ENERGY SYSTEM OPTIMIZATION BY MEANS OF EXERGY ANALYSIS METHOD

Boris DRAGANOV, Volodymyr KOZYRSKYI, Vadym SHCHERBATIUK

NATIONAL UNIVERSITY OF LIFE AND ENVIRONMENTAL SCIENCES OF UKRAINE

Abstract. The foundations of energy system optimization using graph-theoretic modeling are stated. The conception of exergy-economic optimization for energy-consuming systems is presented.
Keywords. exergy, graph theory, topological structure, incidence matrix, exergy destruction, exergy-economic factor, exergy value

INTRODUCTION

One of the most pressing problems of our time is to save energy in industrial processes, as well as in everyday life. Effective tool in solving this problem is to optimize the use of energy structures and their parameters in order to minimize capital and operating costs at the appropriate technical and resource constraints.

The purpose of research – analysis of the priority energy system optimization methods and evaluation of their performance to assess the minimization of energy and economic indicators.

MATERIAL AND ANALYSIS

Optimization of the system under study – the definition of the best of all possible systems on the selected criterion of its effectiveness. Comprehensive, system optimization aims choice of the system parameters (technological, design ones etc.), which would provide optimal or near-optimal values of the criterion of efficiency:

$$Z_{opt} = \underset{x_j \in R^n}{extr} \left\{ Z(x_j) \right\} \tag{1}$$

under constraints:

$$f_i(x_j) > 0\,,\ i = 1, 2, ..., m; \tag{2}$$

$$q_k(x_j) > 0,\ k = 1, 2, ..., L, \tag{3}$$

where: R^n is n-dimentional real vector space.

It is easy to see that the above optimization condition is a multiextremal multivariate problem of discrete nonlinear programming complicated by constraints (2) and (3).

The concept of exergy as a maximum working capacity is useful when considering the degree of perfection of various processes in terms of energy conversion. If the process is completely reversible, the resulting total efficiency of the substance (the same applies to the mechanical work) should be equal to the consumed working capacity. If there is irreversibility then working capacity decrease is a loss of energy [1-4].

Here are some basic facts of the graph theory with respect to the analyzed problem.

Exergetic flow graphs – arc weighted connected directed graphs, showing the transformation by the system elements the exergy consumption of substance and energy flows, as well as the exergy loss in the elements of the system. Vertices of the graph correspond to the elements (technological), carrying conversion of exergy consumption, and also correspond to the sources and sinks of exergy. Arcs of the graph correspond to the flow of exergy and exergy losses in the elements of the system; the weight of its arcs is equal to the exergy consumption for each vertex.

Graph can be represented using matrices. Matrix representation of the graph allows to display the structural features of graphs. To solve the problems of analysis and synthesis of energy-saving systems of greatest interest is the incidence matrix [5].

The following is an algorithm and exergy and thermoeconomic analysis of energy systems [6, 7].

Algorithm $A\Pi_{\Sigma}$ – definition of exergy losses in the energy system. The algorithm consists of the following main steps:

1. Build the system corresponding exergy flow graph $E = (A, U)$, the incidence matrix $||M_{ij}||$ and calculate the exergy flows along the arcs E_j , $j = 1, 2, ..., m$.

2. For all elements $i = 1, 2, ..., m$ identify incoming ($Mij = 1$) and outgoing ($Mij = -1$) flows, calculate the sums E_j^{in} and E_j^{out} of exergy flows i-th elements and their degree of thermodynamic perfection.

3. Calculate the total loss of exergy:

$$\ddot{I}_{\Sigma} = \sum_{i=1}^{m} \ddot{I}_i. \quad (4)$$

It is understood that the value E_j^{in} represents the sum of these flows E_j, which correspond to the columns of the incidence matrix, not containing –1, i.e. these flows do not come from any element of the system, and are only incoming E_j for it or what is the same, the column contains only +1.

Based on the described graph-theoretic optimization, it was solved a number of problems including ones in the field of renewable energy sources.

Let us analyze the method of exergy-economic optimization (Fig. 1).

Exergy-economy uses the results of the system synthesis, cost analysis and thermodynamic modeling of energy conversion systems and further provides with refined information analysis process, a database for mathematical optimization methods, and can be widely used in expert systems to improve the design and operation of the system.

Exergy-economic assessment is advantageously carried out at the level of system components. Due to exergy analysis it is well known [10-15].

