POMIARY

STRUCTURAL ANALYSIS OF KAZAKHSTAN CITIES HEATING NETWORKS

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Abstract. *In this paper the structural analysis of Kazakhstan cities heating networks has been presented.*

Keywords: heating network, modeling, structural analysis, graph model

Analiza strukturalna sieci ciepłowniczych miast Kazachstanu

Streszczenie. *W tym artykule została przeprowadzona analiza strukturalna sieci ciepłowniczych miast Kazachstanu.*

Słowa kluczowe: sieć ciepłownicza, modelowanie analiza strukturalna, graf.

Introduction

Heating networks are classified as topological connected objects; therefore performance of networks is largely determined by their structural features. City heating networks were developed with a growth of city and that is why their structure is random.

Structural analysis allows determining special properties, weak and strong point of these networks. Proposed method of structural analysis was carried out for heating networks of Kazakhstan cities as of 1980-1990.

Created graph models of city heating networks were reflected at the first stage of the analysis by network graph vertex-branches incidence matrixes (A) and independent loops matrix (B).

1. Theory

When performing systems structural analysis it is often necessary to have method allowing determining some structural features of systems and giving them quantitative estimation. Expediency of determining such features is in the fact that the necessity in evaluation of system structure and its elements quality from the position of overall system approach appears already at early design stage. Consider some of them [1].

Structure connectivity. This quantitative characteristic allows detecting presence of breaks, hanging vertexes and etc. in the structure [2-5]. Complete quantitative determination of directed graph elements connectivity is given by connectivity matrix:

$$C=\left\|c_{ij}\right\| \tag{1}$$

Elements of matrix C can be calculated based on matrix:

$$A=\sum\nolimits_{k=1}^{n} A^{k} \tag{2}$$

Element $c_{ij}=1$, if $a\geq 1$; $c_{ij}=0$, if $a=0$. Connectivity of all structure elements for undirected graphs corresponds to fulfillment of the following condition:

$$\frac{1}{2}\sum\nolimits_{i=1}^{n}\sum\nolimits_{j=1}^{n}a_{ij}\geq n-1; i\neq j \tag{3}$$

The right side of the in equation determines minimum required number of connections in the structure of undirected graph containing n vertexes.

Structure redundancy. Structural parameter reflecting excess of the total number of connections over required minimum is denoted as structure redundancy R.

According to (1) structure redundancy R is determined as:

$$R=\frac{1}{2}\left[\sum_{i=1}^{n}\sum_{j=1}^{n}a_{ij}\right]\frac{1}{n-1}-1 \tag{4}$$

This structural characteristic is used for indirect estimation of economical efficiency and reliability of investigated systems. For systems with maximal redundancy that have “complete graph” structure type, R > 0; for systems with minimal redundancy R=0; for disconnected systems R < 0.

Thus, the system with greater redundancy R is potentially more reliable, however in a number of structural reliability analysis tasks it is reasonable to supplement it with other parameter considering connections non-uniformity, ε^2

Uniform distribution of connections in the structure of undirected graph with t edges and n vertexes is characterized by medium vertex degree $\overline{\rho}=2m/n$. Then, having entered deviation concept $\rho_i-\overline{\rho}$ where ρ_i – actual degree of given graph vertex t, it is possible to determine quadratic deviation of the set distribution of vertexes degrees from uniform:

$$\varepsilon^{2}=\sum_{i=1}^{n}\rho_{i}^{2}-\frac{4m^{2}}{n}. \tag{5}$$

Parameter ε^2 characterizes capacity slackness of the set structure with m edges and n vertexes in achievement of maximal connectivity. This parameter in relative terms is used for comparison of various automated control systems structures.

Structural compactness. Parameter reflecting elements proximity is entered for quantitative estimation of structural compactness. Proximity of two elements i and j will be determined through minimal path length for directed graph (circuits — for undirected) d_{ij}. The total structural proximity of elements in the system system has been written as follows:

$$Q=\sum\nolimits_{i=1}^{n}\sum\nolimits_{j=1}^{n}d_{ij}\quad(i\neq j) \tag{6}$$

For quantitative estimation of structural compactness very often is used the relative parameter:

$$Q_{ext}=\frac{Q}{Q_{\min}}-1 \tag{7}$$

where $Q_{\min}=n(n-1)$ is minimal value of compactness for system structure of “complete graph” type.

