operation, and also to maintain the standard parameters of generated electric current the control unit (Fig. 9), performing the following control and information functions has been developed:

– start, stop and operation of the turbine generator in all modes, including emergency ones;

– collection and processing of the process parameters from the generator sensors, information of the state of actuating mechanisms;

– transformation of high-frequency electric energy generated by the turbine generator, into electric energy of the applicable quality for the consumer.

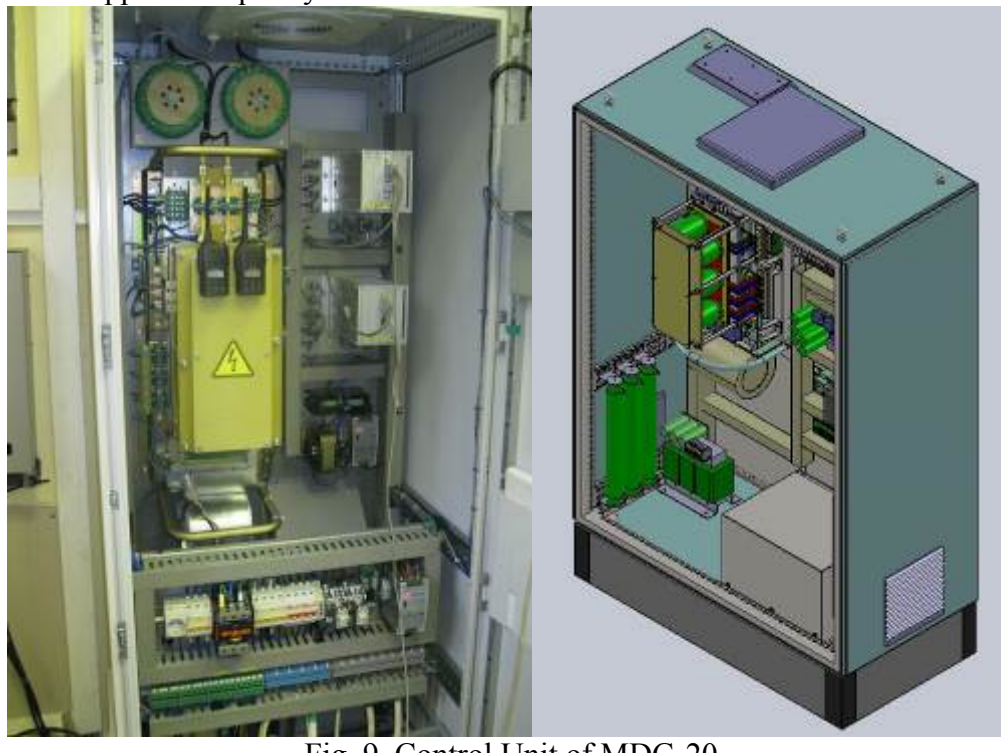

Fig. 9. Control Unit of MDG-20

For the pilot operation of MDG-20 the site of GDS "Sertolovo", the branch of Gazprom transgaz Saint Petersburg LLC - Northern LPDTGP (Fig. 10) has been selected.

Fig. 10. General view of GDS "Sertolovo", branch of Gazprom transgaz Saint Petersburg LLC branch – Northern LPDTGP

At site selection the following requirements have been taken into account:

1. For uninterrupted natural gas supply of household and industrial consumers GDS shall have minimum three reducing threads between input and output headers.

2. The operation of micro-turboexpander generator as an independent local source of electric energy is regulated by an electric load, i.e., through the turbine namely such amount of gas is passed, that is required for generation of power, consumed at the present moment.

3. Natural gas supply of end users is pre-determined by the operating modes of its process equipment and in any way is not connected to needs in electric energy i

gas load, and regulation by electric load, are not connected to each other, that shall be taken into account when selecting the GDS.

4. In view of the necessity in conducting of series of experiments requiring rewiring of both MDG-20, and process units for gas preparation and reduction, and also measuring equipment and its communications, GDS shall be located territorially within the mobile accessibility from St.-Petersburg.

MDG-20 has been mounted instead of one of four reducing lines of the GDS "Sertolovo".

The design of MDG-20 (Fig. 11) comprises the following:

– micro-turboexpander generator with the electric power 20 kW (MDG-20);

– input unit for preparation of process gas, (IUPPG);

– output unit for reduction of process gas, (OURPG);

