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Thermal management technologies development for the gas transport on the gas-main pipeline

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Abstract

The most important feature of the use of variable-speed of air cooling gas fan drive units is the ability to be adapted to different conditions of seasonal operational cooling conditions not only depending on the respective monthly average outdoor temperature, but also as part of daily or hourly operation of the facility. The analysis shows that the possibility of an annual energy savings in view of the current changes by the day outside temperature is about 2500 thousand kW/h, which is 25% more than the annual savings for the average monthly temperatures project.

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Keywords: gas air-cooling unit; cooling mode; VFD; electric power

1. Introduction

Improving the efficiency of thermal management technologies in the gas transport to the gas pipelines is developed in two directions [1-6].

On the one hand, in constructive improvement terms of gas air-cooling installations (GASI), by means of which new air cooling units (GASU) type AUG-85MG, AVGB-83, AUG- BM-83 for the regulation of thermal transport of gas were developed. These devices, if to compare with previously commonly used 2AVG-75, had increased number of fans (from 2 to 6 pcs.); the drive motor power was reduced (from 6.5 to 37 kW), and respectively, the total power

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of GASU engines (from 74 to 39 kW) was reduced. Increasing the number of fans blowing provides more uniform heat transfer surface and a higher precision in achieving the desired temperature level of the cooling gas.

On the other hand, in improvement terms of automatic control systems (ACS) of direct thermal mode in order to achieve the optimum temperature of gas cooling after GASI at the lowest operating cost there can be used a variety of control methods: discrete on-apparatus; discrete order; frequency; combined discrete-frequency [1-6]. The temperature level is provided in discrete regulation with the number of GASU fans, while the frequency control is performed by means of changing their performance. The most preferred is a method of frequency control drives (VFD) of GASU motors, for which there can be formed effective temperature modes of gas transportation [1,3-6], i.e. the optimal gas temperature during the operation. It is accepted in the design practice that the annual operating costs for the drive fans should be determined consistently for each month, with an average outdoor temperature and reasonable value of the cooling temperature of the gas produced at the stage of the energy optimization of the technological site (TS).

The purpose of this work, defining its scientific novelty, is to study the feasibility of optimum cooling using CRP not only a month in a year, but also in the framework of operation for the individual GASI months (depending on the average outdoor temperature of *i*-day of *j*-month) or one day (depending on the average outdoor temperature of *k*-hour of *i*-day of *j*-month).

At the same time it is necessary to develop recommendations for the appropriate cooling mode, the practicability of CRP not only for two, but also for six-fans GASU, applying of the combined discrete-frequency method for controlling the GACU temperature modes within the scientific and practical significance of the issues.

2. Study subject

The study subject is a technological section of gas pipeline, including two compressor stations (CS) connected to the line pipe (LP). In turn, the CS combines gas treatment unit (GTU), gas compressor unit (GCU) and the gas air-cooling units, consisting of various numbers of GASU (e.g., for plant-wide layout it is 12-14 pcs.). In general, the composition and characteristics of optimal performance specifications depend on several factors, among which are: the location of the CS on the pipeline route (intermediate, end); operation period (year-round, seasonal); arrangement of equipment (plant-wide, modular); type of air-cooling gas (two and six fans); a method of controlling the temperature modes (discrete, frequency, combined).

3. Methods

In general, while the economic problem solving of informed choices it is necessary to define a method for controlling the life cycle cost of GACU [4], equipped with the required for this purpose equipment

$$C_{LC}^{GACU} = K + \sum_{t=1}^{T_{cal}} \frac{\left(C_{cool} + C_{rep} + C_{\exp}\right)}{\left(1+E\right)^t} \tag{1}$$

Where K is capital costs, which determine the composition and value of the GASI equipment, including the implementation of a digital or frequency control; $C_{cool}+C_{rep}+C_{exp}=E_{year}$ means annual operating costs of GASI, including the cost of the drive fans C_{cool}, the cost of planned maintenance work $C_{rep,}$, the cost of funding and technical expertise worn-out of GASU and control equipment C_{exp} and E is a rate of return; T_{cal} is a calculating period.