Structural compactness can be also characterized by other characteristic – structure diameter: *d=max*. Taking into consideration prevailing information character of communications in technological networks it can be stated that value Q_{ext} as well as d give integral estimation of inertance of information processes in system, and at equal values of ε^2 and *R* their increase reflects increase of separating communications number thus characterizing reduction of general reliability.

Degree of centralization in structure. Concept of centrality index δ is used for quantitative estimation of centralization degree in structure:

$$\delta=(n-1)(2z_{\max}-n)\frac{1}{(z_{\max}(n-2))} \tag{8}$$

where $z_{\max}$ is maximal value

$$z_{i}=\frac{Q}{2}\left(\sum_{j=1}^{n}d_{ij}\right)^{-1},\quad i=1,2,\ldots,n;\ i\neq j\cdot \tag{9}$$

Element rank is used when representing system structure in the form of directed graph. This characteristic allows distributing of system elements in the order of their magnitude. Element magnitude is defined here only by number of connections of this ele-

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ment with other ones. Certainly, element rank in such definition doesn't give complete characteristic of element importance in system as in this case accuracy, information and other functional characteristics of element are not considered. However, having characterized element by rank the following plausible assumption can be made: the higher element rank the stronger its connection with other system elements and therefore the more severe effect of its performance quality change. Strict definition of element rank is integrated with certain computing difficulties therefore at this stage of structural analysis approximate way is quite enough. For practical tasks this way gives almost true values of element relative ranks and doesn't require big calculations. Values of elements ranks are quite useful information for distribution of temporary, cost and technical resources for achievement of tasks set at technological networks design stage. Quantitative characteristics entered above may be used when performing comparative evaluation of systems structures topological properties.

2. Results

Model of city heating networks is presented in table 1. At that due to volume representation of network graph (e.g. Almaty (Fig.1)) column 2 of table 1 contains only generalized model of network graph.

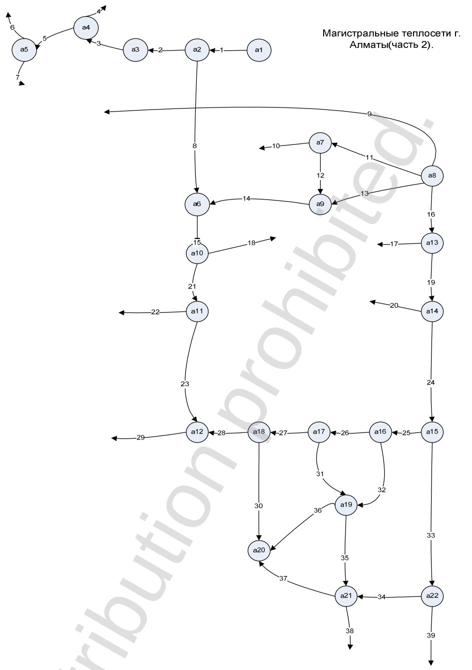
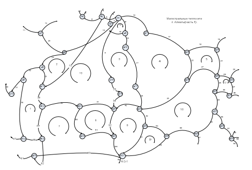
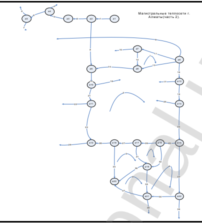
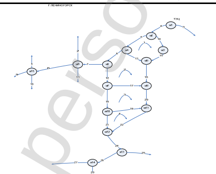
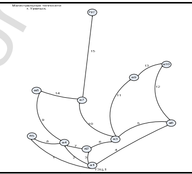
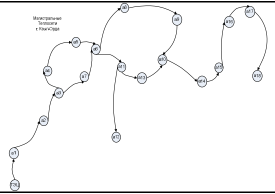
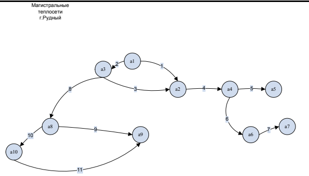
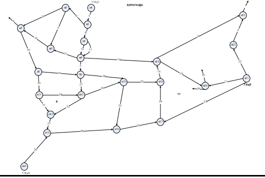
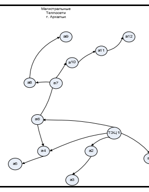


