Group control of air-cooled gas apparatuses

U H Hoshimov and O Kh Ishnazarov

Institute of Energy Problems of the Academy of Sciences of the Republic of Uzbekistan, 2-B, Chingiz Aytmatov street, Tashkent, 100084 Uzbekistan

E-mail: oybek.ishnazarov@gmail.com

Abstract. The paper considers the possibility of reducing electric power consumption by air-cooled gas apparatus of a gas compressor station. The authors propose a system with breakdown of ventilators into IV groups with five ventilators in each group. Comparison of operation modes of a traditional cooling system and a grouped one with fans speed regulation on the basis of a frequency converter showed that the grouped handling system saved up to 40% of electric power.

1. Introduction

It is well known that the fundamental measure retention of gas in the transmission cycle of long-distance gas pipelines is considered a relevant task. It is well known that natural gas needs to be cooled during transport because, after compression of the gas under a certain pressure, it is heated. Natural gas can be cooled in coolers of different systems and designs: shell-and-tube (tube-in-tube), air-compression and absorption machines, different types of cooling towers, air coolers, etc. However, the most widespread systems on compressor stations are schemes using air-cooled gas apparatuses (ACGA), where the depth of gas cooling is limited by the outside air temperature, which especially affects the conditions of Uzbekistan in the summer period of operation. The relative positioning of the heat exchange sections and air circulation fans practically determines the design of ACGA. Heat-exchange sections of ACGAs can be arranged horizontally, vertically, obliquely, zig-zagging, that identifies their layout [1].

Typical ACGAs installed in compressor stations contain parallel air coolers with fans driven by squirrel cage induction motors.

The following requirements must be met in managing of functioning of the cooling system (CS): continuing the relevant gas condition at the entirety escape, ensuring energy-efficient deal of the ACGA.

In Uzbekistan, the installed capacity of electric drives of CS can be up to 0.5 MW, and ACGAs needs at compressor stations with a gas turbine drive account for up to 70% of electricity consumption for production needs. The use of Variable Frequency Drive regulation systems for CS is an effective way to solve these problems. But for more efficient operation of ACGAs, group frequency regulation of fans is proposed. In this case, the CS are divided into four groups, with five fans in each group. For groups I and II, the fans are connected to their own frequency converter. In groups III and IV, each five fans are grouped together and connected directly to the mains supply.

2. Research approach

The explorers have considered the habituate of adjustment and temperature force of ACGA of trunk gas compressor stations in the article. Experimental studies have been accomplished to determine the most efficient group operation of ACGA. Several options of ACGA unit connection were analyzed, including
individual motor speed regulation, group automatic load-frequency regulation system (with two, three, four, five, six and seven fans), group (in this case without a converter) connection. To solve these research problems, an examination of the main gas pipeline and a compressor station was carried out, a mathematical model of ACGA was created and the state of the cooled gas was assessed before the start of work and after the implementation of the developed measures. Further, the most effective scheme and procedure for switching on/off and becharm of the AVGA operation modes were determined. The results obtained confirmed the validity of group manage based on separate CS with four separate groups of fans.

3. Literature review

As it known, many studies are currently being carried out aimed at energy and resource conservation in industries, including trunk compressor stations. One of the main consumers of electricity at gas pumping compressor stations is ACGA, for which the optimal functioning system is determined by the number of operating units, their operating modes, as well as the ambient temperature. The construction of a rational gas CS requires the use of a multistage cycle. In addition, this system must meet the following requirements for the technological process: the gas temperature can vary over a wide range, which depends on external and independent conditions. To meet the requirements of the technological process, the manage system algorithm must ensure a high quality of transients in the input and output gas temperatures, taking into account the switching on and off of II-IV groups, as well as changing the fan speed.

The authors of [2] investigated the possibility of planning the operating modes of air-cooled units based on the overall cost savings. The efficiency of heat transfer processes and the possibility of regulating thermodynamic processes were chosen as the output indicator. The optimal operation of the air-cooled gas apparatus is analyzed and determined, provided that the aerodynamic properties are observed.

Krupnikov et al. [3] studied the comparison of discrete and frequency-regulated methods of CS medium flow command for ACGAs consisting of twin-fan units of 12 and 14 units. It is shown that energy savings per year when using frequency-regulated electric drive can be about 1900 thousand kWh and 700 thousand kWh, respectively. The authors established that for CS with a small number of fans it is preferable to use frequency-regulated drive, and for plants with a larger number of fans - discrete becharm.

