Designing of automated monitoring system technological processes and dispatch control of objects of the gas transport system

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Abstract. The article considers the main functional requirements and software and technical solutions for the implementation of the automation system for monitoring technological objects. It presents a solution to improve the efficiency of the automated system for monitoring technological gas transporting objects based on the research and the experimental data. A model of building a fault-tolerant automation system in the industry that allows you to monitor the performance of the main elements of the automated monitoring systems.

Keywords: Gas-pumping unit, automation system for monitoring technological objects, automated monitoring system, fault-tolerant system.

1. Introduction

Automation of production processes in the oil and gas industry is the highest form of technology development in the field of oil and gas production, processing, transportation and storage, which involves the use of advanced technologies, high-performance and reliable equipment.

Modern oil and gas producing enterprises are complex complexes of technological objects, dispersed over large areas, the sizes of which reach tens and hundreds of square kilometers. Oil and gas production is carried out around the clock, in any weather, and that is why for the normal operation of the oil and gas producing enterprise it is necessary to ensure reliable operation of automated equipment, remote monitoring of the operation of technological facilities and their condition [2].

The need for the use of modern IT solutions companies, oil and gas sector due to a number of factors: geographic scale of the business, a complex branched structure, high security requirements, the need to comply with international standards.

The most important task of the gas industry is further increase in the efficiency of the dispatching control of the gas transportation system based on the creation of complex automated technological facilities and the development of an interconnected hierarchical complex of automated systems based on dispatching management necessary to improve the efficiency of managerial decision-making [3].

Most of the domestic scientists, such as V.A. Ostrejkovsky, I.P. Norenkov, and V.V. Radkevich paid much attention to the issues of automation of design and creation of information systems. The problems of managing complex objects were considered in the works of A.A. Inozemtseva - "Program for managing the problems of a software project", V.N. Cherkassky - "Development and implementation of an integrated automated control system for technological processes of a gas transportation enterprise", Kai Xua, Hong Zhena,Yan Lib и Luo Yue – «Comprehensive Monitoring System for Multiple Vehicles and Its Modelling Study» and others.

However, despite the significant contribution of scientists and their achievements in this field of study has not yet been fully addressed issues of the automated monitoring of technological objects of gas.
transportation systems and approaches to address these issues, in particular based on the dispatch control.

There are separate software complexes based on relational databases or spreadsheets, such as the "Dispatcher's Journal", "Balances" and other applications for automating the main work of the dispatching personnel to control the gas transmission system at enterprises that were created back in the 90's. In recent years, there has been a qualitative change in the functional tasks of dispatching management; therefore, it is necessary to implement integrated dispatch control systems, including the creation of new systems and the modernization of existing ones.

2. Formulation of the problem
The aim is to increase the efficiency of monitoring processes of gas transportation system based on dispatching management.

The main objectives of the study:
1. Conduct research and analysis methods for complex automated systems of dispatching management of gas transportation system based on modern software and hardware;
2. Development of a modular SCADA system based on a distributed architecture that satisfies the functional requirements currently applied to these systems in the gas industry;
3. Construction of a mathematical model of an integrated production monitoring system for gas transmission system facilities, taking into account the specifics of gas transport production;
4. Development of functional algorithms for an automated monitoring system for technological parameters of gas transportation, ensuring stable operation of the system and continuous interrogation of technological data, excluding obtaining unreliable technological data;
5. Development and implementation of a software and hardware complex that includes a SCADA system that monitors technological processes in real time and dispatches control of gas transmission system facilities, as well as an expert automated dispatch control system for technological processes of gas transport, which increases the effectiveness and validity of making operational decisions dispatch and operational personnel.

3. Theory
The gas pressure in the main gas pipeline falls during transportation, so the gas pipeline itself is divided into sections at the junctions of which a compressor station is built; the parameters of the operation determine the mode of operation of the gas pipeline. The presence of this station allows you to regulate the operation mode of the gas pipeline in case of fluctuations in consumption.

To ensure uninterrupted gas transportation, ensuring the supply of gas at a given pressure and temperature in the main gas pipeline, the following tasks of controlling the compressor station are required:
1. Measurement of the temperature and pressure of the working medium;
2. Ensuring the necessary changes in operating conditions of equipment affecting the temperature and pressure of the working medium;
3. Cleaning and cooling of transported gas;
4. Determination of the reasons for the deviation of the process indicators from the current standards.

