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# GAS TRANSMISSION SYSTEMS OPERATION OPTIMIZATION



**In this article the author has analysed a problem of finding optimal operating modes of gas transmission systems. The article also contains the list of factors which influence an optimality of separate subsystems and the gas transmission system as a whole. Estimates of optimization potential for separate technological objects and subsystems of the gas transmission system are made. The author also offered the solution to the problem.**
**Keywords: gas transmission system, optimization potential, optimal mode, compressor station, underground gas storage.**
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## Introduction

The gas transmission system constantly works in an unsteady mode, which predetermines changeability of its fuel and energy costs. These costs are considerable and therefore its operating in near-optimal modes is important. Optimal operating of the gas transmission system (GTS) is related to many factors: the availability of a sufficient volume of accumulated gas in pipelines and underground gas storages (UGS), the seasonality of gas storage operation, unevenness of the outflow from the system and the inflow into the gas system etc. The human factor is important too. Making a timely decision concerning changing the mode of gas transportation can yield considerable economic effect. For a fast assessment of the current operation mode, in the presence of the certain forecast of input-output gas parameters, it is necessary to do a prior research to establish a domain of the optimal operating of the main gas pipelines. Usually forecasts do not come true in full. Therefore the optimality domain should be formed with the use of minimum information, under conditions of existence of uncertainty.

The gas transmission system was designed for a certain nominal load. In recent years, the system load has decreased considerably (due to a sharp decrease in both gas transit to Europe and its consumption within this country), which predetermines the GTS operating in non-rated regimes. The GTS operating in partially reverse mode (through the certain sections of gas pipelines) belongs to non-rated regimes. It is used for both providing local consumers with gas and gas inflowing into the system.

Besides, in recent years, the information on the optimal modes has become also important for an assessment of minimum financial and technical resources to be allocated for GTS modernization. Only the optimal mode answers a question which compressor stations (CS) shops and sections of gas pipelines are to be modernized in the first place. This can also help to choose a gas compressor unit (GCU) with regard to its drive, power, and a type of centrifugal compressor in order to use minimum fuel and energy resources during its operating in predicted modes.

Let us consider major factors of influence on the GTS operation mode. Among the main factors it is necessary to single out daily and seasonal fluctuations of gas consumption, seasonality of processes of gas injection into the gas storage facilities and its withdrawing. Of great importance there are so-called peak (or maximum) loads of system. In such regime the amount of gas being withdrawn out of the system and, respectively, out of the gas storages is the highest.

Partial load of the system does not require a maximum use of the whole capacity of the existing gas storages. In the past in winter periods, with insufficient system deliverability, the required export amounts of gas were provided with gas reservoirs in the west of Ukraine. Currently with excessive deliverability of the system, additional tasks have arisen to provide an optimal planning of gas storages operation and mode control throughout the withdrawal seasons. These tasks include determining gas volumes to be stored; its distribution to storage facilities according to those volumes; formation of operation modes for the whole UGS and for groups of technologically connected UGSs so that throughout the gas withdrawal period the residual active gas provide the maximum total peak withdrawal rate.

**The problem statement is**: to determine the domain of the GTS optimal operation for variable initial-boundary conditions of gas consumption, to formulate conditions of optimal operation of technologically connected main gas pipelines and to find domains of their optimal operation as functions of total inlet and outlet gas consumptions for the given volumes of the accumulated gas in pipelines.

## Description of the object of research

The main export gas flows pass through the single-strand and multistrand gas-mains (GM) with both identical and different nominal gas pressures. Gas cross-flows within subsystems with different nominal pressure are regulated with bypass valves, reducers, consumption regulators and the like. When the bypass valve is open (its internal diameter is significantly less than the internal diameter of the gas pipeline) the gas flow is reducing with reduction of gas temperature. Reducers require determining gas outlet pressure. If gas outlet pressure of the reducer is lower than the set one, then gas flows through the reducer. Gas consumption of consumption regulators depends on pressure difference at outlet and inlet. Usually, threads of multistrand GM are equipped with compressor stations with polytypic GCUs of different power and sometimes GCUs have polytypic drives (electric drives, gas-turbine drives) at different threads.

