

Multi-step probabilistic assessment in the problems of identifying indicators functioning of the gas distribution network

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Abstract. The paper poses and solves the problem of applying the method of multi-step probabilistic assessment in the problems of identifying indicators functioning of the gas distribution network. Gas distribution networks in operation are often subject to emergency situations. This causes the implementation of the restoration work on the basis of experimental a priori information. In this regard, computational experiments make it possible to produce predictive values of the performance indicators of the gas distribution network and, accordingly, to identify them with real data.

1. Introduction

Gas distribution networks, which are a complex technical control system, often operate under the influence of uncontrolled random disturbances (accidents at sites, unauthorized gas extraction, gas leakage). This leads to an assessment of the search for such methods, allowing even on the basis of small a priori information to identify technical and technological indicators functioning of the network that meet production requirements.

Information characteristics of complex technical control systems, and, in particular, gas distribution networks, determine the priority requirements, which consist in qualitative identification of their indicators to ensure uninterrupted gas supply to consumers. At the same time, a qualitative assessment, current situation requires an active computational experiment based on available (even incomplete prior information) information, formalization, simulation cause-and-effect model, which predetermines the nature of conceptual features that allow establish functioning of the considered network in emergency situations [1, 2].

The formation and formalization of a situational cause-and-effect model based on the method of multi-step probabilistic assessment predetermines the possibility of identifying, even if predictable, indicators functioning of the gas distribution network.

The structural and functional properties of the problem under study are determined by the nature of its extremity, which impose requirements on the assessment of disciplining conditions (constraints) that qualitatively affect its solution. In solving such problems, numerical methods are also widely used.

However, as noted in [1], there are still not satisfactory tests to verify whether the specific solution of extremal problem is optimal (with acceptable restrictions) and therefore there are not any general methods for solving them.

The developed algorithms allow only to building sequences, the limiting elements of which satisfy particular optimality conditions in emergency situations. Here it is necessary to operate with the term “permissible” solution, which determines the process of situational expert assessment functioning of the gas distribution network under investigation. Then, on the set of feasible solutions, minimum (maximum) of the objective function is sought.

In this regard, the use method of multi-step probabilistic assessment in identifying performance indicators of the gas distribution network is a practically reasonable approach.



In work [4], questions of the development and implementation of automated control systems (ACS) for pipeline utility facilities were considered. The basic principles of ACS, methods of mathematical modeling and forecasting are given. The features of pipeline utility facilities as large systems are investigated. The basic principles and methodology for constructing structural models of information systems are outlined. All the questions studied, for the most part, are strictly analytical. Applied development they received when solving individual problems in the present work.

The work [5] is devoted to solving the problem of stationary flow distribution for an arbitrary hydraulic system, without volumes with a free level. The solution of the problem can be reduced to the search for extremums of functions of several variables. Here is a mathematical model of the hydraulic system for a radiant structure consisting of many sections, as well as the results of numerical solution of the problem without taking into account pumping stations. This work can be applied to branched or dead-end gas supply systems without hydraulic fracturing, or to collectors connected to urban systems. Here it is necessary to take into account the fact that the pressure of gas and water is subject to various hydraulic laws. Therefore, in general, this work (as a theoretical work) can be developed for collectors of a single-line main pipeline.

The work [6] is devoted to the problems of adapting the numerical solution of systems of nonlinear algebraic equations for solving flow distribution problems in arbitrary hydraulic systems. The task of flow distribution is reduced to finding unknown volumetric or mass flow rates, as well as pressures in all elements of the hydraulic system. To solve the problem, the Newton iterative method is used.

In [7], the algorithm method of multi-step probabilistic estimation was analyzed for analyzing the predictive identification indicators of the gas production process by calculating wellhead pressure (P_y) and changing it at fixed intervals of gas pipeline sections.

In this paper, the development of this algorithm is aimed at solving problems of identifying predictive indicators of pressure drops in areas of dead-end and ring gas supply networks.