The implementation of each of these controlling methods to some extent is related to determining an optimum cooling temperature $t_{cool\ opt}$ and gas transportation. The level $t_{cool\ opt}$ is provided at discrete regulation with the number of GASI fans, while at frequency control by changing their performance. This task allows to determine the annual operating costs for fan drives using schedule downloads CS sequentially for each *j*-month at the appropriate average of outdoor temperature $t_{a\text{-}j.}$ Assessing the capital costs of GASI with different types of ACS, one can draw conclusions about the rational method of capacity control of fan air cooler gas. As a local performance criteria of GASI one can take the power consumption $N_{e,}$, its cost $C_{cool,}$ and the payback period τ_{pb} [4].

However, the VFD use allows to realize optimum cooling not only per month, depending on the respective average outdoor temperature t_{aj} of *j*-month, but also within a single operation for GASI months (depending on the average outdoor temperature $t_{a\,ji}$ of *i*-day of *j*-month), or during the day (at an average outdoor temperature $t_{a\,jik}$ of *k*-hour of *i*-day of *j*-month). This feature is highly significant, since the air temperature drops within a predetermined time period (month, day) and may be significant. For example, Δt_a of outside temperature for CS of LLC "Gazprom Transgaz Yugorsk" averages for each month is of about 20°C.

Accounting of changes in outside temperature $t_{a\,ji}$ within a month may be carried out by forming an optimized cooling mode $R_{cool\ j}=\{t_{cool\ opt\ ji}\}$, where $t_{cool\ opt\ ji}=f(t_{a\ ji})$. GASI effectiveness is also dependent on the current performance of the CS $Q_{cs\,ji}$ and temperature of the gas transported at its input $t_{k\text{-}ji}$. These parameters values within the seasonal operation may differ materially from the anticipated ones (defined in the design). Then the optimization problem for each *j*-month of operation can be formulated as follows:

$$\begin{cases} \psi = \underset{R_{cool\ j}}{opt}\ \psi(\ t_{cool\ opt\ j}, t_{a\ j}, t_{\kappa\ j}, Q_{cs\ j},\ ACS\ CRP) \\ t_{cool\ opt\ j} = t_{cool\ j}^{VFD\ COOL} = t_{cool\ j}^{OTHER\ COOL}\ , \quad j=\overline{1,12} \end{cases} \tag{2}$$

Where $\psi=\{N_{el}, C_{cool}\}$; $t_{cool\ opt\ j}=\{t_{cool\ opt\ ji}\}$; $t_{a\ j}=\{t_{a\ ji}\}$; $t_{\kappa\ j}=\{t_{\kappa\ ji}\}$; $Q_{\kappa c\ j}=\{Q_{\kappa c\ ji}\}$; $R_{cool\ j}=\{t_{cool\ opt\ ji}\}$ is a cooling mode of j-month.

Within the practice of design and operation of CS of LLC "Gazprom Transgaz Yugorsk" there were received the recommended values of $t_{cool\ rec\ j}$ for each j-month for compressor stations with different climatic conditions of operation, as a result of solving the problem of TS energy optimization. On the data basis there can be determined $t_{cool\ rec}$ $f(t_a)$, represented in Fig.1 for one CS. Therefore, the cooling mode of j-month of system (2) in special cases of the practical problems solution can be represented as $R_{cool\ j}=\{t_{cool\ opt\ ji}=t_{cool\ rec}=f(t_{a\ ji})\}$, where $t_{cool\ rec}$ is k-level of the temperature of $t_{coo\ rec\ j,}$ determines the range of values of $t_{a\ ji.}$ In accordance with the available data there were formed cooling modes, one of the most characteristic of which are: the mode for which the values of $t_{cool\ opt\ j}$ match or exceed $t_{cool\ rec\ j}$ (for example, for March month at Fig. 2); the mode for which the values of $t_{cool\ opt\ j}$ may either exceed or be lower than $t_{cool\ rec\ j}$ values; the mode for which the values of $t_{cool\ opt\ j}$ mainly are located below the $t_{cool\ rec\ j}$. In the case of $t_{cool\ opt\ ji}>t_{cool\ rec\text{-}j}$ additional electricity cost savings are achieved by less than the required number of fans running at discrete ABO controlling the flow of cooling air GASI with current CS, or due to the lower performance of all the UVOG fans for frequency regulation. In the case of $t_{cool\ opt\ ji}<t_{cool\ rec\text{-}j}$ additional electricity cost savings are achieved through more efficient operation of all specifications, such as less energy required to compress the gas at the next CS.

