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SIZING OF TECHNICAL NETWORKS OF URBAN UTILITIES SYSTEMS

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Abstract - The review paper presents the general scope of technical engineering and optimization methods of the most important urban utilities facilities: water supply and gas distribution networks functioning in open circuits, heating and electrical distribution networks respectively, functioning in closed circuits.

From the previously undertaken studies, it comes out the version with the most favorable technical and economical exploitation conditions. In the case of large systems, two or even several versions are analyzed in order to determine the optimized solutions.

The paper illustrates the most important documentations sources and results obtained from using urban networks optimizations software, additionally, the optimization models of virtual transitions and the obtained outcomes are presented.

Keywords: technical networks, optimization methods, virtual transitions method

1. PRIORI STUDIES AND URBAN NETWORKS OPTIMIZATION METHODES

It mainly includes the consistent elements coming from the authors' long preoccupation for the urban facilities optimization, regarding on one hand the additional and modernization works undertaken to the existing systems, and on the other hand the newly installed networks in adverse areas, even the either of metropolitan areas or in adjacent localities having

nd the historical and cultural monuments, the green areas, the supply of needed electrical energy.

2. OPTIMIZATION METHODES OF TECHNICAL NETWORKS

2.1 Implementation of software programs

The software programs used for networks optimization were developed for an initial version between 1972-1988, as a result of the collaboration with other institutions: ICH Bucharest, ICEPEGA Bucharest, IPJ Timis, CPJ Tims, IGCL Timisoara, IPROTIM, IPJ Sibiu [77,78].

The software implementation leads to the following conclusions:

a). for the software development, related issues to the graphs theory were used [21, 32, 71];

b). the effective implementation in the PhD thesis of certain special mathematic models have confirmed the efficiency of the optimization procedure [2,5,25,51];

c). the implementation of special software, having as purpose the production of top energy by hydroelectrical stations production optimization, respectively the optimisation of low-cost energy in steam power plants, brings a contribution in the centralized systems. Prior studies are meant to determine the set of measures ensuring the optimal functioning of the systems, the minimal exploitation cost, the technical and technological exploitation conditions.

As far as the technical documentation is concerned, it includes the bibliography list on fields of studies such as: hydraulics [3,18,20,27,28,29,56,57, 58], water supply and water economy [17,32,34,35, 48,52,53,55,57], hydraulics technical applications [14, 19,59,60,67,76,77,78], water supply networks [2,23, 24,25,36,42,43,44,45,46,69,70,71], thermal networks [4,5,6,7,16,40,61,62], gas [9,11,12,14,26,39,41,69,73, 74], hydroenergetic [1,21,31,49,50,51,54,63,64,65,66, 68] and electrical networks [8,10,13,15, 22, 30, 33, 37, 38,75].

There must be also checked the execution conditions of magistrals and service networks optimal tracks, the field's durability and stability in the case of underground networks, the aggressiveness of underground water, as well as the necessary protective steps, the use of new materials and modern technologies.

Equally important, there should be considered the equipments and functioning conditions of urban communication lines, the existing infrastructure a

optimization of technical networks exploitation processes [6,21,35,36,45,46,49,51,66,67,68];

d). the comparison between the results obtained by virtual transitions method implementation, for the first time, in the optimization supply networks, confirms the accuracy of the developed methods;

e)the validity of the functional ring balancing of closed circuit networks, thermal and electrical networks is confirmed exclusivelly by use of standardized diameters, inferior to those determined in optimization, in the pipes/conductors wich are closer to the heating station/transformation station, and respectively the superior standard diameters, in the farther pipes/conductors.

.f). where it is not possible the comparison of the results obtained by the virtual transitions method with those obtained by the software program, they were compared with the results known from the references speciality problems collection, obtained with identical study data.

2.2. Application of virtual transitions general method

The first group of parameters considering virtual transitions is $L_j\sqrt{Q_j}$, where L_j represents the

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length of the pipe and Q_j is the pipe's calculation flow, was applied for sizing the gravitational transportation pipes [35], for optimization applications of arborescent networks, and according to the latest studies [47], generally for systems whose cost is determined by a strictly ascending function depending on any of the pipes' diameter.