Fig. 1. Almaty main heating network (part 2)
Rys. 1. Główna sieć ciepłownicza w Almaty (część 2)

Table 1. Model of city heating networks
Tabela 1. Modele miejskich sieci ciepłowniczych

№	City	Generalized structure of heating network in the form of graph	Heating network model	Quantity of active elements
1	Almaty (part 1)		No. of vertexes – 39 No. of edges – 67 No. of back loops – 13	Heat station -1
2	Almaty (part 2)		No. of vertexes – 22 No. of edges – 39 No. of back loops – 6	Heat station -2
3	Leninogorsk		No. of vertexes – 11 No. of edges – 28 No. of back loops – 4	Heat station -1
4	Uralsk		No. of vertexes – 39 No. of edges – 67 No. of back loops – 13	Heat station -1
5	Kyzyl-Orda		No. of vertexes – 13 No. of edges – 15 No. of back loops – 2	Heat station -1 Pump Station-1 Pump Station -2
6	Rudnyi		No. of vertexes – 7 No. of edges – 14 No. of back loops – 2	Heat station Pump Station-1 Pump Station -2

№	City	Generalized structure of heating network in the form of graph	Heating network model	Quantity of active elements
7	Karaganda		No. of vertexes – 23 No. of edges – 38 No. of back loops – 11	Heat station-1 Heat station-3 Heat station-4
8	Arkalyk		No. of vertexes – 4 No. of edges – 9 No. of back loops – 0	Heat station

Structural analysis results are presented in table 2.

Table 2. Structural analysis results
Tabela 2. Wyniki analizy strukturalnej

City	C	R	ε^2	Q	d	δ
Almaty (part 1)	3960.5>39	6,23	47.1	31,2	78	23,63
Almaty (part 2)	2964>33	4,98	38,76	27,6	69	20,9
Lenino-gorsk	187,1>27	-32,641	29,13	21,2	53	16,06
Uralsk	112,5>11	-13,5	8,04	10	25	7,57
Kyzyl-Orda	118,7>18	-9,05	12.2	14,4	36	10,9
Rudnyi	145,86>16	-15.76	17.31	12,4	31	9,3
Karaganda	496>22	2,7	25.125	18,8	47	14,2
Arkalyk	109>11	1,3	9,05	10,4	26	7,87

Table 2 shows:

1) for disconnected structures R < 0; for structures without redundancy (consequential, radial, tree shaped) R = 0; for structures with connections redundancy (ring, «complete graph» type) — R > 0;
2) structures (consequential, radial, tree shaped) with R = 0 are distinguished by the parameter ε^2; radial structure has the greatest non-uniformity of connections;
3) the structure of "complete graph" type has the greatest elements proximity (parameter Q); the least – consequential; radial and ring structures undistinguishable with regard to parameter d have different Q values;
4) radial and tree shaped structures having equal or near to equal R, Q, d values are significantly different as per ε^2 and δ parameters, that corresponds to physical content as displacement from full centralization in structure results in greater uniformity of elements connections distribution.

Structure processing shows:

a) HN graph has high centralization degree in Almaty, Leninogorsk, Karaganda. In Uralsk, Arkalyk - low.
b) HN graph in Almaty (part 1) Almaty (part 2) has greater structure compactness ratio Q (27.6), the lowest in Uralsk (10).
c) HN graph in Almaty has grater structural redundancy (R=6.23 part 1, R= 4.98 part 2), Karaganda (2.7), the rest cities have structure poorly connected among themselves, that is failure of elements with significant ranks will result in "collapse" of city heating network, that is in potential break-down. In general this parameter of HN reflects proximity and interaction of elements.

3. Conclusions

Reviewed structural characteristics were obtained only based on the information about composition of elements and their connections. Further development of structural parameters construction methodology for solving structural analysis problems can be based on non-structural information by entering numerical functions onto graph. It allows considering other relevant sides of interaction (temporary, reliability, cost and ect.) along with elements composition and interaction directedness when solving structural analysis problems.

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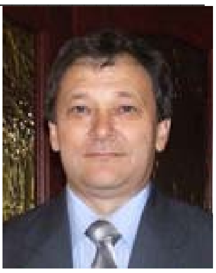

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