Accounting of System Reliability in the Development of the Russian Unified Gas-Supply System Infrastructure

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Introduction

The Unified Gas-Supply System (UGSS) of Russia plays an important role in supplying energy resources not only to the domestic market but to many European countries as well. Hence, issues of providing security, reliability and uninterrupted gas supply to users are of paramount importance. Long service life of many UGSS facilities, on-going connecting to gas supply of Russian regions, design and construction of new export gas-lines (SEG and South Stream) put forward more stringent requirements to validation of design solutions for UGSS development and reconstruction.

UGSS is a unique pipeline transportation system that surpasses other national gas-supply systems in production capacities of its facilities and in the power potential of gas streams. At the same time it is under the control of single operator – JSC 'Gazprom'. All the above mentioned circumstances determine a special importance of the reliability problem for UGSS.

It's necessary to point out that the creation of the Eurasian network gas market and other projects related to the electric-power industry globalization shall inevitably increase the priority ranking of the problem of reliable gas-supply to users, and then the experience in UGSS problem solving can prove to be very useful for continental and transcontinental pipeline transportation systems in the electric-power industry.

Objectives

This paper establishes the following objectives:

- To set up and discuss problems of the UGSS reliability;
- To traverse main provisions of the new JSC 'Gazprom' standard on system reliability;
- To provide a brief description of computation procedures and their computer-aided implementations, that allow quantitative evaluation of the effectiveness of the measures for ensuring system reliability.

Until now UGSS has not experienced fatal accidents comparable in their scope to mass power blackouts on large industrially-packed territories (in North America, Western Europe etc), to the accident at the Sayano–Shushenskaya hydroelectric power station (August 2009). To a large extent the reason lies in the fact that the system reliability factor was taken into account during the formation of the UGSS structure and the design solutions for the trunk gas transportation facilities. In its turn this can be explained by the fact that the management over the UGSS development was carried out from a single center, and it was not scattered among several companies. Since the development of the pipeline infrastructure is slow, and the expenditures required for it are rather large, the measures for ensuring the system reliability should be developed well in advance.

Reliability. Various Aspects of the Reliability Problem.

The notion of reliability is defined in accordance with the standard, adopted in Russia. For large power industry systems (including UGSS) it is interpreted more widely [1], than for the systems of general technical purpose. UGSS reliability is the system characteristic to fulfill the prescribed functions, i.e. to provide the users with gas while meeting the

requirements as to its quality. Reliability is positioned as a comprehensive characteristic that includes certain individual characteristics, namely: failure-free operation, recoverability, survivability, manageability, repairability, and longevity. Reliability indices are figured out depending on the specifics of the target and, accordingly, the most important characteristics of the reliability.

The issue of reliable energy-resources' supplies to RF regions and functioning of UGSS facilities and subsystems is multilayered, but the most critical stages are planning of UGSS development and designing its facilities. The system structure should be designed to supply the agreed gas quantities, including in extreme conditions: extremely low temperatures in the regions where the main gas users are situated and system outages. The validation of the system development programs and large-scale and global projects includes examination of options with regard to future consumption volumes and probable withdrawal from the main gas producing regions. One of the basic criteria for comparison of options and selecting the preferable one is the securing of reliable gas transport.

The key indicators of the delivery stability should also be taken into account during signing of export contracts.

Another aspect in the problem of the system reliability consists of ensuring uninterrupted gas supplies from main trunk pipelines to each gas distribution plant (GDP). Technologically this aspect corresponds to the territorial gas-supply systems and includes such facilities as trunk gas-distribution pipelines, gas pipeline branches and GDP. In proportion to the UGSS development, the flexibility of the territorial gas-supply systems is increased, the systems' structure is changed from mainly dead-end to loop-back ones.