The virtual transitions general method, elaborated by Mosnin, consists of introducing a virtual flow X=1 into a closed loop network, determining then its distribution in the optimized closed loop network with the values x_j for all pipes in the network. In the first translations, the parameters x_j where named " virtual flows", which created confusions because of the improper term. The correct names are appreciated to be „sizing parameters" and are defined by the relationship (1) for water and thermal networks,

$$x_j = \frac{D_j^{\alpha+m}}{EQ_pQ_j^2}, \tag{1}$$

(2) for gas networks,

$$x_j = \frac{d_j^{\alpha+m}}{Eq_{v0}q_{vj}^2} \tag{2}$$

and (3) for electrical networks

$$x_j = \frac{s_j^{\alpha+m}}{EI_oI_j} \tag{3}$$

where:

α is the exponent of the diameter/section in the relation of the pipe/conductor unitar cost;
m is the exponent of the diameter/section in the relation of the energy losses;
Q_p is the pumped flow in the system;
Q_j are the balanced flows of the j pipes;
q_{vo} is the total flow in the system;
q_{vj} are the balanced flows of the j pipes, in $\mathrm{m^3_N/s}$.
I_o is the total electrical current intensity;
I_j are the balanced electrical current intensities in the j conductors;
E is the economic factor.

The optimization mathematical method are based on the relation of the multicriterial complex K, the equivalent yearly costs:

$$K = \sum_1^c \;(p_1+\beta)*I_c + (p_2+\beta)*I_p + eTP \tag{4}$$

where the first term represents the indirect operation cost and the second, the yearly energie cost. In the relation (4) aer used the notations:

p_1 - amortization rate for pipes;
p_2 - amortization rate for pump station;
β - accumulation and benefits yearly rate;
I_c - network investments cost;
I_p - pump station investments costs;
e - energy cost, in c.u./kWh;
T - operation time at maximum load, in h/y;
P – maximum load, in kW.

The economic factor E is defined by different relations, (5) for water and thermal networks,

$$E = 9{,}81mk\frac{[(\beta+p_2)fr+eT]}{\eta B\alpha(\beta+p_1)} \tag{5}$$

(6) for gas networks,

$$E = \frac{9{,}81}{1000\eta}5Tk\frac{e}{B\alpha} \tag{6}$$

and (7) for electrical networks

$$E = k\rho\frac{[(\beta+p_2)f+eT]}{\eta B\alpha(\beta+p_1)} \tag{7}$$

where:
f is the specific installation cost;
B *is* the unitar cost of the pipes/conductors.

In the first effective applications [3,5], in all technical networks, optimization software [7-15], this method is considered to be a correct and a useful one, qualified as a fundamental method [55]. This method has been studied and compared to the other methods, in a new optimization cycle of water supply, gas, heating and electrical networks [37-47]. It has been evaluated as compared to other objectives of optimal solutions [70-72]and applied in most research-design contracts.

The study of the electro-hydrodynamic analogy [76] opened the way for electrical networks balancing. Other paper [16] presents the virtual transitions and the relations used for optimizing through iterations of fluid networks. In the [13,15] papers are presented the optimization relations of the electrical networks. The value of the sizing parameters at the arboresent networks pipes are $x_j = 1$.

In the Table 1 are presented the real parameters and the virtual transitions used in the optimization calculus of the fluids, respectively of the electrical networks and the relations of cycle corrections in two considered balancing methods of the closed loop networks.

Iterations balancing of the closed loop networks

Table 1

Crt. nr.	**Fluid networks**		**Electrical networks**	
	Real parameters	**Virtual transitions**	**Real parameters**	**Virtual transitions**
1.	$a_j = \frac{k_j}{D_j^m}$ -specific hydraulic resistance	$a_{vj} = \sqrt{\lvert Q_j \rvert}$ -virtual specific hydraulic resistance	$\frac{\rho_j}{s_j}$ - specific electrical resistance [Ω/m]	$a_{vj} = \sqrt{\lvert I_j \rvert}$ - virtual specific electrical resistance
	unoriented parameters			

