Case-Based Reasoning Approach for Automating Control of Gas-Compressor Unit Within Gas-Compressor Station

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Abstract. The aspects of Case-based reasoning system operation are described. The possibility of application such system to gas-compressor units within gas-compressor stations for revealing emergencies is considered. A functional diagram of intellectual case-based decision-support system is offered. The diagram is to minimize maintenance staff operation during control of technological gas-compression process, which leads to minimizing human factor influence on the quality of decision-making in the field of control in emergency cases.

Introduction
Gas conversion and transportation processes are ones of the most relevant in the field of production processes. Full automation of these processes provides with essential safety conditions, economical effectiveness and functioning reliability of up-to-date gas transportation system.

The main power unit of any gas transportation system is a gas-compressor unit (GCU), which is a part of a gas-compressor station (GCS). A continual activity of GCU influences transported gas volume and, therefore, economical effectiveness of the whole system. At the same time, off-schedule stop of GCU remains one of the primary reasons of economical effectiveness decrease, which demands the further elaboration of exploitation improvement methods for GCU and GCS in large [1-4].

In case of emergency, GCU or GCS operation is stopped by the maintenance staff or automatically according to the safety control devices command. Either way, it is essential not only to estimate and project current condition of station objects, but also to make decisions on effective operation of maintenance staff for emergency response in order to decrease the number of off-schedule stops and their duration. This is facilitated by adopting an intellectual decision-support system (IDSS), which includes recognizing situations and decision-making by means of recommendations or instructions for maintenance staff. A promising area is elaboration of intellectual decision-making means on the basis of Case-based reasoning (CBR) approach, which has become widely used in the field of automation of complex production processes, including oil industry [5-10], recently. The work is devoted to the issues of CBR-approach implementation for controlling GCU.

Models and Method
CBR-approach finds a solution considering precedents, i.e. uses solution found in the past for a similar problem in the present [10-14]. Precedent or case base (CB) serves as a knowledge base in CBR-systems, meanwhile reasoning consists of four basic stages, also known as CBR-cycle [13]: Retrieval, Reuse, Revision and Retention.

At the Retrieval stage one or few cases, which may be useful for decision-making in current emergency, are chosen from the CB. It is considered that similar problems correspond to similar solutions, and the cases are chosen on the base of current problem similarity to the problems described in the CB.
The Reuse stage aims at a repeated application of decision made or another information stored in retrieved cases for a new problem. Considering that, a new problem and a retrieved case may have different similarity degree, it may be required to adjust decision from a case to a new situation, which is implemented at the Revision stage. When a decision is adjusted, it may be saved into the CB along with a problem to make up a new case. This issue is solved at the last Retention stage of CBR-cycle.

An initial formation of CB is beyond CBR-cycle. It represents a separate task to be solved by different means in a certain production system. Thus, in CBR-systems for monitoring oil and gas pipelines a CB is formed during a laboratory modelling and expert estimation of condition of flows studied [15]. In the work [16] it is offered to make up a CB by involving experts, who suggest typical problems and ways to solve them considering normative documents. In the work [17, 18] it is offered to use companies’ archives, in [19] the typical cases are found in a publicly available information bases by means of text mining. In a studied GCU control system it is relevant to apply a combined method, which includes involving experts and using technological and normative documents and archives as well. Any way, an urgent issue is to elaborate a model of a formalized case representation, which will provide with algorithms for a decision search in a CB.

For describing GCU and GCS systems connected to it, it is offered to use a finite set of parameters \( x_1, x_2, \ldots, x_n \), then a situation in a control system \( S = (x_1, x_2, \ldots, x_n) \) is given as a vector in \( n \)-dimensional parametric space.

A model of a formalized representation of \( C \) case is given as:

\[
C = \langle S, D, R \rangle,
\]

where \( S \) is a vector of a problematic situation in a parametric space, \( D \) is a text description of a problematic situation with possible causes and consequences pointed out and another information, \( R \) is a decision. The decisions are represented by recommended management actions, a technological map (program) of GCS maintenance staff actions in current situation or a group of actions demanded to solve them considering normative documents. In the work [19] it is offered to apply a combined method, which includes considering normative documents. In the work [17, 18] it is offered to make up a CB by involving experts, who suggest typical problems and ways to solve them considering normative documents and archives as well. Any way, an urgent issue is to elaborate a model of a formalized case representation, which will provide with algorithms for a decision search in a CB.