4. Results and discussion

GASI calculations results are made on the basis of 14 two-fan 2AVG-75C at discrete frequency and methods of regulation for the implementation of month-optimum cooling, depending on the respective average outdoor temperature $t_{a\,j}$ of *j*-month and they are are shown in Table 1.

Table 1. Annual electricity costs to drive the fan at the monthly regulation.

Power consumption	Q_{el}, Ths. kWh
When discrete monthly regulation	7172.5
At monthly frequency regulation	5243.7
Savings per year from the use of VFD	1928.8

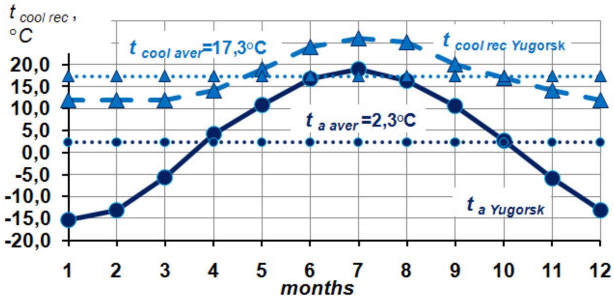

Fig. 1. The recommended temperature of the cooled gas and air.

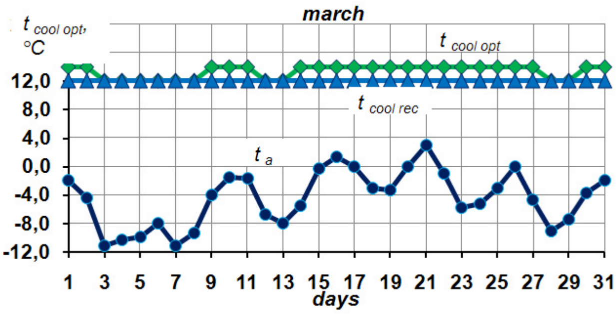

Fig. 2. Temperature mode implementing the recommended and optimized temperature of the cooling gas for March.

The results of GASI calculations at discrete frequency and methods of regulation for implementation by the day-optimum cooling, depending on the respective average of outdoor temperature $t_{a\,ji}$ of i-day when $j=3$ of March month are shown in Table 2. Annual electricity consumption for fan drives and a discrete frequency regulation rented per night performance is reflected in Table 3.

Table 2. Monthly cost of electricity to drive the fan if rented per night for regulation in March.

Power consumption	Q_{el}, Ths. kWh
When discrete regulation rented per night	589.7
In frequency regulation rented per night	385.1
Savings per month from the use of VFD	204.6

Table 3. Annual cost of electricity to drive the fan if rented per night regulation.

Power consumption	Q_{el}, Ths. kWh
When discrete regulation rented per night	6511.2
In frequency regulation rented per night	3922.9
Savings per year from the VFD use	2588.3

Our analysis shows that as a result of CS compared with discrete regulation annual savings are possible if based on the current changes by the day outside temperature at about 2500 thousand. kW/h, which is 25% more than the annual savings for the average monthly temperature design (Table 1).

The results of calculations for one of GASI CS LLC "Gazprom Transgaz Yugorsk", made on the basis of six-fan AUG-85MG or two-fan 2AVG-75C at discrete frequency and methods for plant-wide control and modular layout are shown in Fig.3 and Fig.4, respectively. Their analysis allows us to solve the problem of CS practicability not only for two, but also for six-fan GASU.