2.	$M_j = L_j a_j$ -hydraulic resistance module	$M_{vj} = L_j a_{vj}$ - virtual hydraulic resistance module	$R_j = \rho L_j / s_j$ - electrical resistance [Ω]	$M_{vj} = L_j a_{vj}$ - virtual module of electrical resistance
	oriented parameters			
3.	Q_j - real volume flow of *j* pipe	x_j - sizing parameter of *j* pipe	$I_j; \left(P^2 + Q^2\right) / \sqrt{3U}$ - electric current intensity	x_j - sizing parameter of *j* conductor
	oriented parameters			
4.	$h_j = M_j Q_j^2$ - hydraulic miscarriage	$h_{vj} = M_{vj} x_j^{-0,75}$ - virtual hydraulic miscarriage	$\Delta U_j = \frac{\sum \left(p_k R_k + q_k X_k\right)}{U_n}$ - voltage drop (three-phase lines)	$\Delta U_{vj} = M_{vj} x_j^{-0,5}$ - virtual voltage drop on a line
	oriented parameters			
5.	$Q_j h_j = M_j Q_j^3$ -energetical product	$x_j h_{vj} = M_{vj} x_j^{0,25}$ - virtual power	$L_j I_j; \left(R_j I_j\right)$ - rigidity product	$L_j x_j$ - virtual rigidity product
	unoriented parameters			
Calculation method relations of cycle corrections **Method I of balancing**				
Stage 1	$\Delta Q_i = -\frac{\sum_{(i)} \varepsilon_j L_j Q_j^2}{2 \sum_{(i)} L_j Q_j}$		$\Delta I_i = -\frac{\sum_{(i)} \varepsilon_j L_j I_j}{\sum_{(i)} L_j}$	
Stage 2	$\Delta x_i = +\frac{4}{3} \frac{\sum_{(i)} \varepsilon_j M_{vj} x_j^{-0,75}}{\sum_{(i)} M_{vj} x_j^{-1,75}}$		$\Delta x_i = -2 \frac{\sum_{(i)} L_j x_j^{-0,5}}{\sum_{(i)} L_j x_j^{-1,5}}$	
Method II of balancing				
Stage 1	$\Delta x_i = +\frac{\sum_{(i)} \varepsilon_j M_{vj} x_j^{-1}}{\sum_{(i)} M_{vj} x_j^{-2}}$		$\Delta x_i = \frac{\sum_{(i)} L_j x_j^{-1}}{\sum_{(i)} L_j x_j^{-2}}$	
Stage 2	$\Delta Q_i = -2 \frac{\sum_{(i)} L_j x_j^{-0,75} \left\|Q_j\right\|^{0,5}}{\sum_{(i)} L_j x_j^{-0,75} \left\|Q_j\right\|^{-0,5}}$		$\Delta I_i = \frac{\sum_{(i)} \varepsilon_j L_j x_j^{-0,5} I_j}{\sum_{(i)} L_j x_j^{-0,5}}$	

The fluid networks with at least one ring formed by the interconnection of the pipes and nodes are considered closed loop networks. The flows/electrical current intensities depend on the pipes/conductors diamaters/sections.

The unknown parameters are the flows Q_j /electric current intensity I_j in each pipe/conductor which must be balanced through succesive iterations and the diameters for each pipe/conductor which will be sizing in economical optimized solution.

In a network with *n* nodes, the partial derivatives of the optimizing criteria $\frac{\partial K}{\partial h_j}$ can be equalised with zero for a number of (*n*-1) values of the head losses h_j, considerated like independent quantities. From the optimising conditions results that the x_j values and the flows/intensities most be balanced in nodes.

Analytic, the mathematical system can't be solved, because the remained equations are in implicite form:

$$f(i) = \sum_1^i Q_j^{\frac{2\alpha}{\alpha+m}} x_j^{-\frac{m}{\alpha+m}} = 0 \qquad (8)$$

A first model, [35], was elaborated from the condition of the minimum energetical content of the real trasitions in each ring

$$\sum_i h_j Q_j = \sum_i M_j Q_j^2 Q_j \qquad (9)$$

or a model with appropriate values

$$\sum_i L_j Q_j^3 = \text{minim} \qquad (10)$$

For the sizing of the closed loop networks, there are three methods of balansing proposed.

In the first method, initial is proposed an arbitrary distribution of the flows $\{Q_j\}$/electrical current intensities $\{I_j\}$ independently of the $\{x_j\}$ distribution [35]. This values are corrected through succesive iterations on the base of cycle corrections ΔQ_j. In the second stage it is proposed an arbitrary $\{x_j\}$ distribution, which also must be balanced through iterations.

In the second method, [5], first the distribution of $\{x_j\}$ is balanced, independently of the $Q_j\}/\{I_j\}$ distribution, and than the distribution of $\{Q_j\}/\{I_j\}$ through succesive iterations.