The problem of reliability is closely connected with safety: technological safety measures lead, as a rule, to higher supply reliability indices and vice versa. One should pay for safety. Validation of the investments in reliability and safety enhancement face certain difficulties for several reasons. The main ones are as follows:

- Damages from interruptions in gas-supply are difficult to authentically evaluate, especially if we take into account not only direct but consequential damages as well;
- Outages are incidental, and technological disasters are rare, since they can either happen or not happen, so for many persons who are responsible for decision-making, the arguments about the necessity of the expenditures for the prevention of accidental, or moreover unlikely, events do not seem convincing.

Lately the necessity of taking into account of the reliability factor has been regularized. A new industry standard – STO Gazprom «System Reliability of Gas Transport and Stable Gas Supplies to Users [2] (hereinafter - the Standard) has been developed and put into force.

The Standard establishes the requirements to ensuring system reliability and stable gas supplies to users in design of the trunk lines facilities and their development and reconstruction planning; it complements and develops the existent regulations in this field.

The Standard requirements apply not only to the design and decision-making procedures but to the development of special software in this field as well.

Methodology.

The standard makes it obligatory that the decisions (including the reliability decisions) on the development/reconstruction of UGSS and its major subsystems should as much as possible take into account the specificity of its facilities together with technological, economic, social, environmental, and competition requirements.

The standard is based on the principles of systems approach to design implying that the following should be taken into consideration:

- the development (reconstruction) of a major facility is treated as a UGSS development stage;
- the requirements are to be made both to UGSS elements and facilities, and to the system in general;
- a quantitative evaluation of the reliability of gas transport and gas supplies to users is undertaken;

- the design solutions are validated with regard to reliability indices;
- the crucial design solutions are selected on a multi-criteria basis.

The Standard development has accumulated the Russian experience in the theory and practice of strategic and design solution validation with regard to reliability assessment. Methods of calculation of reliability indices are not of a general technical character, but meant for pipeline systems and take into account their specifics [3].

Since the UGSS development stages are characterized, first of all, by commissioning of trunk gas-lines (TL), the document sets forth the requirements to do additional investigations for the systems analysis of the situation and justification of the designed TL parameters

It is recommended to validate the design solutions for development/reconstruction of UGSS facilities, firstly, on the basis of the results of computed model calculations, and, secondly, on the basis of experts' judgments. For the expert analysis, teams of specialists are established and the expertise and processing of results are carried out by the hierarchy analysis method. This method allows clear identification and ordering of the experts' judgments. Experts' judgments are processed with the help of computer software.

During the standard development foreign experience has been taken into the account. International and national standards have been analyzed in the sphere of reliability of oil and gas complex facilities, as well as national standards in the sphere of technological systems' reliability. It provided additional arguments in favour of abandoning the valuation of the reliability numeric values of such complicated industrial facilities as trunk gas-lines. It is not possible to envisage and cover all potentially necessary factor combinations upon which the reliability indices depend. Recording of the reliability indices would prevent progress in the sphere of improving the current and appearing new technologies for the prevention and preventive measures against pipes and equipment failure.

In accordance with the new standard, the selection of measures for the reliability insuring – reliability management – is carried out at all stages of the project development, during construction and assembly operations, repairs planning and operation of the UGSS facilities. As the initial information is specified and the knowledge about the facility under the design is enhanced, the decisions on reliability enhancement are elaborated and where required, corrected.

To manage the reliability various methods and means which are summarized in the table are applied. For each measure an advance time level for its implementation (planning time-frame) is indicated.

