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SUBSTANTIATION OF THE METHOD OF COMPLEX ASSESSMENT OF ENERGY-ECOLOGICAL-ECONOMIC EFFICIENCY OF ENERGY SUPPLY SYSTEMS WITH COGENERATION HEAT PUMP INSTALLATIONS AND PEAK SOURCES OF HEAT

Substantiation of the method of complex assessment of energy-ecological-economic efficiency of energy supply systems (ESS) with cogeneration heat pump installations (CHPI) and peak sources of heat (PSH), that has in-depth approach to the assessment of energy transformations in the elements of ESS has been performed, it enables to provide the substantiated determination of high energy efficient, ecologically safe and economically substantiated operation modes of ESS with CHPI and PSH on conditions of variable: operation modes of ESS and its elements, levels of ESS elements energy efficiency, refrigerants, sources of drive energy and topological composition of ESS.

Key words*: methodical fundamentals, energy-ecological-economic efficiency, energy supply system, cogeneration heat pump installation, peak source of heat.*

Introduction

Energy supply systems (ESS) with cogeneration heat pump installations (CHPI) and peak sources of heat (PSH) provide high indices of energy efficiency on conditions of high efficient operation modes, determined in a number of home and foreign publications [1 – 7], can be two times more efficient than conventional sources of energy supply, based on high efficient electric and fuel-fired boilers. A number of publications of Ukrainian authors [8 – 9] are study the problems of the assessment of energy and economic efficiency of ESS with CHPI and PSH, however, the attention should be focused on certain drawbacks of the approaches, chosen by authors. In particular, in the research [8], the analysis of the operation modes of the combined energy supply systems with CHPI with gas-piston engines and hot water boilers was performed. In the studies [8, 9] simplified approach to the assessment of energy transformations in CHPI is used, it does not allow to apply the obtained results for various operation modes of the heat pump, using different sources of low temperature heat in the process of CHPI operation in ESS for complex assessment of energy-ecological-economical efficiency of the above-mentioned ESS.

Aim of the research is the substantiation of the method of complex assessment of energy-ecological-economic efficiency of energy supply systems with cogeneration heat pump installations and peak sources of heat, that has more in-depth approach to the assessment of energy transformations in ESS elements, enabling to provide the substantiated determination of high energy efficient, ecologically safe and economically valid operation modes of ESS with CHPI and PSH on conditions of variables: ESS and its elements operation modes, levels of ESS elements energy efficiency, refrigerants, sources of drive energy and topological composition of ESS.

Main part

Methodical fundamentals for carrying out complex assessment of energy-ecological-economic efficiency of ESS on the base of CHPI and PSH applying the suggested complex generalized dimensionless criterion of energy-ecological-economic efficiency of ESS with CHPI and PSH are proposed in our research [10]:

$$K_{ESS}^{compl.} = K_{ESS} + \Delta E_i^{ESS} + \Delta EC_i^{ESS} = (1-\beta)\cdot K_{PSH} + \beta \cdot K_{CHPI} + \Delta E_i^{ESS} + \Delta EC_i^{ESS}, \qquad (1)$$

where K_{ESS} – is complex dimensionless criterion of energy efficiency of ESS with CHPI and PSH from the studies [1 – 7, 10 – 11], used for the assessment of energy efficiency level and determination of highly efficient operation modes of the above-mentioned ESS on condition that $K_{ESS} > 1$; ΔE_i^{ESS} – is relative economic efficiency (in shares) for ESS with CHPI and PSH for the *i*-th operation mode of ESS from the study [10 – 11], this index enables to determine economically valid operation modes of the above-mentioned ESS on condition that $\Delta E_i^{ESS} > 0$; ΔEC_i^{ESS} – is relative ecological efficiency (in shares) for ESS on the base of CHPI and PSH for the *i*-th operation mode of ESS from the study [11], this index enables to determine ecologically safe operation modes of the ESS with CHPI and PSH on condition that $\Delta EC_i^{ESS} > 0$; β – portion of the loading of CHPI within ESS from the studies [1 – 7, 10 – 11]; K_{PSH} – is the dimensionless criterion of PSH energy efficiency within ESS from the study [1]; K_{CHPI} – is the dimensionless criterion of steam compressor CHPI energy efficiency, suggested and substantiated in the studies [1 – 7].

