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A REGIONAL GAS SUPPLY MODEL

1. Network Model of a Gas Supply System

The problem of the gas supply of a region, in fact, includes such problems as (a) determining consumers of natural gas under limited resources of this fuel, (b) optimal distribution of gas and other types of fuel, (c) finding optimal gas flows from sources to consumers, and some others. The regional gas supply (RGS) model consists of a gas pipeline network and some bipartite graphs which correspond to distributive networks of other types of fuel. A network RGS model with a non-linear objective function for technical and economic designing of RGS systems can be described mathematically as follows [1].

Let b_{kv} denote a capacity of an arc kv; d_k and s_k — the amount of and demand for fuel in a node k; $p_{kv}(x_{kv})$ — cost function which depends on the wanted flows x_{kv} of fuel. All the values are given in natural gas equivalent.

The problem is to find (x_{kv}) minimizing

$$\sum_{kv\in Q} p_{kv}(x_{kv})\,x_{kv} \tag{1}$$

subject to

$$0\leqslant x_{kv}\leqslant b_{kv} \quad (\forall kv\in Q), \tag{2}$$

$$\sum_{v} x_{kv}-\sum_{v} x_{vk}=d_k-s_k \quad (k=1,\ \ldots,\ K), \tag{3}$$

where Q is the network under consideration. If the node k is a source, then $d_k>0$, $s_k=0$; if k is a consumer, $d_k=0$, $s_k>0$; if k is a transitional node, $d_k=s_k=0$.

$p_{kv}(x_{kv})=c_{kv}$ for the arcs of the gas main and gas distributive network with the fixed flows x_{kv} of natural gas, where c_{kv} is the fixed link cost;

$p_{kv}(x_{kv})=(c_{kv}+\alpha_k)$ for the arcs leading from the sources of gas, where α_k is the cost of one unit of natural gas extraction;

$p_{kv}(x_{kv})=\beta_v$ for the arcs leading to the consumers, where β_v is the cost of using one unit of gas;

$p_{kv}(x_{kv})=c_{kv}(l_{kv},\ x_{kv})$ for the arcs which are in project; here l_{kv} is the distance (in kilometres) between the nodes k and v;

$p_{kv}(x_{kv})=(\alpha_k+c_{kv}+\beta_v)$ for the arcs leading from the sources of other types of fuel to the consumers.

It is assumed that the total demand for fuel is equal to its total supply.

Gas holders can be included into the RGS model for taking into account the winter demand increase. The gas holders are considered as consumers in the summer period and as sources in winter. The problem of gas holders allocation can be solved by dividing the annual demands of the consumers into two parts corresponding to summer and winter periods and by considering summer and winter networks separately.

2. Algorithms and Programs

A general scheme of the RGS system optimization consists of the following principal steps:

I. determining an optimal fuel distribution among the consumers, based on annual or seasonal demands and supplies;

II. determining an optimal daily fuel distribution;

III. finding the gas pressures at initial first nodes of the distributive gas pipelines;

IV. determining an optimal gas distribution among the consumers of the distributive gas pipelines with the calculation of pressures;

V. finding new values of the gas pressure at the initial nodes of the distributive gas pipelines on the basis of the gas flows found at Step IV.

The problem of Step I is solved by the transportation costs recalculation (TCR) program in the following way [2].

At Step I the construction costs of the minimal capacity gas pipelines are chosen for the pipelines which are at the design stage, and transportation costs are calculated on the basis of the length of these pipelines. Then the transportation problem is solved.

At Principal Step the transportation costs are corrected to correspond to the gas flows found at Step I. For this, an interval $b^{i-1}_{kv} < x_{kv} \leqslant b^{i}_{kv}$ is to be found, and the cost c^{i}_{kv} is to be chosen according to that interval and the length of the pipeline kv. Then the transportation problem with the recalculated costs is to be solved.

The iterative process stops when two successive solutions of the transportation problem have equal values of the objective function (with a given accuracy).

When turning from annual demands to the daily ones, the network is defined more exactly and the consumers are desaggregated.

The distribution of natural gas over the distributive network is optimized by means of the above-mentioned TCR program. For the pipelines which are at the design stage, the costs are calculated in the following way. The costs on every basic arc kv of the solution (x_{kv}) found at the previous iteration are determined as follows:

$$p_{kv}(x_{kv}) = \frac{c}{x_{kv}} l_{kv},$$

where the cost c corresponds to the minimal feasible diameter d of the pipeline. d is chosen from the given variants with the consideration of the following restrictions:

$$d = \min(d_j), \quad j = 1, \ldots, J,$$

$$d \leqslant \min(d_{tk}), \quad t = 1, \ldots, T,$$

and the restrictions on the gas pressure and speed. Here J is the number of the variants of the pipe diameters; T is the number of pipes leading into node k, and (d_{tk}) are diameters of these pipes.

All the basic arcs are considered until the necessary values of gas pressure are obtained at the end nodes of the pipelines. The iterative process must stop when two successive solutions of the problem have equal values of their objective functions (with a given accuracy).

Then the gas pressures at the initial nodes of the distributive gas pipelines are calculated again by means of the optimization of gas main flows which correspond to the gas distribution plan found. If there is significant difference between the gas pressures found earlier and the new values, the distributive gas network is to be optimized once more. Practical experience has shown a good convergency of the suggested method. In fact, the process ends in two or three iterations.

The programs are written in FORTRAN IV version for the ES computers, and can be used for networks with up to 2000 nodes and 10000 arcs (for the ES 1022 computer).