The process of decision-making under the traditional method of control of technological parameters, the decision of which takes a person, and the quality of this decision will largely depend on such factors as: the level of professional qualifications, quality and reliability of monitoring tools. In this case, the decision-making process, with control over a large number of technological parameters and insufficient level of professional training of technological personnel, is an iterative process, which is presented in the form of an algorithm scheme (Fig.1.).
Figure 1. The algorithm of the module operation

The decision-making process is iterative, with adjustments to the initial data on process monitoring parameters, for example, flow, pressure, temperature of the incoming gas for each data request. Due to
the receipt of incomplete information, we need to adjust the requests. The request for obtaining the necessary technological information without iterations is in this case a random process, and therefore such an order of information request has a low search efficiency for the necessary information.

The decision-making procedure in this case can be represented as the following expression:

\[ P: q \rightarrow D_j , q \in Q ; j = 0,1,2,.. m. \]

\[ D_j = f(T,V,A) = f(q), \]

where:
- \( P \) – purpose of decision;
- \( T \) – semantic query accuracy;
- \( D_j \) – some result set;
- \( A \) – efficiency of response to additional information.
- \( Q \) – some set of requests for information;
- \( q \) – content of a single request;
- \( V \) – completeness of request, information;

To solve the problems of gas flow control in operation, it is assumed in the work that the gas flow passes through a controllable circuit, therefore it can be controlled by selecting a network configuration-one partial subnet of the core network. Let us imagine algorithms that allow formulating rules using the description of the decision tree as input information (Fig. 2). A decision tree is defined as a structure where leaf nodes represent a specific class, and decision nodes represent certain procedures that must in turn be performed with respect to one of the attribute values. From the decision-making node, branches are included in an amount corresponding to the number of possible outcomes of the procedure. The intermediate nodes of the tree represent decision points about the choice of control actions based on the attributes of the data elements. The decision tree is a representation method in which a particular classification rule can be associated, which gives for each object a solution to which class to assign an object to (the set of tree leaf values). The leaves of the trees are marked with one of the classes \( k_1, ..., k_4 \).

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{decision_tree.png}
\caption{Decision tree}
\end{figure}

The plurality of messages is determined by the weighted sum of the amount of information in each individual message. The probabilities of obtaining the corresponding messages will be used as weights. Thus, we obtain the expression:

\[ H(S) = - \sum_i [s_i \log(p_{s_i})], \quad i = 1, \ldots, n. \]
It follows from the expression that the more surprising is the receipt of a certain message from the possible, the more it is informative. In the case when all messages are equally probable, the entropy of the set of messages \( U(S) \) reaches a maximum.

Let \( N \) be the number of objects in the set \( M \) belonging to the class \( k_i \). Then the probability that an arbitrary object \( k \), obtained from \( M \), belongs to the class \( k_i \), can be estimated from the formula:

\[
p(k - k_i) = \frac{N}{|M|}
\]

And the amount of information that carries such a message is

\[
I(k \sim k_i) = -\log_2 p(k - k_i)
\]

Therefore, as the next attribute for the partition, you need to select the attribute that provides the greatest increase in information. The increase in the information \( G(P) \) after the procedure \( P \) with respect to the set \( s \) is equal to

\[
G(P) = H(M) - H_1(M),
\]

where \( H(M) \) – entropy of the set of integer classes.

The fuel regulator is designed for regulating the speed of rotation, limiting temperature control, pressure and speed, positioning of the control valve, as well as automatic starting and stopping of two- or three-shaft gas turbine units serving as a drive for a natural gas centrifugal blower.

On gas pumping units, the fuel regulator can be combined into a single control system with anti-surge regulators and process controllers to create a combined control system, anti-surge protection and testing procedures for starting and stopping the whole turbomachine unit as a whole.

The fuel regulator provides the following options:

1. Measurement of the rotational speed of each of the rotors of a two- or three-seater turbine using active or passive magneto-inductive sensors included in the triple-redundant scheme;
2. Control of the speed of the power turbine (or high-pressure turbine) with a shock less transition from local to remote and back;
3. Protection against exceeding and falling of the speed of uncontrolled shafts;
4. Limiting the temperature in the combustion chamber or exhaust gas temperature;
5. Pressure limitation at the gas generator compressor outlet;
6. Positioning of the vanes of the input guide, taking into account the temperature at the entrance to the engine;
7. The limitation of acceleration (acceleration and deceleration of the rotor) and the rate of deceleration, which protects the turbine from sudden disturbances associated with a flame failure or excessively large fuel supply;
8. Adjustment of the position of the control valve by the pressure and temperature of the fuel gas;
9. Development of starting and stopping procedures according to engine manufacturer's algorithms;
10. Maintaining the operation of the redundant input and output means of analog and digital signals;
11. Configuring and adjusting the controller.