## Criteria of GTS operation mode optimality

The most frequently used criteria are the minimum fuel and energy costs. Another similar criterion is minimum total work of all GCUs involved in the operation mode. Under conditions of altering operation modes being used, the stability of CS operating with respect to the number of GCUs, which is ensured with a certain remoteness of the centrifugal compressor from an injection zone (unstable GCU operating) is of great importance. Frequent GCU switching on and off negatively affect its technical characteristics. Due to the constant underutilization of GTS, the criterion of maximum gas flow has become less important. The latter is more frequently used in rated and non-rated regimes caused by the restriction of GTS deliverability.

By analogy with trucking, in gas transport such indicator as the commodity transport work (CTW) is used, which is calculated as multiplication of volumes of transported gas by delivery distance. For each subdivision, CTW is the sum of the CTWs of all pipeline segments with gas flow of this subdivision. It is obvious, that a value of TTR depends on the network topology (the state of multipurpose valve), distribution of accumulated gas volumes along gas pipelines segments and on its varying dynamics, which affects the CS operation mode, the temperature conditions of gas transport as well as numerous other factors.

The above mentioned theory proves that the connection between the GTS optimal operation and CTW maintenance minimum costs are not unequivocal. It is clear that fuel and energy costs cannot be used to evaluate CTW of subdivisions; particularly, if GTS is underutilised (at some subdivisions CTW can be performed without CS operating).

*Table 1*

**Optimisation, optimal planning, optimal control under circumstances of uncertainty**

| No | Object | Criterion of optimality | Major factors of influence on optimality | Factors which generate uncertainty |
|---|---|---|---|---|
| 1 | Pipeline section | Minimum drop of pressure | - the coefficient of hydraulic resistance<br>- discharge gas pressure at input of pipeline section<br>- the gas-environment contact heat transfer coefficient | Insufficient number of metering, measurement precision, unsynchronicity of measurement |
| 2 | GCU | Reduced costs | - Gas compressor parameters<br>- polytrophic performance efficiency<br>- drive performance efficiency | Continuous change of modes |
| 3 | CS workshop | Reduced costs | - operating scheme of a workshop<br>- GCU operation mode | Accuracy of a forecast of mode parameters |

| | | | | |
|---|---|---|---|---|
| 4 | Multishop CS with polytypic GCU | Reduced costs | - CS operating scheme<br>- GCU operation mode<br>- workshops load | Insufficient number of gas consumption metering |
| 5 | UGS bed | Operation under technological restrictions | - injection mode<br>- rate of entering operation mode<br>- borehole parameters | Gas withdrawal mode |
| 5 | Multilayer system | Operation under technological restrictions | - layers interaction system (through perforation or gas-collecting station)<br>- injection mode<br>- borehole opening quality | Geometry and inhomogeneity of layers,<br>pressure metering in the certain wells, well production rate metering absence |
| 6 | UGS | Booster CS optimal operating | -gas pressure in the gas main | |
| 7 | Groups of technologically connected UGS | Fuel and energy costs over a period of operating | - gas distribution among layers<br>- withdrawal modes | Gas outflow forecast |
| 8 | Gas main | Fuel and energy costs | -accumulated gas volume distribution between gas main sections | Gas inflow forecast |
| 9 | Multistrand main gas pipeline | Fuel and energy costs | -gas transportation absence in certain strands of GM<br>-possible only when insignificant volumes of gas is transmitted | Gas Inflow and outflow forecast |
| 10 | UGS and a gas-main | Total fuel and energy costs | -gas transmission mode, gas injection and withdrawal modes are related | Initial- and boundary conditions forecast |

**Factors of influence on optimization potential**

The main task is to reveal and realize the available potential of optimization.

**Gas pipelines.**

The potential for optimization can be evaluated with respect to: the distribution of volumes of accumulated gas along the segments of the main gas pipeline; the volume of the accumulated gas in gas-main for the given volumes of gas to be transported; deviation of hydraulic resistance ratios from those set as a standard for the given value of the roughness of internal walls at some gas pipeline segments; the temperature conditions thruought gas transportation; degree to which the mode is unsteady and the character of transitional modes.