Abakumov et al [3] defined an energy-efficient mode of operation of ACGAs based on intelligent adaptive control. The authors set and solve this problem taking into account variability of thermal and technical parameters of compressor stations. Structural scheme of adaptive control system of ACGs with intellectual stuffing has been developed. The paper proves the possibility of increasing the efficiency of operation of ACGAs by combined use of a variable frequency drive and an intelligent adaptive direct system. Experimental results with a comparative analysis are given below.

In these works, [5-7] the authors have developed a mathematical model of operation modes of ACGAs, as well as a model of influence of technological parameters on operation mode. It is shown that pump rotation speed regulation is an important and essential factor when building a mathematical model of energy- and resource-saving system, the technological features of gas temperature maintaining in a two-stage design of the CS section in ACGAs are investigated, an equation of the thermal efficiency is derived, a method for running a frequency-regulated drive is proposed, a method and an algorithm for calculating the optimal in terms of energy saving rotation frequency of electric drives of ACGA.

Danilushkin et al [8] have determined the efficiency of automatic maintaining of CS operation modes, which can be ensured only if a two-level run system is created. The operation mode of ACGA s has been determined, which ensures minimization of electric power consumption spent on CS. As shown, the presence of a differential component "turns off" the correcting element at a constant value of perturbation. Depending on this, the authors have proposed a two-level run system, which provides correction of operating modes of electric drives of compressor station fans depending on parameters of
pumped gas and on external environment conditions by a combination of discrete and continuous command methods.

4. Discussion of the obtained results

The natural climate of the area where the compressor station is located is known to affect the energy consumption of the compressor station. It is required that the temperature of the gas leaving the compressor is close to the earth's temperature in the area where it is located, as this can otherwise lead to changes in pressure. In addition, an increase in the temperature of the gas released into the gas pipes causes damage to the protective layer of the pipes. Damaged pipes pose a potential accident risk.

In order to determine the amount of electricity consumed by ACGA and to determine the laws of variation of electricity, experimental studies have been carried out at a gas compressor station. Figure 1 then shows the load diagram of the ACGAs for one year. Figure 2 shows the gas capacity of the gas compressor station. The analysis shows that the gas transmitted and the electricity consumed are inversely proportional to each other. As a result, the variation of the normative value of electricity consumption per unit gas transmission varies from season to season, and is as high as 60%.

![Figure 1. The load chart of the ACGAs for one year.](image1)

![Figure 2. Gas throughput of a gas compressor station.](image2)
In the proposed system, as shown in figure 3, the air coolers consist of four groups. There are five fans in each group. The first group of air-cooled gas unit is connected to one frequency converter, while the remaining groups II - IV are connected to another frequency converter. In this case, for the second group, the frequency converter can only be connected to one group of CS. Group I is therefore in regulation mode and groups II - IV work as follows: if the capacity of group I fans is insufficient, the temperature rises, the 2nd frequency converter starts group II fans in a smooth manner. However, if group II is also insufficient, i.e. the temperature rises, group II fans reach their maximum capacity and are connected directly to the mains and the frequency converter starts group III fans sleeplessly. If necessary, the frequency converter can also start group IV of fans, having previously switched group III of fans to mains supply.

![Figure 3. Proposed manage structure for ACGA.](image)

The introduction of the method of splitting the ACGAs into groups using a frequency regulation achieves high results in seasonal variations at low load on the compressor station CS. This is due to the fact that the fans in this system are activated - as a result of their use in soft-start mode, high starting current values are eliminated, and when maintaining the minimum rotational speed given the direct range, a minimum consumption of electrical energy is ensured.

The electrical power required at the shaft of the fans is determined by the following formula [9]:

$$ P_{ir} = \sum_{i=1}^{N} P_{in} \left( \frac{n_{ir}}{n_{in}} \right)^3, $$

where $P_{ir}$ - actual power of the i-th fan motor, $P_{in}$ - nominal power of the i-th fan motor, $n_{ir}$ - actual (required) speed of rotation of the i-th fan motor, $n_{in}$ - nominal speed of rotation of the i-th fan motor.

Figure 4 shows a schematic diagram of an automatic CS command based on ACGA capacity manage.
Figure 4. Schematic diagram of CS manages.

According to figures 3 and 4, group I is connected to the mains via one frequency converter, and the fan speed is continuously commanded as a group. The reference signal is the information transmitted by the temperature sensor on the [10]. As a result, the power input corresponds to the power requirement needed to maintain the temperature. The minimum power consumption of the fans is determined by the expression:

$$P_{\text{min}} = 10 \cdot P_n + 5 \cdot P_n \left( \frac{n_3}{n_1} \right)^3 + 5 \cdot P_n \left( \frac{n_2}{n_1} \right)^3,$$

(2)

where $P_n$ is the nominal capacity of the fan group, $n_n$ is the nominal rotation speed of the fan group, $n_1$ is the actual (required) rotation speed of the fan group, $n_2$ - actual (required) rotation speed of the fan group (only if fan group II is connected).