2. Main part

In the complex of forecasting methods, a particularly important role is assigned to probabilistic approaches based on existence of a correlation relationship between the phenomena being studied. In solving practical problems, it is often necessary to encounter situations in which the characteristics of an object are not known in advance and organization of system management requires obtaining estimates of the system parameters from measurement results at the input of the control object. In addition, the need for stochastic formulation of control problems arises in those cases where there is a fundamental opportunity to collect all required information.

With insufficiently substantiated selection of source data, useful information is often lost and false information is introduced into the problem statement, which is irrelevant to the phenomenon being studied and distorts the process under study. In this regard, it is required to construct a mathematical model for estimating some unobservable random variables using observables. This process requires study conditional distribution of the vector of unobservable random variables for a given vector of observables and formation of a causal model.

The considered computational scheme of the method multi-step probabilistic assessment allows us to solve estimation problems without having clear information. Therefore, in the field of information processing, the tasks of estimating unknown parameters of controlled objects, which are characterized by the presence of interference in the object, the random nature of changes in the parameters of the object, obtaining performance indicators of the object from observations separated by random time intervals, are highlighted[3,5].

3. Formulation of the problem

Consider, on the basis of N points and n -dimensional domain Ω_n , given by its coordinates, and, in some part of which, value of the parameter under study is known. It is required to restore, with a certain degree of reliability, values of this parameter in the regions is interest to us, or in all the studied points of the region.

Suppose that N known points have geometric coordinates $X_1(x_{11}, x_{12}, \dots, x_{1n}), \dots, X_n(x_{n1}, x_{n2}, \dots, x_{nn})$, and unknown M points - $Y_1(y_{11}, y_{12}, \dots, y_{1n}), \dots, Y_m(y_{m1}, y_{m2}, \dots, y_{mn})$. Then for the probabilistic forecast parameters studied unknown or studied points, we apply the multi-step probabilistic approach.

To do this, we introduce the distances $\rho(x_i, x_j)$ between two points x_i and x_j n -dimensional domain Ω_n defined by the formula:

$$\rho(x_i, x_j) = \sqrt{\sum_{k=1}^n (x_{ik} - x_{jk})^2} \quad (1)$$

We define the diameter of original region as maximum geometric distance between two points of the region Ω_n , i.e.

$$d = \max_{i,j} \rho(x_i, x_j) \quad (2)$$

Further, in accordance with the proposed model, the incoming information from known N points of the Ω_n space, can based on the correlation properties of the model, be extended to studied points using decomposability principle of initial information.

Let us set a positive number h , which we call step influence of information sets, and which for practical calculations can be taken by the formula:

$$h \sim \frac{d}{N} \quad (3)$$

Choose an arbitrary point Y_j ($j = \overline{1, M}$) and we will build n -dimensional concentric hyperspheres with a common center Y_j and radii $h, 2h, \dots, k_j h$ until the k_j -th hyper sphere will not cover the entire area. As a result of this, the desired area will be divided into k_j subdomains, that we call zones of influence on a point Y_j . Each of these subdomains contains some points from a known basis set of points X_i ($i = \overline{1, N}$). Their number is denoted by N_s ($S = \overline{1, K_j}$, $j = \overline{1, M}$). If we consider only base points from the S -th zone, then expectation of predicted value of one of the parameters $\overline{Z_j}$ relative to these base points, can be found by the formula:

$$M\overline{Z_j^{(s)}} = \sum_{i=1}^{N_s} Z_i P_{ij}^{(s)}. \quad (4)$$

Where $P_{ij}^{(s)}$ is probability of the base points in the S -th zone, which, for example, takes into account the distance as the first term and as the second term of the parameter under study and is determined by the formula:

$$P_{ij}^{(s)} = \frac{q_1}{q_1 + q_2} * \frac{d_i^{(s)} - d_{ij}^{(s)}}{(N_s - 1)d_i^{(s)}} + \frac{q_2}{q_1 + q_2} * \frac{z_j}{z^{(s)}}. \quad (5)$$

Here, q_1 and q_2 are levels of influence factors and distances values of parameters at a given point, which can be determined using well-known factor algorithms [4, 5].