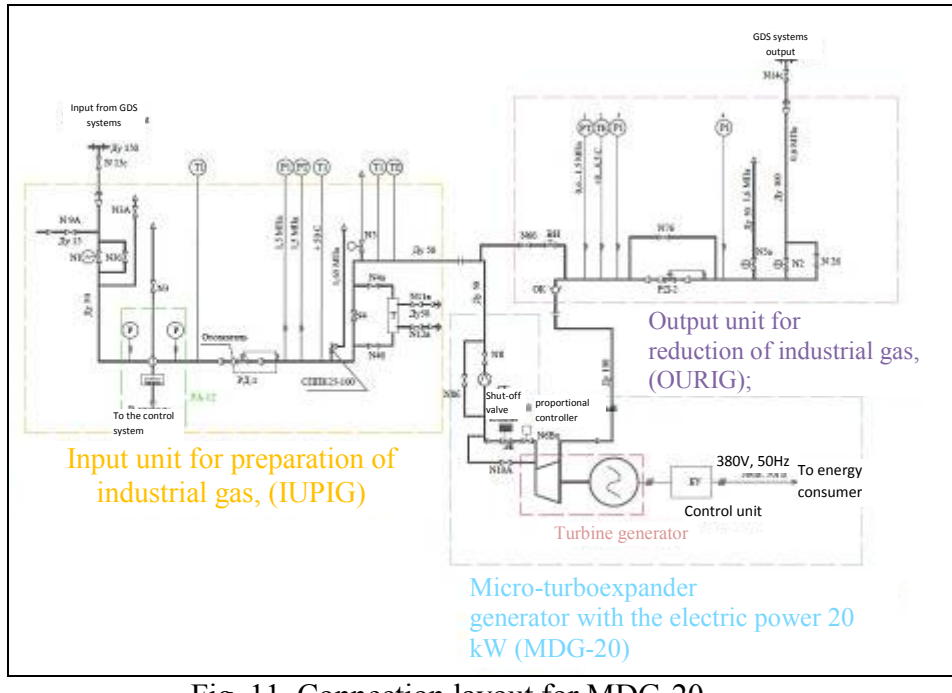

Fig. 11. Connection layout for MDG-20

Appearance of the unit MDG-20 in GDS "Sertolovo" is given in Figure 12:

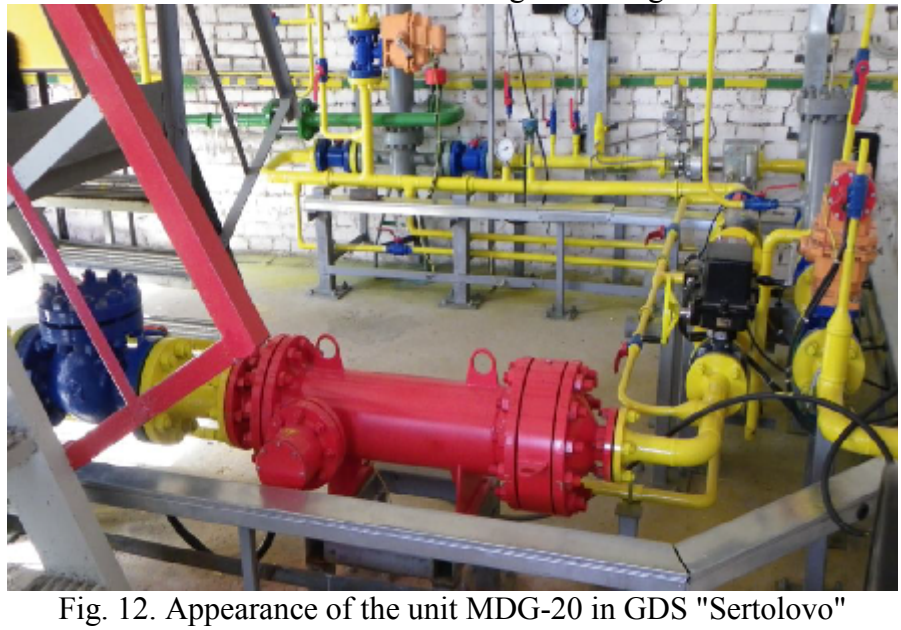

Fig. 12. Appearance of the unit MDG-20 in GDS "Sertolovo"

The pilot operation of MDG-20 in GDS "Sertolovo" has allowed to confirm its declared characteristics.

As a result of the executed estimate and experimental studies the selection of the composition, parameters, design layout has been substantiated, and micro-turboexpander generator MDG-20 has been implemented, and passed certification, has been tested and put into pilot operation.

Main characteristics of MDG-20:

Input parameter:	
Working medium:	gas GOST 5542-87
Gas pressure, MPa	1.5
Pipeline diameter, DN, mm	50
Gas purity, microns	10 maximum
Input parameters	
Gas pressure, MPa	0.6
Pipeline diameter, DN, mm	100
Rated electric power, kW	20
Rated output voltage (line), V	380
Rated output voltage (phase), V	220
Number of phases	3+PE
Frequency, Hz	50
Output voltage total harmonic distortion, %	12 maximum
General parameters:	
Turbine generator rotor rpm	36,000
Flow rate of reduced gas, nm³/h	1,700 maximum
Gas temperature drop, degrees Celsius	42 maximum
Turbine efficiency, %	70 minimum
Specified lifetime, year	20
Total amount of starts	2,500 maximum

The applied technical solutions predetermined the unique parameters of the unit: compactness, absence of oil system, reliability, long service life. Electric current of high frequency and voltages is conditioned in the control unit up to industrial parameters for supplying of the consumer. Independent power source operates completely in automatic mode without operator participation, equipped with the gas content monitoring system for internal parts, automatic ventilating, alarm system. The supervisory control system allows to perform remote control of operating modes of the unit and monitoring from the central supervisory control console. The power transformation system of micro-turboexpander generator allows to generate electric energy in a parallel mode with an external electric mains and, in case of necessity, to return excess power back into mains.

In further with the purposes of improvement pf MDG-20 the container arrangement of all process equipment (Fig. 13) has been implemented.

Fig. 13. Container implementation of MDG-20

Such approach allows to unitize the implementation of an independent power source, to configure and the equipment in factory bench conditions and to provide the stability of characteristics of MDG-20. Besides, there is no need in the individual layout for MDG-20 wiring for each of GDSs, but only the layout of connecting of the container to the existing GDS communications - gas, water and electric power.

In 2014 the similar units are to be installed at additional 6 GDSs of Gazprom transgaz Saint Petersburg LLC, and in further – at a number of other facilities of the Company and OJSC "Gazprom".

The unique joint development of the specialists of the enterprise of the Russian gas industry and Russian scientists allows to increase significantly the reliability of power supply for facilities of gas transmission systems, increase in general the energy efficiency of gas transmission system of the Russian Federation and, as a result, lower the cost price of natural gas transmission at the expense of use of potential energy of reduced natural gas.