3. Solution of a Detailed Problem

Consider an RGS model with the consumers detailed up to power units. The problem is formulated as follows:

$$z=\sum_{i\in M}\sum_{kv\in Q_i} c_{kv}^{(i)} x_{kv}^{(i)} \to \min, \tag{4}$$

$$\sum_{iv\in Q_i} x_{iv}^{(i)} \leqslant d_i \quad (\forall i\in M), \tag{5}$$

$$\sum_{kj\in Q_i} x_{kj}^{(i)} = \begin{cases} s_j \\ 0 \end{cases} \quad (\forall i\in M,\quad \forall j\in N), \tag{6}$$

$$\sum_{i\in M} \operatorname{sign}\Big(\sum_{kj\in Q_i} x_{kj}^{(i)}\Big)=1 \quad (\forall j\in N), \tag{7}$$

$$\sum_{k\in Q_i} x_{vk}^{(i)} - \sum_{k\in Q_i} x_{kv}^{(i)}=0 \quad (k\,\overline{\in}\, M,\ k\,\overline{\in}\, N,\quad \forall i\in M), \tag{8}$$

$$x_{kv}^{(i)} \geqslant 0 \quad (\forall kv\in Q_i,\quad \forall i\in M). \tag{9}$$

Here M is the set consisting of m sources of fuel, each source i having an amount d_i of the i-th type of fuel; N — set of consumers (units) j ($j=1, \ldots, n$) with the demands s_j; Q_i are the distributive networks of every i-th type of fuel (these subnetworks have common nodes — the consumers); $c_{kv}^{(i)}$ is the transportation cost on the arc kv of the subnetwork Q_i; $x_{kv}^{(i)}$ — the variables to be found; $\operatorname{sign}(x)$ is a function that is equal to 0 when $x=0$, and to $+1$ when $x>0$. If the unit j cannot use the fuel of the i-th type, then $c_{kj}^{(i)}=+\infty$. Restrictions (6) and (7) mean that each unit must be supplied from one source only.

The problem (4)—(9) can be represented in a matrix form, so that each subnetwork would be a bipartite graph. Suppose that the problem is transformed in that way and consider it as a special minimum cost flow problem.

The partitioning method for solving the problem is based on some ideas of G. Kron's «diakoptics» [3] and can in general be described as follows [4].

I. Partitioning the given transportation network Q into smaller isolated subnetworks Q^i and a subnetwork Q_{m+1}: $Q=Q^1\cup Q^2\cup\ldots\cup Q^m\cup Q_{m+1}$; $Q^k\cap Q^l=\varnothing$, $k\neq l$, k, $l\leqslant m$. Subnetworks Q^i consist of one source i connected by the arcs with any number of consumers. The arcs that are not included into these subnetworks and all the sources and consumers form the subnetwork Q_{m+1}.

II. Changing the partitioning of the network Q to reduce the number of the negative cycles in a feasible solution at the next step. The negative cycles consisting of four nodes and arcs are to be excluded by changing the places (subnetworks Q^i) of some consumers.

III. Finding a feasible solution of the problem by a separate optimization of each subnetwork.

IV. Changing the partitioning of the network according to the feasible solution found at the previous step.

V. Improving the solution by eliminating possible negative cycles and comparing the new solution to the one of the previous iteration. Returning to Step II.

The algorithm ends when at some iteration a worse solution is obtained than at the previous iteration, and this previous solution is to be accepted as an approximate one. The algorithm is programmed in FORTRAN IV version for ES computers. Problems with up to 10^2 sources and 10^4 consumers can be solved with the help of the program.

4. Practical Experience

Our models and programs have been used for the European part of the USSR gas supply optimization in projecting the gas main North Tyumen — Central and Western regions.

The Institute of Economics has participated in technical and economic projecting of the gas supply system in the North-European part of the USSR, the Baltic Soviet republics, Byelorussia and some other regions.

The methodology of RGS systems optimization developed at the Institute of Economics has been accepted by the Ministry of the Gas Industry of the USSR and has been widely used [5].

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RAJOONI GAASIVARUSTUSSÜSTEEMI MUDEL

Artiklis on käsitletud mittelineaarse sihifunktsiooniga gaasivarustussüsteemi võrkmudelit ning esitatud süsteemi optimeerimiseks iteratiivne kulude ümberarvutamise algoritm. Samuti on uuritud gaasivarustussüsteemi detailiseeritud mudelit, mis sisaldab diskreetseid muutujaid ning mida lahendatakse dekompositsioonimeetodil. On juhitud tähelepanu kirjeldatud algoritmidele vastavate FORTRAN-programmide kasutamisvõimalustele.

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МОДЕЛЬ РАЙОННОЙ ГАЗОСНАБЖАЮЩЕЙ СИСТЕМЫ

Рассматривается сетевая модель районной газоснабжающей системы (РГС) с нелинейной целевой функцией. РГС моделируется в виде транспортной сети, состоящей из сети газопроводов и нескольких двудольных графов, соответствующих сетям распределения других видов топлива. Приводится общая вычислительная схема оптимизации РГС, включающая алгоритм итеративного пересчета затрат. Рассматривается также модель РГС с дискретными переменными для решения детализированной задачи распределения топлива. Описывается декомпозиционный метод решения последней задачи. Указываются вычислительные возможности ФОРТРАН-программ, реализующих приведенные алгоритмы. Кратко обобщается практический опыт.

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