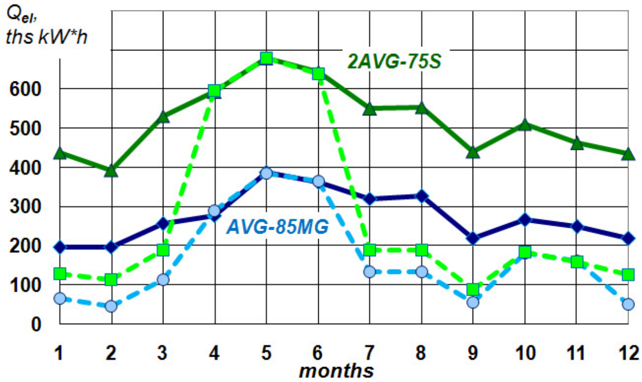

Fig. 3. Electricity consumption for fan drive GASU for plant-wide layout in discrete and frequency regulation.

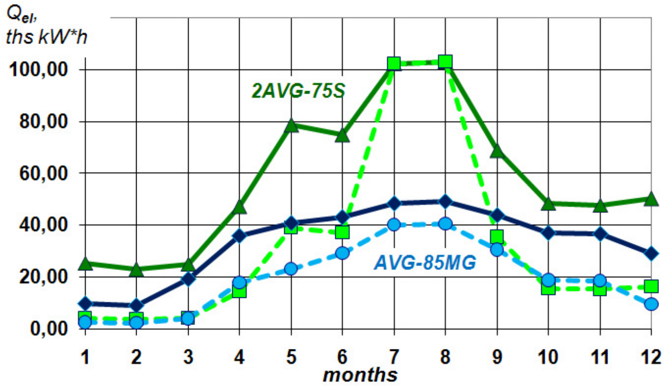

Fig. 4. Electricity consumption for fan drive GASU modular layout in discrete and frequency regulation.

As it is seen from the graphs the reduction in electricity consumption when using VFD for plant-wide or modular GASI based six-fan AUG-85MG is significantly lower than for two-fan 2AVG-75C. For example, for a modular GASI based on two sets 2AVG-75S annual savings of electricity consumption is set to about 304 thousand kW/h. And when two six-fan GASU type AUG-85MG it is set to 165 thousand kW/h.

However, when using six-fan GASU it is possible to use a combination of discrete-frequency method for controlling the temperature modes of GASI [6]. In this case, one of the fans at the GASU discrete regulation (DR) can have two modes of operation (on, off), and another part of the fans at the frequency control (FC) has the ability to change smoothly its performance. This method is associated with a loss of energy savings through the use of variable frequency drives, but also it implies lower costs on the formation and operation of automatic control systems within ACS GCU as a whole. The combined discrete-frequency method for controlling the temperature modes of GASI may be interesting in the case of restrictions on the layout of the equipment in the unit box ACS GCU within the modular technology.

Solution to the optimization problem for the combined method of regulation was considered for the CS with a modular layout of GASI based on two six-fan GASU types AUG-85MG. As one of the variable parameters there was used GASI share fans with frequency regulation, the other variable parameter was the number of disabled fans from having DR. Thus each variant of discrete-frequency layout *n*DC-*m*FC (*m*=1-12, *n*=12-*m*) was used to optimize energy consumption for cooling gas in GASI with different numbers *(n 1)* of the fan shutdown from *n,* with DC depending on the operating conditions *(j*-month). In particular, the modular layout with GASI (8DC-4FC) was examined with a number of options for disconnected fans *n1*=0-8 (depending on the operation month) of the number of *n*=8, with DC. The best mode of discrete frequency regulation (if *n1*= 8, 8, 6, 2, 1, 1, 1, 1, 1, 2, 2, 4 for the respective *j*-month) is displayed on Fig.5.