At the application of the third method of balansing [8,15], the proportionality method of the dimensoning parameters, the calculus values are obtained direct through the balancing of the flows/ electrical current intensities on the base of lengths, through the balansing of $L_jQ_j^2$ transitions.

The analytical relationship of the sizing parameter x_j is

$$x_j = \Phi Q_j \tag{11}$$

for fluid networks and

$$x_j = \Phi I_j \tag{12}$$

for electrical networks.

Once the optimized distributions $\{Q_j\}$ and $\{x_j\}$ known, the sizing relation for water and thermal networks is

$$D_j = \left(E\, x_j Q_p\right)^{\frac{1}{\alpha+m}} Q_j^{\frac{2}{\alpha+m}}, \tag{13}$$

for gas networks is

$$d_j = x_j^{\frac{1}{\alpha+m}} E^{\frac{1}{\alpha+m}} q_{vo}^{\frac{1}{\alpha+m}} q_{vj}^{\frac{2}{\alpha+m}} \tag{14}$$

and for electrical networks

$$s_j = \left(EI_0 I_j x_j\right)^{\frac{1}{\alpha+m}} \tag{15}$$

where s_j is the section of the electrical conductor.

In the arborescent networks, the flows in the j pipes are known and does not depend on the pipes diameter.

In a network with n nodes, from the (n-1) equalised with zero equations of the head losses results the relationship:

$$D_j^{\alpha+m} = EQ_pQ_j^2 \tag{16}$$

The economical diameter for arborescent water networks results

$$D_j = \left(EQ_p\right)^{\frac{1}{\alpha+m}} Q_j^{\frac{2}{\alpha+m}} \tag{17}$$

and for gas networks

$$d_j = E^{\frac{1}{\alpha+m}} q_{vo}^{\frac{1}{\alpha+m}} q_{vj}^{\frac{2}{\alpha+m}}. \tag{18}$$

In the applications had been used the following values of the parameters α=1,8; m=5,33, 1/(α+m)=0,14. The economic diameters values do not depend on the pipes length.

The pressure losses for gas pipes are limited on the value

$$\Delta p = p_1 - p_2 \tag{19}$$

where:

p_1 is the outlet pressure measured at the station gas regulator;

p_2 is the necessary pressure at the entrance at the consumer regulator.

At the low pressure gas networks the unitar pressure losses are:

$$\frac{\Delta p}{L} = aq_{\mathrm{v}}^2 = \frac{k}{d^5} q_{\mathrm{v}}^2 \tag{20}$$

where a is the specific resistance, in $\left[\left(\frac{mmH_2O}{m}\right):\left(\frac{m_N^3}{s}\right)^2\right]$ and k a coefficient, in $\left[\left(\frac{mmH_2O}{m}\right)m^5:\left(\frac{m_N^3}{s}\right)^2\right]$.

For the low or medium pressure networks, the volum flow is not constant and so in the calculus are used the flow G, in m^3_N, in the standard state, divided by the average pressure value.

In the case of the networks supplied in diferent nods with the flows Q_1, Q_2,..., Q_n / electrical current intensities I_1, I_2, ..., I_n, the equalities of the fractions can be written, for the j pipes of water or thermal systems

$$\frac{X_1}{Q_1} = \frac{X_2}{Q_2} = ... = \frac{X_n}{Q_n} = \frac{1}{Q_p} = \Phi, \tag{21}$$

or for the j conductors of the electrical network

$$\frac{X_1}{I_1} = \frac{X_2}{I_2} = ... = \frac{X_n}{I_n} = \frac{1}{I_0} = \Phi, \tag{22}$$

so that the additions $Q_o = Q_1 + Q_2 + ... + Q_n$ and $I_o = I_1 + I_2 + ... + I_n$ mut be respected.

3. CONCLUSIONS

The paper is an optimization technical and economical study of the open and closed loop networks. The optimized sizing of the networks on the base of the equivalent yearly costs criteria determines the optimal diameteres independently of the lengths of the pipes/conductors. So in the sizing relationship don't occurs the lengths of the pipes/conductors.

The optimal dimensioning of the many sources supplied networks is an efficient method because, through the application of the virtual fluxes components proportionaly with the values of the flows/electrical current intensities at sources, an optimal repartition of the calculus parameters are assured.

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