As previously stated, the number of fans used in the compressor station refrigeration system under study is 20 units. The IV groups of air-cooled units operate depending on the temperature in the heat exchanger. As a result, the electrical energy consumed by the compressor station CS is defined by the following expression:

$$W_{\text{CS}} = \sum_{i=0}^{i} 10 \cdot P_n \cdot t_i + \sum_{j=0}^{j} 5 \cdot P_n \left( \frac{n_j}{n_n} \right)^3 \cdot t_j + \cdots + \sum_{l=0}^{l} 5 \cdot P_n \left( \frac{n_l}{n_n} \right)^3 \cdot t_l.$$

(3)

Table 1 presents a comparative assessment of the existing ACGAs system and the proposed (grouped) system on the basis of calculated and experimental data.

**Table 1. Electricity consumption of ACGA (in terms of heat exchanger and outside air temperature) in «motor-fan» and «frequency converter-motor-fan» systems.**

| Interim time | Nominal air-conditioning unit power $P_n$, kW | Outside temperature, °C | Exhaust gas temperature from the ACGA, °C | Number of ACGAs in operation, units | Total capacity of ACGAs in operation, kW | Electrical consumption $W$, kWh | Exhaust gas temperature from the ACGA, °C | Number of ACGAs in operation, units | Total capacity of ACGAs in operation, kW | Electrical consumption $W$, kWh |
|--------------|---------------------------------------------|--------------------------|------------------------------------------|-----------------------------------|-----------------------------------------|---------------------------------|------------------------------------------|-----------------------------------|-----------------------------------------|---------------------------------|
| 02-00        | 75                                          | 24                       | 59.9                                    | 45                                | 420                                      | 840                             | 45                                       | 10                                | 0.6                                      | 162.00                          | 324.0                           |
5. Conclusion
Thus, a comparison of the two CS options (conventional (1) and with group splitting (2)) has shown that the second option, in which all fans are split into four groups, is the most promising. This method will allow to reduce power consumption up to 40%. In the second variant, the speed of the fans is regulated by a frequency converter while maintaining the minimum speed of group I. In addition, the division into groups has reduced the load on the main compressor drive, thereby reducing electricity consumption by up to 3%.

References
[1] Kryukov O V 2013 Synthesis and analysis of electric drive units of compressor stations under stochastic perturbations Electrotechnics 3 22-7
[2] Yanvarev A, Vanyashov A D and Krupnikov A B 2018 A combined version of gas air cooling units on linear and booster compressor stations AIP Conference Proceedings 2007 030022 https://doi.org/10.1063/1.5051883
[3] Krupnikov A V, Vanyashov A D and A Yanvarev I A 2015 Determination of energy efficiency of air-cooling units based on apparatuses with different number of fans Omskiy Nauchniy Vestnik 3(93) 173-6
[4] Abakumov A M, Kuznetsov P K and Stepashkin I P 2018 Adaptive automatic control system for air-cooled gas apparatus J. Phys.: Conf. Ser. 1111 012031
[5] Ishnazarov O and Hoshimov U 2021 Mathematical modeling of electric consumption of the gas cooling process E3S Web of Conferences 264 04088
[6] Koroli M and Ishnazarov O 2020 Mathematical modeling of a heat pump and its operation modes E3S Web of Conferences 216 01165
[7] Ishnazarov O and Koroli M 2020 Combined heat supply "heat pump-solar plant" system J. Phys.: Conf. Ser. 1691 012051 doi:10.1088/1742-6596/1691/1/012051
[8] Danilushkin A I, Danilushkin I A and Danilushkin V A 2019 Improving the efficiency of electrotechnical complex of gas cooling on the basis of modernization of management system Urban Construction and Architecture 9(3) 167-74
[9] Artyukhov I and Arshakyan I 2010 Innovative technologies in energy of gas transportation magistation VII Russian Scientific and Practical Conference «Innovative Technologies in Training and Production» 1 100-1
[10] Arshakyan I I, Trimbach A A and Artyukhov I I 2008 Experience of creation and operation of gas temperature stabilization system with frequency-controlled electric drive of air-cooling unit fans Problems of Electric Power Engineering: Collection of Scientific Works 1 55-64