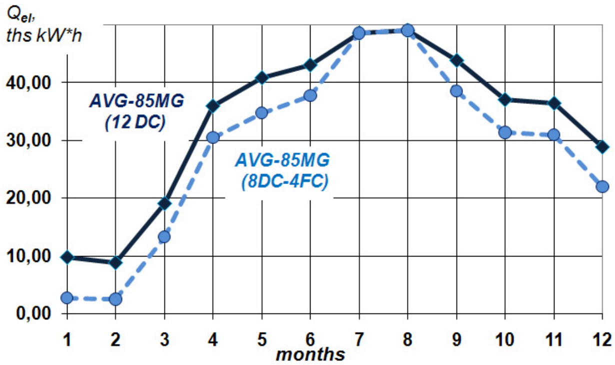

Fig. 5. Electricity consumption for fan drive GASU of gas modular GASI with the layout (8DC-4FC).

Table 4 shows the calculated values of energy consumption in discrete (DC) and discrete-frequency (D-FC) control modes for different amounts of fan motors equipped with VFD.

Table 4. Annual costs of electricity to drive the fans in the combined (DC-FC) control method.

Arrangement	10DC-2FC	8DC-4FC	6DC-6CHR	4DR-8FC	2DC-10FC	0DC-12FC
Q_{el} 12DC, thousand kW * h	400.89	400.89	400.89	400.89	400.89	400.89
Q_el-DC FC thousand kW * h	363.58	341.26	321.47	306.01	259.13	234.96
ΔQ_{el}, thousand kW/* h	37.31	59.63	79.42	106.08	141.76	165.93

When determining the payback period τ_{CVCA} there was accounted a change in the cost of equipment (in particular due to the different number of engines equipped with variable frequency drives), and the change in annual electricity consumption for fan drive at discrete (DC) and discrete-frequency (DC-FC) control modes. As follows from the results, obtained with year-round operation payback of ACS with VFD fans GASU of gas modular GASI based six-fan AUG-85MG for different amounts of variable-speed fan motors is in the range of 3-5 years. When seasonal (winter) operation payback is then the period is 6-14 years. When determining the payback period it is especially important to value ratio of ACS thermal mode of transport of gas and electricity consumed in the fan drive, which in recent years has changed significantly. In particular, over the past 5-6 years, there grew faster cost of ACS with VFD fans GASU (in 5-6 times) than the increase in the cost of electricity (in 2-2.5 times) that can substantially increase the payback period.

5. Conclusion

Thus, from the above calculation results, the following conclusions may be made:

- As a result of the VFD for plant-wide GASI on the basis of 12 two-fan units 2AVG-75S and on the basis of 14 six-fan GASU type AUG-85MG, annual savings of electricity consumption is 30% and 22%, respectively, compared with discrete regulation.

- As a result of the VFD for modular GASI based on 2 two-fan units 2AVG-75S and on the basis of 2 six-fan GASU type AUG-85MG, annual savings of electricity consumption is 43% and 41%, respectively, compared with discrete regulation.
- The cost of electricity in the frequency regulation for plant-wide like and for modular GASI based AUG-85MG generally for seasonal operation is less than 2AVG-75S
- Application of VFD for plant-wide or modular GASI based six-fan GASU with low power motors (AUG-85MG) in their year-round operation leads to a noticeable increase in payback period (in 2-3 times in comparison with the two-fan 2AVG-75C), but in acceptable limits adapted in gas industry.
- The use of combined discrete-frequency method for controlling the temperature conditions GASI is associated with some loss of energy savings through the use of VFD. For example, for the embodiment 4DC-8FC it is about 10%, and for the embodiment 8DC-4FC - 25%.
- Combined discrete frequency method of controlling the temperature conditions GASI may be interesting in the case of restrictions on the layout of the equipment in the block boxing ACS GCU within a modular technology.
- The payback period of the combined discrete-frequency method for controlling the temperature conditions at GASI year-round operation is in the range of 3-5 years. The accelerated growth in the value of ACS with VFD fans GASU (in 5-6 times) compared to the rising cost of electricity (in 2-2.5 times) can significantly increase the payback period.

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