In the study [10] it is determined that ecologically safe, energy efficient and economically valid operation modes of ESS with CHPI and PSH are provided on the condition that $K_{ESS}^{compl.} > 1$. Energy efficiency, ecological safety and economic efficiency of the ESS with CHPI and PSH increase with the increase of this index.

The impact of the components of energy efficiency, economic efficiency and ecologically safety of ESS with CHPI and PSH on the value of the generalized complex index of energy-ecological-economic efficiency will be illustrated on the example of ESS with CHPI, using the heat of sewage, and peak gas-fired boiler.

The efficiency of the above-mentioned ESS is determined for the change of CHPI load share within the limits of β = 0,1…1,0. The results of the study are given for energy efficient operation modes of CHPI with K_{CHPI} =1,1…2,1 (on conditions of maximum efficiency of gas-piston engine (GPE)) on the base of studies [1 – 7] results, that correspond to real coefficient of performance of CHPI within the limits of φ_r = 2,7…5,4 for CHPI of large capacity, according to [12].

Fig. 1 shows the area of energy efficient operation of ESS, determined for the modes of high efficient operation of CHPI. This area is determined by the index of efficient operation of ESS with CHPI and PSH from the formula (1) on conditions of maximum efficiency of GPE and peak fuel-fired boiler, without the account of two last components that take into consideration economic and ecological efficiency. This area is determined on the conditions of high efficient operation of CHPI with K_{CHPI} =1,7…2,1 and the change of CHPI loading share in ESS within the limits of β = 0,125…1,0.

Fig. 2 shows the area of energy efficient operation of ESS, determined for wide range of CHPI efficiency change. As in the previous case, this area is determined by the index of the efficiency of ESS with CHPI and PSH from the formula (1), on conditions of maximum efficiency of GPE and peak fuel-fired boiler, without the account of two last components that take into consideration economic and ecological efficiency. This area is determined on conditions of energy efficient operation of CHPI with K_{CHPI} =1,3…2,1 and the restricted range of CHPI loading share change in ESS within the limits of β = 0,25…1,0.

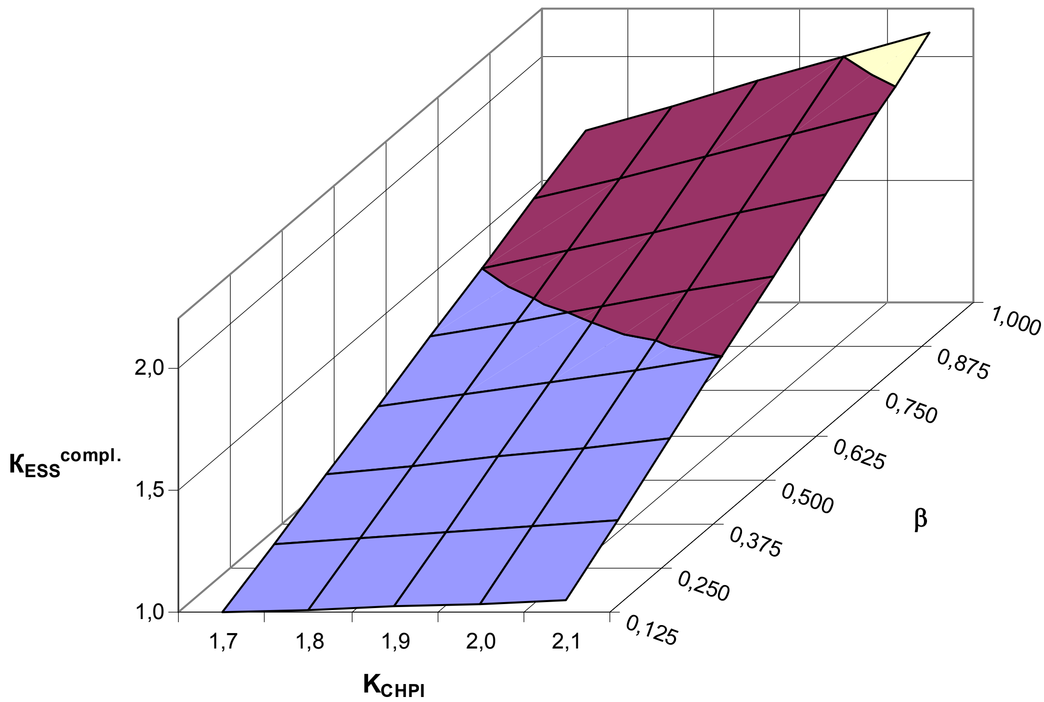

Fig. 1. Area of the energy efficient operation of ESS, determined for the modes of high efficient operation of CHPI by the efficiency index of ESS with CHPI and PSH without the account of the components, taking into consideration economic and ecological efficiency