**Multistrand gas pipelines**. Potential of optimization can be realized by: redistribution of volumes of the accumulated gas to gas pipeline threads at the fixed volumes of its transportation; at the insignificant volumes of transportation of gas, it may be advantageous at certain sections of strands not to compress the gas (that is separate CSs can work in a deliverable mode); support of close regimes of transportation of gas in threads of the multistrand gas pipeline, except for cases of the admission of gas through separate threads bypassing CS shops.

**Multishop CS with polytypic GCU.**

The potential for optimization is realized through: redistribution of gas volumes, in the course of its compressing by CS shops; running optimal capacity of GCU at each shop; the coordinated operation mode of

CS with an operation mode of adjacent gas pipeline segments; compromise between the optimality of GCU operation mode and its reliability.

**Underground gas storages.**

The optimal operation requires: a coordinated UGS operation mode with gas-main operating; in the case of water-pressure mode, the coordination of withdrawal rate with rate of advance of a water contour; in multy-layer beds with hydraulic incoherence and for given volumes of gas for storage, to distribute optimally volumes to them; the availability of optimal volume of buffer gas due to which it is to possible to regulate pressure in a gas-main; a full use of periods of noncompressor injection and withdrawing of gas (it is possible to set them with established plans of gas injection and gas withdrawing; a coordinated gas pressure in the main gas pipeline.

**Groups of technologically connected gas storages**. Optimal work is connected with the solution of the following tasks: to distribute planned volumes of storage gas to storage facilities so that total maximum peak deliverability may be ensured when withdrawing, and also to ensure maximum average peak of the withdrawal rate within a predicted interval of time of withdrawing; to distribute planned volumes of collecting of gas to storages so that the maximum peak total gas storage capacity through a predicted interval of time may be ensured in the course of gas withdrawing; to develop such strategy of optimal control of gas storages which satisfies the balanced optimality criterion which includes parameters of peak capacity and fuel-energy costs.

**Gas transmission system.** Annual optimal GTS operating demands maintaining certain volumes of gas accumulated in its pipelines.

**Volumes of gas storage facilities.** Volumes of gas storage are connected with the assurance of the balance of gas delivering over a heating season and peak loads in the autumn-winter period. Total peak gas storage capacity is connected with total volumes of stored gas, its distribution to gas storage facilities and possible minimum pressure in pipelines which are branches from DCS to gas-main.

**Groups of technologically connected gas storages and the main gas pipelines.** For effective distribution of gas to groups of technologically connected gas storages, it is necessary to use distribution of loading of GTS region, especially in the conditions of peak loadings of segments which are adjacent to groups of gas storages.

**Management of gas-flows in GTS**

Promt optimal control of gas-streams in GTS requires the creation of a complex of modelling of non-stationary operation modes of gas transmission systems in optimization statement. Because of the complexity of GTS, this problem generally is still unsolved. Change of control parameters, generally, depends on the operational condition of the system, use of criteria of optimization and principles of optimal control, and it does not demand their exact performance in full. The GTS is not operating optimally over considerable intervals of time and has considerable reserves with respect to economic, ecological, power and other criteria.

At present, the majority of the main objectives of the fundamental plan are sufficiently studied [1-5]. Efficiency of the use of the developed systems is often not related to their quality, but most likely with impossibility of their inclusion into the general process of formation of system control.

*The task consists in formation of optimal control of the system by means of control of all compressor stations operating over the interval of time* $\left[0,t\right]$ *for the purpose of minimization of expenses for gas transportation that is minimization of total gas volumes consumed by gas-turbine plants and the electric energy for the electric drive installations operation.*

Components of a vector of control are the following: valves and control valves state; CS capacity (change of rotation speed of centrifugal compressors, number of GCUs); gas outflow from system, or its inflow into the system (pressure or consumption regulators); hydraulic resistances of objects (opening bypass valves).