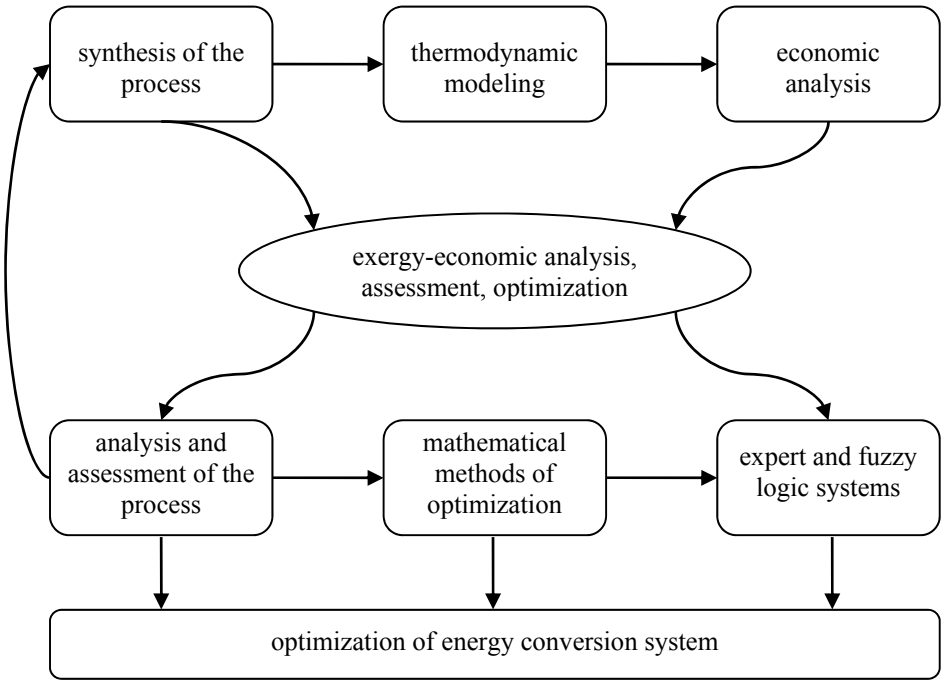

Fig. 1. Exergy-economic procedure of optimization.

- $E_{D,k}$ – the absolute destruction of exergy:

$$E_{D,k} = E_{F,k} - E_{P,k} - E_{L,k}, \quad (5)$$

where $E_{F,k}$ – absolute exergy of the fuel; $E_{P,k}$ – absolute exergy of the product; $E_{L,k}$ – the loss of exergy.

- ε_k – exergy effectiveness

$$\varepsilon = \frac{E_{P,k}}{E_{F,k}} = 1 - \frac{E_{D,k} + E_{L,k}}{E_{F,k}}; \quad (6)$$

- y_k – relative exergy destruction

$$y_{D,k} = \frac{E_{D,k}}{E_{F,tot}}. \quad (7)$$

Criteria of exergy-economic analysis:

- cost of the fuel exergy

$$c_{F,k} = \frac{C_{F,k}}{F_{F,k}}; \quad (8)$$

- cost of the product exergy

$$c_{P,k} = \frac{C_{P,k}}{F_{P,k}} \quad (9)$$

- cost associated with the destruction of exergy

$$C_{D,k} = c_{F,k} \cdot E_{D,k}\,; \quad (10)$$

- cost associated with the loss of exergy

$$C_{L,k} = c_{F,k} \cdot E_{L,k}\,; \quad (11)$$

- cost of capital investment Z_k^C;
- operating and maintenance costs Z_k^{OM};
- sum Z_k of the last summands

$$Z_k = Z_k^{Cl} + Z_k^{OM}\,; \quad (12)$$

- relative price difference:

$$r_k = \frac{C_{P,k} - C_{F,k}}{C_{F,k}} = \frac{1 - e_k}{e_k} + \frac{Z_k}{e_{F,k}}. \quad (13)$$

RESULTS

Exergy cost equation [5] can be written for the incoming and outgoing material flows associated with the conversion or transfer of power W and heat E_q:

$$C_i = c_i E_i = c_i \left(m_i l_i \right), \quad (14)$$

$$C_e = c_e E_e = c_e \left(m_e l_e \right), \quad (15)$$

$$C_w = c_w W, \quad (16)$$

$$C_q = c_q E_q, \quad (17)$$

where c_i, c_e, c_w, c_q – the average costs of exergy.