Table: Classification of Reliability Enhancement Measures, Taking Planning Time-Frame into Account

Methods and means of the reliability enhancement	**Planning time-frame**			
	10-30 years	5 - 10 years	1 - 5 years	1 year
Structural decisions at the systems level	■			
Excessiveness and reserves at the systems level	■			
Decisions on reconstruction	■		■	
Selection of technology	■	■		
Backing up of the production capacities during the selection of the facility's main technological parameters (including calculated reserve)	■	■		
Excessiveness at the equipment level		■		
Selection of materials, schedule-size of the equipment and manufacturing plants		■		
Automation and informatization, measuring equipment		■	■	

Methods and means of the reliability enhancement	Planning time-frame			
	10-30 years	5 - 10 years	1 - 5 years	1 year
Streams' maneuvering, reserves management;				
Diagnostics				
Measures ensuring the industrial safety				
Environment protection measures				
Repairs and technical maintenance strategy				
Repairs and technical maintenance quality				
Reliability tests				
Concept of management and operation organization				
Management and operation (human resource management, human-computer interaction)				

During the gas-transport system's planning stage the reliability requirements are taken into account at the comparison of scenarios, each of which is characterized by a long-term gas streams diagram. The analysis of supply reliability for aggregated users (stream diagram components) is provided for each of the stream diagrams under review.

Optimization of the decisions (the selection of an efficient design solution) to ensure reliability is carried out within the limits of the compliance with the current requirements and restrictions. The optimal option is selected from a number of targeted options by way of their comparison on a multi-criteria basis. Whenever possible, during all design stages the requirement of simplicity and unification of the adopted decisions is taken into account as well. Professional qualification of the project team members in the sphere of providing GTS reliability is the required condition of the design solutions' optimization.

During the development stages of the investments' validation the reliability of the facilities under design is provided by means of clarification of conceptual decisions which were adopted at the level of the design of branch development master plans. The requirements subsequent upon the gas streams adopted for the long-term, are taken as the basis. The reliability of the facility under design is influenced by the decisions on the selection of:

- the technology;
- main technological parameters;
- directions of the gas pipeline routes;
- routing on the terrain;
- the materials, schedule-sizes of the equipment and manufacturers (steel grade, availability and quality of internal and external pipe coating, design and quality of the equipment manufacturing);
- the pipeline electrochemical protection system;
- technological diagrams of the facility;
- matching the facility under design with the stream-distribution system and the gas resources management system;
- equipment pool (redundancy);
- the productive capacity reserves and their distribution among the gas-pipeline facilities;
- the automation and informatization systems of the facility under design in relation to its instrumentation and fitting out with the diagnostic equipment; methods of increasing of the industrial and fire safety;
- environment protection methods.

Reliability indices.

The generalized quantitative characteristic of the designed TL reliability is the reliability factor $K_{нд}$ [4] – a ratio between the average and nominal supply volumes.

$$K_{нд} = \mathbf{E}x / Q, \quad (1)$$

where $\mathbf{E}$ – is the expectation operator, x – factual gas supplies, and Q – the demand. Along with $K_{нд}$, to justify the enhanced reliability measures, other reliability indices are also employed. First of all, the indices that are calculated on the basis of the functions of the gas supply distribution to the users: quantile of the under-delivery distribution for a certain period of time. For example, $P_{\gamma,t}$ probability that the supplies to the user will provide for no more than $100\gamma\%$ of the demand for the time interval t

$$P_{\gamma,t} = \mathbf{P}\{x_t \leq \gamma Q_t\}, \quad (2)$$

where x_t – is factual deliveries, and Q_t - the demand for the time interval t, $\gamma = 0{,}5;\ 0{,}25$ и др. etc , and *t* = 1 day, 1 week etc. Probabilities of disastrous events are also important indices, for example,

$$P_{t,\gamma} = \mathbf{P}\{x_t = 0\}, \quad (3)$$

The probability that for the time period *T* (years) the gas supply to the users will be fully cut off for the time period *t*.

Comparison of various options (strategic development programs, design solutions) is carried out on the basis of the totality of reliability indices that allow taking into account comprehensively various aspects of ensuring reliable gas supplies to users.

In performing the reliability indices calculations, preference is given to the dedicated methods and algorithms that take into account the functioning specificity of the UGSS facilities functioning.