## Optimal control of gas-flows. Algorithm options

The main problem is an optimization of non-stationary modes. We consider the control of gas-flows to be provided only by change of capacity of CS. For its formation we need to impose conditions on altering of control parameters. Technological static and dynamic restrictions (technological corridors) can be imposed as such conditions. The problem is the choice of magnitudes of control parameters which influence the rate of variation of parameters of gas flow.

**Option 1. Within technological corridors.** Change of control mode is carried out when gas dynamic processes close to their technological limits. The choice of the magnitude of the control parameter is carried out so that the gas dynamic process can be put out of its technological limit, usually with respect to pressure.

**Option 2. Within dynamic technological corridors**. Dynamic technological limits are determined on the basis of the volumes of the accumulated gas in the system and the volumes of gas transportation. This option is more optimal because the flow rate of gas dynamic processes is chosen in the way that the certain calculated average pressure in subsystems and in the whole system is maintained.

**Option 3. Towards the optimal predicted mode**. This option is the most complicated. It consists in determination of control parameters depending on predicted optimal mode for a given time. Depending on behaviour of changing of the boundary conditions, the predicted mode can be remote from real time by a variable time magnitude. Having an optimal predicted mode, the control is chosen so that the current mode can be put into predicted one.

**On the potential of optimization and its realization**

Fuel gas consumption significantly depends on volumes of gas transportation. Dependence of fuel gas consumption on volumes of gas transportation is nonlinear (Table 2).

Table 2

**Consumptions of fuel gas in gas transportation down two Ø1400 mm threads (the figures are given in m$^3$/year and in %)**

| No | Transport (bil. m$^3$/year) | Fuel gas (bil.m$^3$/year) | Costs in % |
|---|---|---|---|
| 1 | 21.9 | 0.25 | 1.14 |
| 2 | 36.5 | 0.5 | 1.36 |
| 3 | 43.8 | 1 | 2.28 |
| 4 | 58.4 | 2.5 | 4.28 |

When planning modes, the crucial task is automation of optimal mode search in the steady state. Complexity of automation is influenced by existing technology of gas transportation. The optimal stationary mode for the set expected input data is formed in the way of distribution correction of flows in the main gas pipelines. Optimization is performed in two actions - at first we correct gas flows, and then we conduct redistribution of flows between shops of multishop CS. Such actions are carried out until we reach the minimum volume of fuel-energy resources. The search algorithm is expedient. In its development, properties of an optimal mode of both separate threads, and systems of gas pipelines connected technologically are taken into account.

For studying the potential of optimization, numerical experiments with a help of the program complex "GTS Mode" are made. Accuracy of calculation depends on the accuracy of adaptation of mathematical models of technological objects. Adaptation of models received for some days' meterings is within 1%. The main part of an error of calculation consists of a systematic error, which has insignificant influence on the accuracy of calculation of relative values.

Results of one of numerical experiments are given below. The case when one of the shops of 3-shop CS (the town of Gusyatyn, Ternopil region) is put off the operation is considered (Fig. 1). Results are given in Table 3.