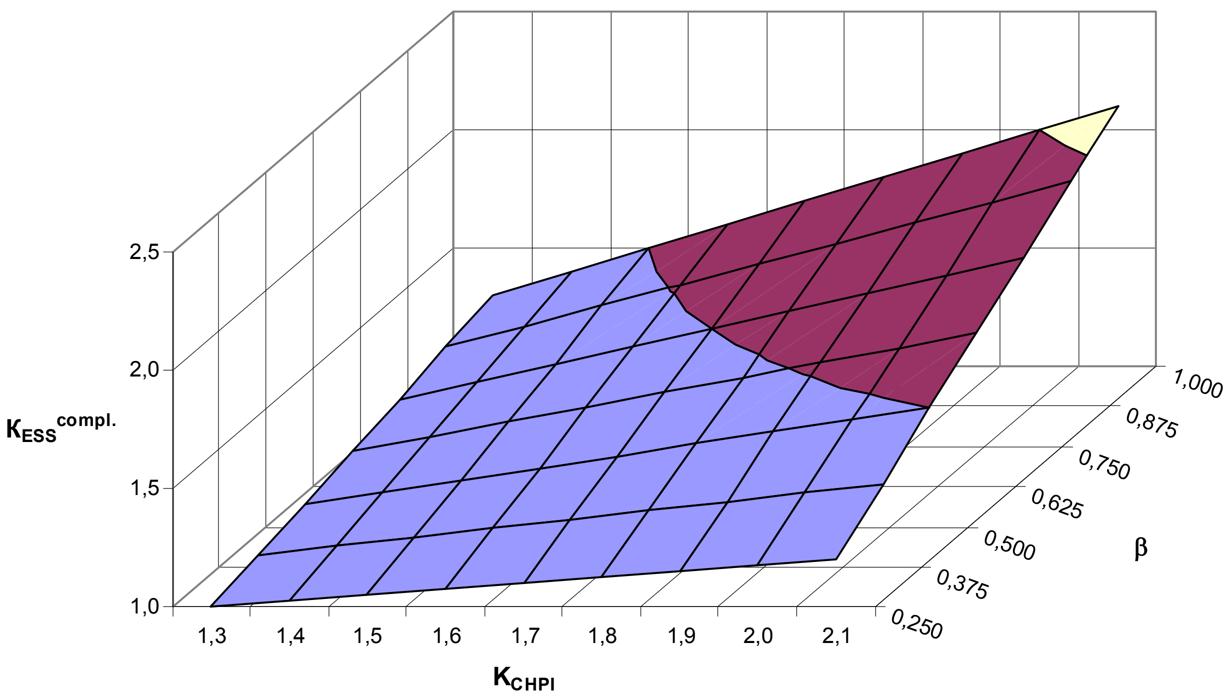

Fig. 2. Area of the energy efficient operation of ESS, determined for wide range of CHPI efficiency change by the efficiency index of ESS with CHPI and PSH, without the account of the components, taking into consideration economic and ecological efficiency

For the results of the research, shown in Fig. 1 and 2, according to [13], such indices of ESS equipment are taken into consideration: value of GPE efficiency factor η_{EM} = 0,42; the value of the electric motor efficiency with the account of energy losses in the control unit η_{ED} = 0,8. As the PSH fuel-fired boiler house with η_{FB} = 0,9 is provided in ESS. The value of the dimensionless criterion of fuel-fired boiler energy efficiency, according to [12], is K_{PSH}^{FB} = 0,9. The dependences, shown in Fig. 1 and 2, are determined on condition of K_{ESS} > 1.