Methods of the reliability index enhancement

The reliability of gas supplies to users is provided by a rational combination of the own reserves of the gas-line capacity and the production capacities' reserves of the multi-string corridor and system reserves due to interaction of UGSS gas production, transport, storage, and distribution facilities. Comprehensive analysis of the interrelations between all processes and a combination of different backup techniques optimize the expenses at high reliability of gas supplies.

Methods and means of the backup techniques of the facilities and subsystems of the trunk transport are divided into the system and intra-facility ones (within the limits of TL and TL right-of-way).

The system means include:

– construction of gas-pipelines-locks and inter-system locks, that ensure the stream distribution during the long-term, seasonal and emergency control;

– construction or reconstruction of UGSF and/or other gas storage facilities interacting with the facility under design; UGSF ensure a fuller use of the production capacities of the facility under design, decrease the gas deficit for the users during the period of break-downs and peak demands;

– creation of the production capacity reserves (back -ups) of the gas producing enterprises for the period of excess demand;

– field development and field facilities construction of the regulating fields.

Own capacity back-up of the gas pipeline or the gas-pipeline corridor is determined by the following methods and means:

– selection of the reasonable structure for the gas line (the CS sites, operating pressure, linear segment's diameters and number of strings, compressor equipment configuration at each CS);

- GCU back-up at CS;
- rational division of the pipeline into sections;
- erection of locks in the linear segments between the strings of a multi-string corridor;
- erection of inter-shop locks that allow combining the CD (compressor department) aggregate reserve and enhancing the possibility of a maneuver at the CS;
- implementation of reasonable piping lay-outs of CD and the aggregates inside the department.;
- reasonable selection of GCU unit capacity or a combination of unit capacities of each CS and CD in general to ensure flexibility (manageability) of the facility;
- providing a load (operating) reserve for CS and CD;
- linear redundancy by way of pipe-laying of parallel strings and loops at the most important pipeline sections (water and mountain crossings, etc).

Justification of reliability measures.

Reliability measures are put together on the basis of special investigations (with the application of indices (1-3)) for each gas line under design taking into the account of its specific peculiarities. The back up methods and volumes are selected when the main decisions on technological scheme of gas transport are adopted, i.e. when the sites for CS, string diameters, equipment schedule-size and the structure of the linear segments and CS are adopted.

System reliability enhancement measures are validated following the results of special investigations. The UGSS gas stream diagrams for the long-term and short-term and the options of reliability enhancement measures serve as the input data for the calculations. In the course of calculations, situations are analyzed that might occur during system functioning, best solutions (distribution of streams) are found for each situation, and the resultant reliability indices are calculated, which allow assessing the importance of every UGSS facility in providing gas supplies and their stability so as to choose the best set of measures.

Software

Following the ISO practice, the Standard does not specify formalized (computation) procedures, computation methods or algorithms; it rather prescribes the necessity of doing this validation or another.

For implementation of the computation procedures applied during the validation of the reliability enhancement measures, JSC «Gazprom promgaz» has developed special software (SW). Here it is necessary to mention, first of all, the VTP MG software system for simulation of modes, selection of optimal parameters and calculation of trunk gas-line reliability indices; and the SINAGS software system for calculation of reliability indices of supplies to users of UGSS and its major subsystems. We'll point out certain traits that characterize the developed SW:

- modern and wide-spread computer technologies are used as evaluation environment;
- the concept that envisages a general data base for the solution of a wide range of design issues, reconstruction planning and the trunk gas transport system development, has been taken as a basis;
- systems have got an advanced service and are user-friendly;
- SW and its methodological and algorithmic base have been developed by domestic specialists that suggests the opportunity of adjustment in accordance with the end users' requirements.

Conclusion

The paper presents a contemporary approach to the issue of ensuring reliable gas transport. Certain provisions of STO «System Reliability of Gas Transport and Stable Gas Supplies to Users» have been tackled. Methodological basics for the systems analysis of the design solutions for development and reconstruction of UGSS facilities in terms of provision

of reliable and stable gas supplies to users have been set forward.

Literature Reference

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