Balance of the cost, formulated for each component separately, shows that the sum of the costs arising from the process of exergy transport is the sum of the values of all exergy entering the system, as well as the appropriate cost of capital investment Z_k^C and maintenance costs Z_k^{OM}. Denoting the sum Z_k^C and Z_k^{OM} as Z_k for the component receiving the heat flow and generating work, we can write the equation of exergy balance:

$$\sum_e \left(c_e E_e \right)_\kappa + c_{w,\kappa} W_\kappa = c_{q,\kappa} E_{q,\kappa} + \sum_i \left(c_i E_i \right)_\kappa + Z_\kappa. \quad (18)$$

In the analysis of the component it is based on the assumption that the costs in terms of exergy are known for all incoming flows (10-14).

Criterion of optimization is exergy-economic factor:

$$f_k = \frac{Z_k}{Z_k + c_{F,k}\left(E_{D,k} + E_{L,k} \right)}. \quad (19)$$

The values $c_{F,k}$ depend on the relative position of the k-th component of the system and its relationship with the preceding and the subsequent components.

A distinctive feature of exergy-economic optimization is that to determine the energy and economic performance in their interdependence for analyzed structural and parametric options.

CONCLUSION

1. A positive feature of exergy, compared to the energy lies in the fact that there is no energy loss in energy processes occurring, while for each particular case can be determined losses of exergy.
2. Method of graph-theoretic constructions has the advantage that the investigated structures are presented in graphic form, and is convenient to choose possible solutions.
3. Feature of exergy-economic optimization is that both energy and economic indicators are defined in the relationship. Therefore, the optimization criterion is the most comprehensive indicator.

REFERENCES

[1] Эксергетические расчеты технических систем. Справ. пос., под. ред. А.А. Долинского, В.М. Бородянского, Киев, Украина, 1993, 360 с.

[2] Драганов, Б.Х., Морозюк, Т.В. Система теплоснабжения на базе теплового насоса с аккумуляторами теплоты Киев, Украина, 1985, № 03-50, С. 16-22.

[3] Драганов, Б.Х., Гулко, Т.В. Оптимизация методами теории графов систем теплохладоснабжения с использованием возобновляемых источников энергии, Вестн. Челябин. агроинж. ун-та, Челябинск, Россия, 2000, № 31, С. 62-66.

[4] Гулко, Т.В., Драганов, Б.Х., Морозюк, Т.В. Использование нозкопотенциальных источников энергии при помощи абсорбционных теплотрансформаторов, Энергосбережение в сельском хозяйстве, Москва, Россия, 1998, Ч. 2, С. 225-226.

[5] Харари, Ф. Теория графов, Москва, Россия, 1973, 300 с.

[6] Драганов, Б.Х., Гулко, Т.В., Мищенко, А.В. Использование абсорбционного теплового насоса с аккумулированием энергии в системах теплохладоснабжения, Докл. IV. Междунар. конф. по экологии, Тамбов, Россия, 1996, С. 52-54.

[7] Никульшин, Р.К., Драганов, Б.Х., Морозюк, Т.В. Анализ теплонасосных систем теплохладоснабжения

на основе эксерготопологического представления математической модели, Материалы IV съезда АВОК, Москва, Россия, 1995, С. 215-218.

[8] Draganov, B. H., Fara, L.A. Complex Use of Renewable Energy Resources for Heating Cooling Systems, Solar Energy for Sustainable Development, Kiev, Ukraine, 1995, 4, № 1/2, p. 38-41.

[9] Draganov, B.H., Dolinsky, A.A. Determination of thermophysical characteristics of the underground heat accumulator // 6-th Intern. Conf. of Thermal Energy Storage, Espoo. Finland, 1994, p. 26.

[10] Tsatsaronis, G. Design optimization using exergoeconomics, Pгoc. ASI «Thermodynamics and the optimization of complex energy systems», Neptun, Romania, 1998, p. 394-410.

[11] Bejan, A., Tsatsaronis, G., Moran, M. Thermal Desing and Optimization, New York, USA, 1996, 530 p.

[12] Lorano, M.A., Valero, A. Application of the Exergetic Costs Theory to a Steam Boiler in a Thermal Generation Station , THERMODYNAMICS AND THE DESIGN, ANALYSIS AND IMPROVEMENT OF ENERGY SYSTEMS, AES vol. 27, ASME Book no. G00717, 1992, p. 91-99.

[13] Тсатсаронис, Д. Взаимодействие термодинамики и экономики для минимизации стоимости энерго-преобразующих систем, Одесса, Украина, 2002, 152 с.