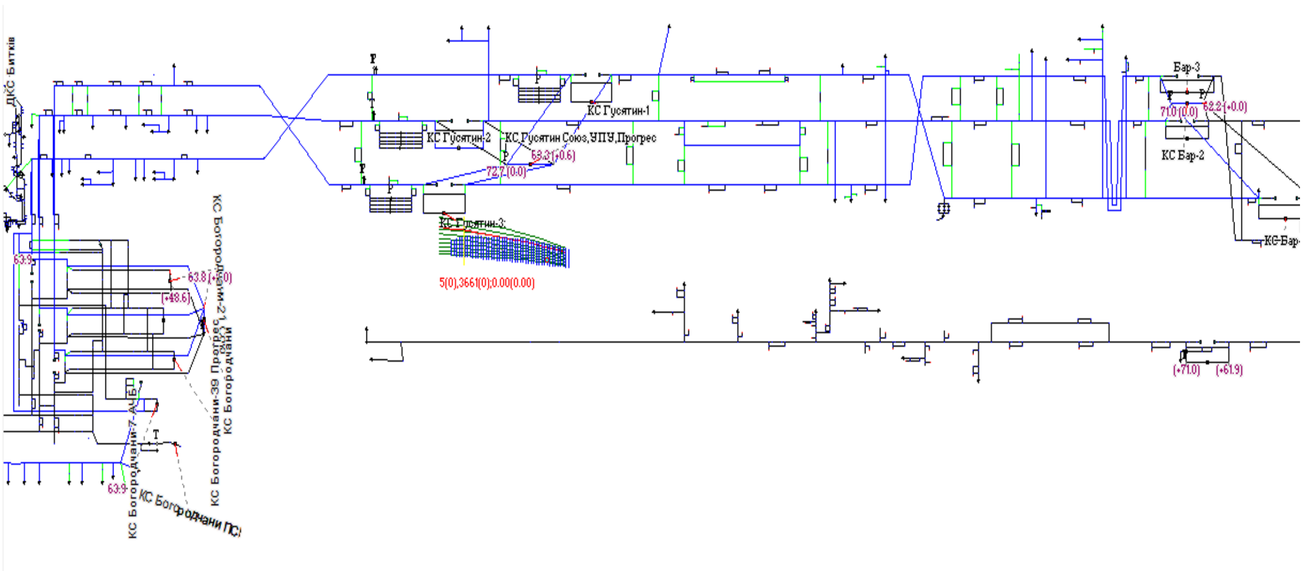

*Fig. 1. Segment of the technological scheme of three-strand gas pipeline*

| Total capacity (mln.m3/day) | Fuel gas consumption (parallel operating workshops) (mln.m3/day) | Fuel gas consumption (one operating workshop in a mode for pass) ( mln.m3/day ) |
|---|---|---|
| 150 | 0,33 | 0,24 |
| 180 | 0,42 | 0,38 |
| 210 | 0,53 | 0,5 |
| 230 | 0,67 | 0,66 |

Table 3

**Results of operation modelling of a three-strand gas pipeline**

Thus, minimization of the number of operating GCUs can ensure reduction of fuel gas consumption under the CS mode within 3-11%. Redistribution of gas consumption between GCUs of the same type allows us in some cases (not in all of them) to reduce the use of fuel gas no more than by 1%. Redistribution of gas flows between the main gas pipelines can ensure the economy of fuel gas within 3-4%. The specified potential of optimization can be detected, mainly, by the use of modelling. In the course of realization of the potential, it is necessary to be sure that the costs for realization of the potential will not exceed the expected effect.

Redistribution of flows between shops of multishop CS allows us to reduce consumption of fuel gas within 6-8% (the influence of the change in hydraulic losses on gas flows between shops is not taken into account). Timely transition from 2-, 3-compression ratio to 1-,2-compression ratio gives the economy of fuel gas to 23%.

The economy of energy resources can be also achieved with the putting GCU (which are operating in fan mode) off their operating in due time and with timely transition to such GTS mode when some of shops and CS are put off their operations (when the gas flow rate is abruptly decreased). Redistribution of volumes of the accumulated gas which is available in the system between separate subsystems, including its change at the expense of UGS, gives the economy to 5%. The use of this potential of economy can be reached as a result of introduction of a system of control parameters formation of gas-flows in GTS. Control of temperature regime of gas transport is APO gas cooling (control of fans – their number and rotational speed) for a year (the economy during certain periods is possible to 5% with respect to fuel gas, and it is also possible to increase the capacity of the main gas pipeline to 3%). The aforesaid estimates of effectiveness are obtained from the use of the software complex for the simulation.

**Conclusions**

It is not the planning of optimal modes alone that is important but also the formation of optimal transitional modes. The challenges of formation of optimal non-stationary regimes consists in the fact that optimality of GTS operation through long time intervals, excluding the time of transitional modes, does not ensure optimal operating throughout the time of modelling. It may turn out that non-optimal operation in many time periods can ensure optimality throughout the GTS operating time. In such cases, search of optimal modes requires fairly exact forecast of initial and boundary conditions achieving which is problematic under real conditions.

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