If it becomes necessary, besides the distance and values of parameters at a given point, to take into account other influencing factors, for example, P -factors, then their characteristics q_i ($i = \overline{1, P}$) will enter into formula as weight terms:

$$\frac{q_i}{q_1 + q_2 + \dots + q_p}. \quad (6)$$

The following notation is introduced in the above formulas:

$$z^{(s)} = \sum_{j=1}^{N_s} z_j; \quad (7)$$

$$d_i^{(s)} = \sum_{j=1}^{N_s} \rho_{ij}^{(s)} \quad (8)$$

here $\rho_{ij}^{(s)}$ – distance from point y_i ($i = \overline{1, M}$) to the point x_j ($j = \overline{1, N_s}$) from the S -th zone ($S = \overline{1, K_j}$).

At the same time, the condition of completeness for $\rho_{ij}^{(s)}$ i.e.

$$\sum_{j=1}^{N_s} \rho_{ij}^{(s)} = 1 \quad (9)$$

Now we will determine the effect of zones depending on the difference:

$$M\bar{Z}_i^{(s)} - M\bar{Z}_i^{(s+1)}, S = \overline{1, K_{j-1}}, i = \overline{1, M}. \quad (10)$$

Next, we introduce the averaged probabilities: $F_i^{(s)}, i = \overline{1, M}, S = \overline{1, K_{i-1}}$ for each information set, on basis, which probability influence considered set on result of the model evaluation will be taken into account, where we set:

$$F_i^{(s)} = \{\sum_{j=1}^{N_s} P_{ij}^{(s)}\}^{\frac{1}{s}} \quad (11)$$

The influence of the S -th zone on the point Y_i through $S-1$, the preceding zones will be defined as $F_i^{(1)} * F_i^{(2)} * \dots * F_i^{(s)}$ and we obtain a convergent process in a finite number of steps S , taking into account the number of given points.

To evaluate this process, the final formula for determining predicted value of parameter is written z_i :

$$M\bar{Z}_i = M\bar{Z}_i^{(1)} F_i^{(1)} + M \left(\frac{\bar{Z}_i^{(1)}}{\bar{Z}_i^{(2)}} \right) F_i^{(1)} F_i^{(2)} + \dots + M \left(\frac{\bar{Z}_i^{(K_{i-1})}}{\bar{Z}_i^{(K_j)}} \right) F_i^{(1)} F_i^{(2)} \dots F_i^{(K_i)} \quad (12)$$

Where $F_i^{(K_i)}$ – transitional probability of the i -th zone, and $M\bar{Z}_i$ – mathematical expectation of a random variable specified in the i -th zone.

Therefore, the relative accuracy of overall estimate depends on the number of zones K_j . With an increase in the number of zones from S to C , where $S < C$, there is a relative increase in accuracy of calculations by:

$$\delta_{s,c} = \frac{\mu_{1,2,\dots,s}^2 e^{-\mu_{1,2,\dots,s}^2}}{1 - \mu_{1,2,\dots,s}^2} \quad (13)$$

Where $\mu_{1,2,\dots,s}^2$ – the correlation relation between the total estimate and random vectors $\bar{Z}_i^{(1)}, \bar{Z}_i^{(2)}, \dots, \bar{Z}_i^{(s)}$, determined by the formula:

$$\mu_{1,2,\dots,s}^2 = 1 - \frac{\bar{D} \bar{Z}_i}{D \bar{Z}_i}, \quad (14)$$

here $\bar{D} \bar{Z}_i$ – calculated variance, $D \bar{Z}_i$ – marginal (ideal) variance determined by the expression:

$$\bar{D} \bar{Z}_i = \sum_{j=1}^{K_s} \left\{ \bar{D} \bar{Z}_i^{(j)} + [M(\bar{Z}_i / \bar{Z}_i^{(j)})^2] \right\} F_i^{(1)} * F_i^{(2)} * \dots * F_i^{(j)} - \{M\bar{Z}_i\}^2 \quad (15)$$

Consider the use of computational procedure, method of multi-step probabilistic assessment for the problem of identifying performance indicators of the gas distribution network. To identify predicted values of the gas distribution network performance indicators based on the method of multi-step probabilistic assessment, computational experiments were conducted, the results of which were tested on real gas distribution networks is Samarkandshakhargaz [6, 7].