A CB represents a set of parameters \( \{C_k | k=1, 2, 3, \ldots\} \). Thus, a task of a decision search in CB consists of selecting case \( C^* \) or a subset of cases, the decision \( R^* \) of which is to be offered for a current situation, under condition of effectiveness criteria. Identification of current problematic situation \( S \) takes place at the Retrieve stage, the values of \( x_1, x_2, \ldots, x_n \) are surveyed for that matter. Selection on the criterion \( \rho(S, St) \to \min \text{ or } \rho(S, St) < \varepsilon \) is implemented hereafter, where \( \rho \) is somehow calculated distance between the situations, \( \varepsilon \) is a preset selection threshold value. In the second case, the system is to suggest a subset of decisions instead of one decision.

Choosing metric for calculation distance between situations \( S \) and \( St \) appears to be a relevant issue. If parameters \( x_1, x_2, \ldots, x_n \) present the similar numerical scale, which can be achieved by normalization of current values, then the Euclidean, Manhattan or other metrics may be used [5, 6]. If the parameters are given on the mismatching scales, it is desirable to use Juravliov metric, where \( \rho(S, St) = \rho_1 + \rho_2 + \ldots + \rho_i + \ldots + \rho_n \), and \( \rho_i = 0 \) if the \( i \)-th parameter is similar in \( S \) and \( St \) descriptions or varies in \( \varepsilon_i \) limits, and \( \rho_i = 1 \) otherwise. A more universal selection model, which considers a relative significance of parameters in the descriptions of the situations, is a modification with regard for weight coefficients \( \alpha \) [15]:

\[
\rho(S, St) = \alpha_1 \rho_1 + \alpha_2 \rho_2 + \ldots + \alpha_i \rho_i + \ldots + \alpha_n \rho_n,
\]

where \( \alpha_i \in [0; 1] \) and \( \sum \alpha_i = 1 \).

In [19] it is offered to handle similarity degree:

\[
F(S, St) = 1 - \rho(S, St)
\]

or:

\[
F(S, St) = \alpha_1 f_1 + \alpha_2 f_2 + \ldots + \alpha_i f_i + \ldots + \alpha_n f_n
\]

where \( f_i = 1 - \rho_i \).

In this case, a selection criteria in CB is presented as \( F(S, St) \to \max \text{ considering } F(S, St) > F_{por} \) limitations, where \( F_{por} \) is a preset threshold (as a rule, \( F_{por} = 0.5 \)), and there is a match between the situations on the parameters from a “necessary” set \( J \), i.e., \( f_j = 1 \) for all \( j \in J \).
For a practical expert use of $\alpha_i$ parameters it is desirable to set them as degrees, for instance, from 0 to 10. Then, for application of this model the coefficients of a relative significance are initially normalized.

**Results and discussion**

For implementing CBR-system for GCS, it is advisable to consider two related variants of its usage. The first variant includes projecting and prevention emergency, when IDSS allows GCS maintenance staff on the base of existing cases to reveal a conflict situation in advance and offers GCS operator (decision maker or DM) control actions for neutralization the situation. The second variant includes revealing the situation, which resulted in the off-schedule stop of GCU or GCS. It includes offering maintenance staff an effective program of technological actions. This case considers multi-user IDSS.

The first variant is both relevant for providing with a continual activity of GCU and more simple in terms of implementation. In addition, elaboration results for this stage serve as a base for developing multi-user IDSS in the next stage.

In the process of GCU operation a modest variation of a parameter, which characterizes unit condition, may appear. Generally, a shift engineer hourly records values of all the parameters, but only the basic of them are taken into account: gas compressor beam rotational frequency, temperature in front of the high-pressure turbine (HPT) and after the low-pressure turbine (LPT), temperature and pressure at the pump inlet and outlet, etc.

From this perspective, a modest excursion of other parameters, for instance, bearing temperature, may remain unnoticed. But bearing temperature increase may lead to an emergency situation and emergency stop under the “High bearing temperature” safety control condition. It is possible to reveal the situation by increasing the number of oil air-cooling units (oil ACU). If the shift engineer doesn’t turn on oil ACU in time, the IDSS notifies to do that. Meanwhile, the IDSS continues supervising parameters, and if oil ACU activation does not give a desirable result, i.e. bearing temperature doesn’t decrease, the IDSS notifies the DM, and if there is an instruction in CS on this situation, the system reports new recommendations.

There are the emergencies, in case of which a range of parameters varies, which is to be taken into account for a precise determination of an emergency type.