The fuel regulator can have up to 12 inputs for speed signals. It is possible to use these inputs to control the rotation frequencies of all the turbine shafts (low-pressure turbine rotor, high-pressure turbine rotor, power turbine rotor and turbine expander rotor). Each shaft can be equipped with one to three sensors [4]. The corresponding input circuits of the controller receive the frequency signals generated by the active or passive sensors of the magneto-inductive type. The controller can be configured to calculate the actual speed by:

1. Said signals;
2. Number of teeth on the measuring gear;
3. The ratio of the rotational speed of the shaft on which the measuring gear is located and the rotational speed of the turbine shaft.

In order to control the position of the fuel-regulating valve in order to maintain a given engine speed of the main engine shaft, the fuel regulator uses a proportional-integral-differential control algorithm.

In this case, the local job changes from the operator's workstation screen and the remote reference can be supplied either as an analog input signal or as a process controller.

If the pressure in the combustion chamber is too high, in the case of prolonged operation, the gas turbine can be seriously damaged. The fuel regulator minimizes this danger by implementing a limiting pressure regulation circuit for the axial compressor.
In the fuel regulator, there is a limited temperature control circuit that allows direct change of fuel consumption, reducing the temperature in the combustion chamber or the temperature of the exhaust gases. In this case, it is possible to configure so that the set point varies depending on the rate of change of temperature. Also, the upper and lower alarm set points are set and the turbine stop is configured when these values are exceeded. If temperature sensors give signals that can be considered reliable, then the signal for control purposes is selected as average, averaged or maximum, depending on the system setting [1,2,3].

Feeding a large amount of fuel into the turbine can lead to incomplete combustion and the formation of potentially explosive exhaust gases. On the other hand, a lack of fuel can lead to a flame failure, so if you do not immediately cut off the fuel supply, an explosive mixture of fuel and air is also formed. The fuel regulator makes it possible to prevent these potentially dangerous situations. This can be done by setting the minimum and maximum amount of fuel consumption that can be determined as a function of the discharge pressure of the axial compressor and the rotor speed of the high-pressure turbine.

Each fuel regulator adapts to its specific application by assigning certain values to its configuration and tuning parameters.

To increase the efficiency of automated monitoring of technological objects of gas transport, experimental studies were carried out to determine the dependence of fuel gas consumption on the operating conditions of the gas-pumping unit.

The above and other features should be taken into account when constructing a system for managing the objects of the gas transportation system. The peculiarities of the technological processes of gas transport impose serious limitations on the control systems of these processes, and therefore there is no single criterion for evaluating the decisions taken in the system of redistribution of gas transport flows, especially when it comes to management decisions. In this case, we have to solve a multicriterial problem.

4. Results of experiments
The analysis of complex automated dispatch control and control systems in the gas industry based on modern information technologies and software and hardware. During the experiment with the existing system, the operating time of the superchargers of the gas-pumping unit was recorded in critical mode. For the superchargers of types GTK 10-4, GPA C-16, GPA Ts1-16S, GTK 25 and John Brown, the average operating time in the critical mode was 8 hours (time averaged). When the proposed system for monitoring gas transportation facilities was put into operation, the time of the supercharger operation was recorded in the critical mode - 1.5 hours, i.e. the time of reaction of the system to non-emergency situations decreased. This allows the unit to operate in the rated operating mode and allows increasing the time of operating the gas-pumping unit to failure, which also allows reducing wear of the working units and mechanisms of the unit.

5. The discussion of the results
After the introduction of the proposed system based on the dependence of the fuel gas consumption of the gas compressor unit under various operating modes of operation, sudden increases in jumps in the frequency increase of the supercharger shaft speed and fuel gas consumption are not observed. The units are operated in permissible technological regimes that do not cause a dynamic change in the state of the gas compressor unit, which ensures the uninterrupted transportation of natural gas.

6. Conclusions
When implementing the proposed monitoring system for gas transport facilities, the fixed operating time of the supercharger in critical mode was 1.5 hours, instead of 8 hours on the same equipment, prior to the introduction of the system. The reaction time of the system to non-emergency situations has been reduced, and this allows the unit to operate in the nominal operating mode, increases the time of the gas compressor unit’s running time for failure, and allows reducing the wear of the working units and mechanisms of the unit.
Based on the resulting graph in Figure 3, it can be seen that there are no sharp increasing jumps to increase the speed of the supercharger shaft and fuel gas consumption, and consequently, the units are operated in permissible modes, which ensures uninterrupted transportation of natural gas.

![Figure 3. Dependence of gas flow rate on frequency change](image)

The proposed model for building a fault-tolerant system allows achieving reliability of the functioning of the main elements of an automated monitoring system. Fault tolerance of the system is provided by the introduction of the latest software and hardware, as well as the introduction of redundancy. Recovery of failed components occurs in the shortest possible time.

The efficiency of automated monitoring of technological processes of the gas transportation system objects based on dispatching control has been increased.

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