Qualitative operation of gas distribution networks directly resulted from problems and challenges of optimization of gas supply networks, covering a wide range of interrelated issues of optimal system design, operation control in the course of their operation, as well as a number of other tasks. These problems are of a certain complexity, since the gas supply networks are essentially subsystems of large scale power systems, are constantly evolving and characterized by multi-factor dependence of technical and economic indicators. This requires the development and implementation of modern tools, methods and systems of information-communication technologies.

Modern gas supply networks (Fig. 1) are a complex structure, consisting of the following main elements: the gas networks of low, medium pressure, gas distribution stations, regulating stations and installations.

Normally, if the length of the settlement network sites and design flow of gas is known, it enables set the diameter of the pipeline up and determine the pressure loss, then check not exceeding the

standard value of the resultant pressure drop. Failing which the held some adjustment diameters, more design considerations than to optimize the system. The distribution of the estimated pressure drop between sections of the gas network is one of the most important optimization problems.

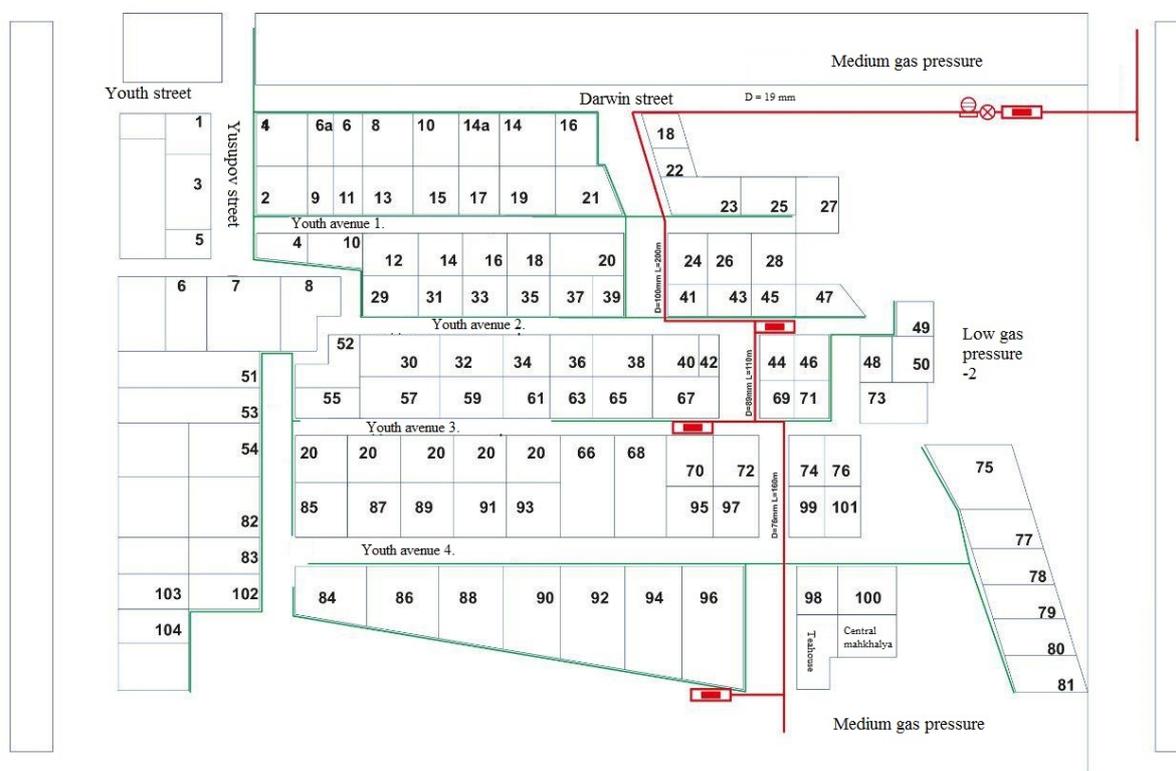


Figure 1. Systems of gas supply networks.