For instance, if a centrifugal pump (CP) changes into a surging effect, the pressure difference in convergent tube decreases, the temperature increase at the pump inlet and the over-rise of the LPT rotations may appear. If there is a case in CB, which describes this emergency, it is to be retrieved when all of these parameters vary from set values. For instance, if the only parameter that varies is LPT rotational frequency, the odds are that the emergency has nothing to do with a surging effect. Then, emergency-preventing activities are different from the ones undertaken in case of a surging effect.

An analyze of a group of parameters, which characterize GCU condition, showed that the most meaningful parameters are: temperature in front of the HPT, after the LPT, oil-gas pressure difference, pressure difference in the convergent tube, bearing temperature, temperature after the oil ACU.

An emergency unit stop is foreseen in case of the majority of these parameters variation from the set values.

Less meaningful parameters, which characterize GCU condition, are: temperature in front of the oil ACU, inlet temperature of the CP, outlet temperature of the CP, inlet pressure of the CP, outlet pressure of the CP, gas fuel pressure, gas fuel temperature, air temperature at the inlet of the axial compressor.

Emergency settings on these parameters are not foreseen in the system, consequently, they are the least meaningful. A range of discrete parameters is to be taken into account as well. They characterize ACU and oil management system pumps condition.

As it can be seen from the examples mentioned, the most meaningful parameters are not the parameters themselves, but their variations from set values. Thus, the components of the vector of situations $S = (x_1, x_2, ..., x_n)$ may be divided into the subsets: $X_1$ – situation features, which may take 0 value if the $i^{th}$ parameter doesn’t vary from an emergency setting, 1 value – otherwise; $X_2$ – other features, which characterize GCU parameters and other systems on a numerical or a qualitative scale.

Considering the importance of features from subset $X_1$, it may be assumed that $X_1$ is a “necessary” subset of parameters, similarity of $S$ and $S_i$ on which is required while selecting a matching case in the
CB. The features from $X_2$ define a context, against which the emergency develops. The context may influence the specificities of the decision-making, as well as program and parameters of activities undertaken.

For an IDSS of a case type within GCU ACS the functional diagram, shown in Fig. 1, is offered.

Fig. 1. IDSS operation process

Two continual stages of operation are expected. At the first stage (black and red elements in Fig. 1) specialists undertake a systematic CB and knowledge base supplement. An active participation of DM, who control all system actions, is also expected.

In case of emergency, the matching cases are retrieved from the CB. For each parameter, there is a similarity degree, and it depends on parameter weight and may vary for each parameter.

The weightiest parameters are to have the highest likelihood value, for instance, a permissible variation $\varepsilon_i$ may be set in limits 2-4%. For less weighty parameters, it may be set 7-9%.

Thus, a few cases or no cases (if the situation is new) may be under the description of current situation. Then, the system adjusts the decisions described in retrieved cases to the current situation considering permissible variation of parameters according to the knowledge base. Hereafter, it makes a decision on a necessity to perform actions in current situation. A decision offered is checked by DM, corrected, and the final decision is made. All data on current case: a situation, a decision made, expected and obtained results, - are used for system training. The case is written to the CB.

The second stage (black and green elements in Fig. 1) starts from the moment when the CB includes a large enough number of cases, and the domain knowledge base is of a large size of adjustment rules for highly mismatching emergencies. At this stage it is considered that the system continues its operation, but without human action, or with minimal human activity. After selection and adjustment of a range of such cases, the IDSS independently makes decisions on actions in case of emergency.

Before shift to this stage, it is essential for a DM to estimate the system performance. DM supervises all the emergencies and system offers on revealing them during system training. Unless the system demonstrates a correct and adequate operation on identification emergencies and solutions adjustment, the DM is to engage fully into the system performance.
For accelerating IDSS training, it is offered to integrate all the GCSs, which use similar GCUs. GCU of GTK-10-4 type make up a main GCU park in Gazprom Company. Therefore, it is rational to establish an IDSS within GCU ACS with a unified training system for this exact unit type.

Conclusion

The practical issues for Case-Based Reasoning approach for automation production processes of controlling gas compressor units within gas compressor stations are established in the paper. The approach application is rational for intellectual support for GCU maintenance staff during identifying emergencies, selecting actions to reveal them and recommending effective programs of staff actions in such situations to decrease GCU force outage.

A model of formalizing cases by presenting $S$ situations, $D$ diagnoses and $R$ decisions is offered, a model of reasoning on the base of a complex similarity degree of situations considering “necessary” subset of their parameters is offered as well. An analyze of parameters of typical GCU emergencies is undertaken. A “necessary” subset of parameters and a subset of parameters, which make up a context of emergency, are established. A functional model of case-based IDSS within GCU ACS is elaborated.

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