Where: numbers from 1 to one hundred and four are numbers of apartments:

D – pipe diameter in millimeters, L – length of the pipeline in meters.

A fluctuation in gas to consumption by hour of the day comes from the downward flow of gas at night on the domestic needs of the population, and also depends on the mode of industrial enterprises. Therefore, to ensure continuity of supply to consumers of gas supply system is calculated on the maximum hourly flow rate.

Gas flows from the main gas pipelines in the city, settlement and industrial gas supply system through the gas distribution stations. Distribution station is the final portion of the main gas pipeline and is a kind of boundary between the city and the main gas pipelines [7].

4. Module and algorithm of the problem of choosing the diameter portions gas supply networks

The purpose of the calculation is the identification and selection of the diameters of the gas supply network sites based on the minimum capital requirements, while ensuring security of supply given. The main input data of the program are:

Q_i – consumption of the gas at each part of the network, m^3/h ;

l_i – length of sections, m; $\lambda_i, \lambda_r, \lambda_j$ – Lagrange multipliers for rings and directions specified arbitrarily; m – number of rings of the network;

n – number of sections of the network;

ν – kinematic viscosity coefficient, m^2/s ;

d – internal diameter of the pipeline, mm;

γ – number of directions in which it should meet the conditions do not increase the pressure loss allowable value;

ΔP – pressure drop in the pipeline;

c_i – the importance of linking to each ring;

Z_i – amendment of each ring; a – correction factor.

The calculation program performs the following steps:

a) the values are calculated Z_i for each segment gas distribution network according to the formula:

$$Z_i = \frac{1}{11,02|\lambda_j + \lambda_i + \lambda_f|}; \quad (16)$$

b) the condition is checked using a differential pressure in the gas supply networks in the directions (from power supply to distant points in the network):

$$\sum C_i Z_i^{0,826} = \Delta P_0; \quad (17)$$

c) if the condition is not executed then it is corrects for all Z_i areas included in this course:

$$Z_i' = Z_i a^{1,2106}, \quad (18)$$

where

$$a = \frac{\Delta P_0}{\sum C_i Z_i^{0,826}}; \quad (19)$$

d) condition is checked for each link of the rings:

$$\sum C_i Z_i^{0,826} = 0; \quad (20)$$

e) if the condition is not executed then we are entered amendments on Z_i for all of the rings:

$$Z_i' = Z_i - \Delta Z_I + \Delta Z_{II}, \quad (21)$$

where ΔZ_I - the correction of the ring; ΔZ_{II} – amendment of the neighbouring rings, which borders this site.

The amendment ΔZ to the ring is given by:

$$\Delta Z = \frac{\sum C_i Z_i^{0,826}}{0,826 \sum |C_i Z_i^{0,826-1}|}; \quad (22)$$

f) in the case of the condition linking the network and condition (22) in the directions are calculated diameters of all areas, then:

$$d_i = Q_i^{0,304} \frac{1}{Z_i^{0,174}} \quad (23)$$

Further, for calculating the pressure drop necessary to determine settings such as the Reynolds number is dependent on the nature of the gas flow, and the hydraulic resistance coefficient λ [7, 8].

Hydraulic calculation of gas pipelines should be performed, as a rule, on an electronic computing machine with an optimal distribution of calculated pressure between network sections. The pressure drop in low pressure gas pipelines should be determined depending on the mode of gas flow through a gas pipeline, characterized by the Reynolds number [9]:

$$Re = 0,0354 \frac{Q}{dv}, \quad (24)$$

Depending on the value of Re, the pressure drop in pipelines is determined by the following formulas:

for the laminar mode of gas $Re \leq 2000$ [9]:

$$H = 1.132 \cdot 10^6 \frac{Q}{d^4} vpl, \quad (25)$$

for the critical mode of gas flow at $Re = 2000 - 4000$ [9]:

$$H = 0.516 \frac{Q^{2.333}}{d^{5.333} v^{0.333}} pl, \quad (26)$$

where H is the pressure drop, Pa;

p is the gas density, kg / m^3 ;

The program code is presented on Figure 2.

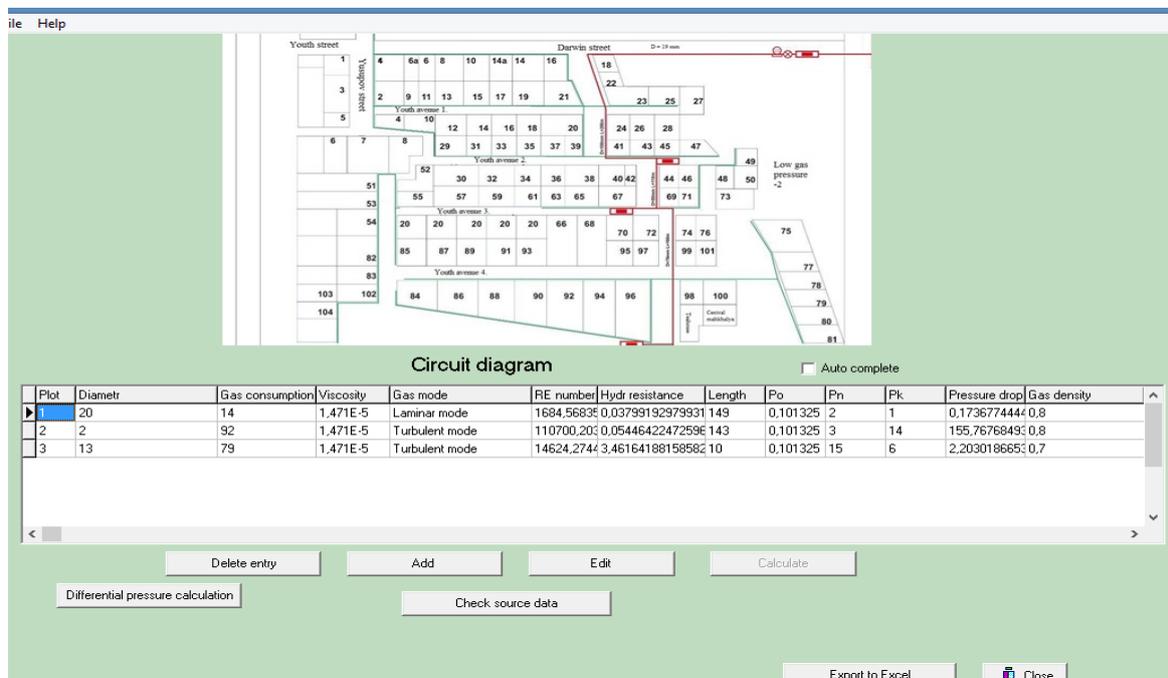


Figure 2. Computer code

5. Conclusions:

- formed the hydraulic calculation algorithm of symmetric and asymmetric schemes gas supply systems;
- designed a program for multi-step probabilistic assessment in the problems of identifying indicators functioning of the gas distribution network;
- the results of computational experiments showed good agreement with the actual production data;
- designed the software "Comprehensive program of automation of hydraulic calculation; functioning composite pipelines" for putting the patent office of the Republic of Uzbekistan;
- designed complex of programs for automating calculation of gas supply network operation indicators, was tested on real data on the mahalla "Marakand" of Samarkand, the Republic of Uzbekistan. The results of calculations show a fairly practical consistency with expert estimates.

6. References

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