Fig. 3 shows the area of energy efficient operation of ESS, determined for high efficient operation modes of CHPI, by efficiency index of ESS with CHPI and PSH from the formula (1), on conditions of maximum efficiency of GPE and peak fuel-fired boiler with the account of the component, that takes into consideration ecological efficiency and without the consideration of the component, that takes into account economic efficiency. To evaluate the relative ecological efficiency of ESS with CHPI and PSH, gas-fired boiler house of corresponding power was provided as the alternative source of heat [10]. This area is determined on the conditions of high efficient operation of CHPI with K_{CHPI} =1,7…2,1 and CHPI loading share change in ESS within the limits of β = 0,125…1,0.

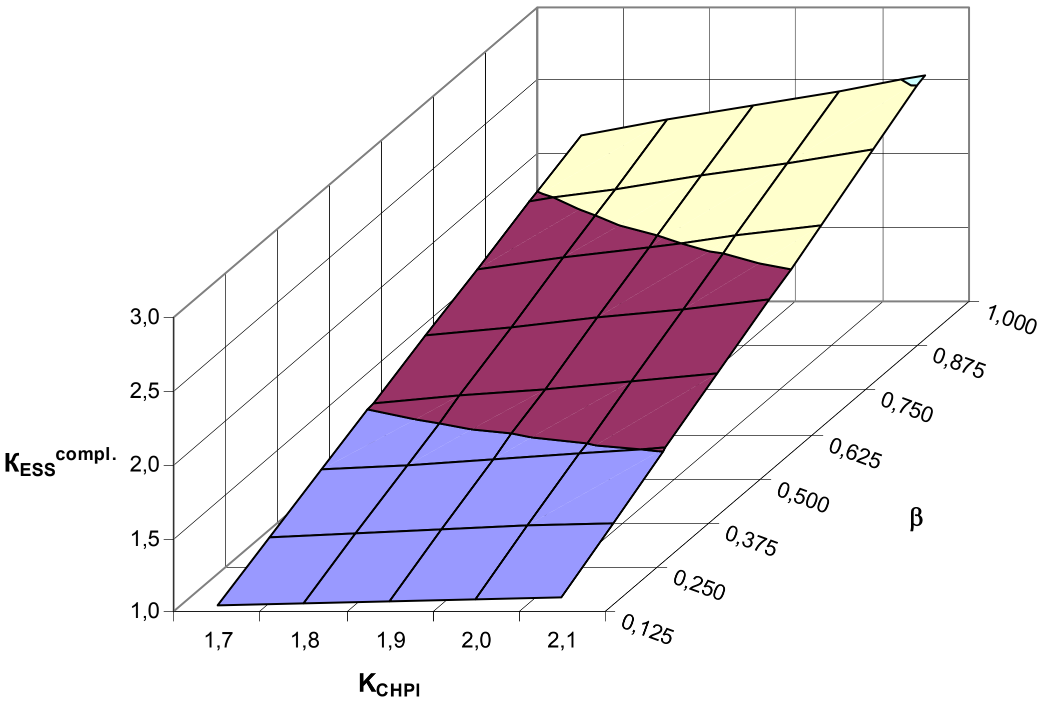

Fig. 3. Area of energy efficient operation of ESS, determined for the high efficient operation modes of CHPI by the efficiency factor of ESS with CHPI and PSH, with the account of the component that takes into account ecological efficiency and without the account of the component, taking into consideration economic efficiency

Fig. 4 shows the area of energy efficient operation of ESS, determined for wide range of CHPI efficiency change. As in the previous case, this area is determined by the efficiency index of ESS with CHPI and PSH from the formula (1), on conditions of maximum efficiency of GPE and peak fuel-fired boiler, with the account of the component, that accounts ecological efficiency and without the account of the component that takes into consideration economic efficiency. This area is determined on conditions of energy efficient operation of CHPI with K_{CHPI} =1,3…2,1 and contracted range of CHPI load share change in ESS within the range of β = 0,25…1,0.

Dependences, shown in Fig. 3 and 4, are determined on the condition of K_{ESS} > 1. As compared with the similar dependences in Fig. 1 and 2, in Fig. 3 and 4 the impact of ecological efficiency component on the value of the index of energy-ecological-economic efficiency in ESS can bee seen.

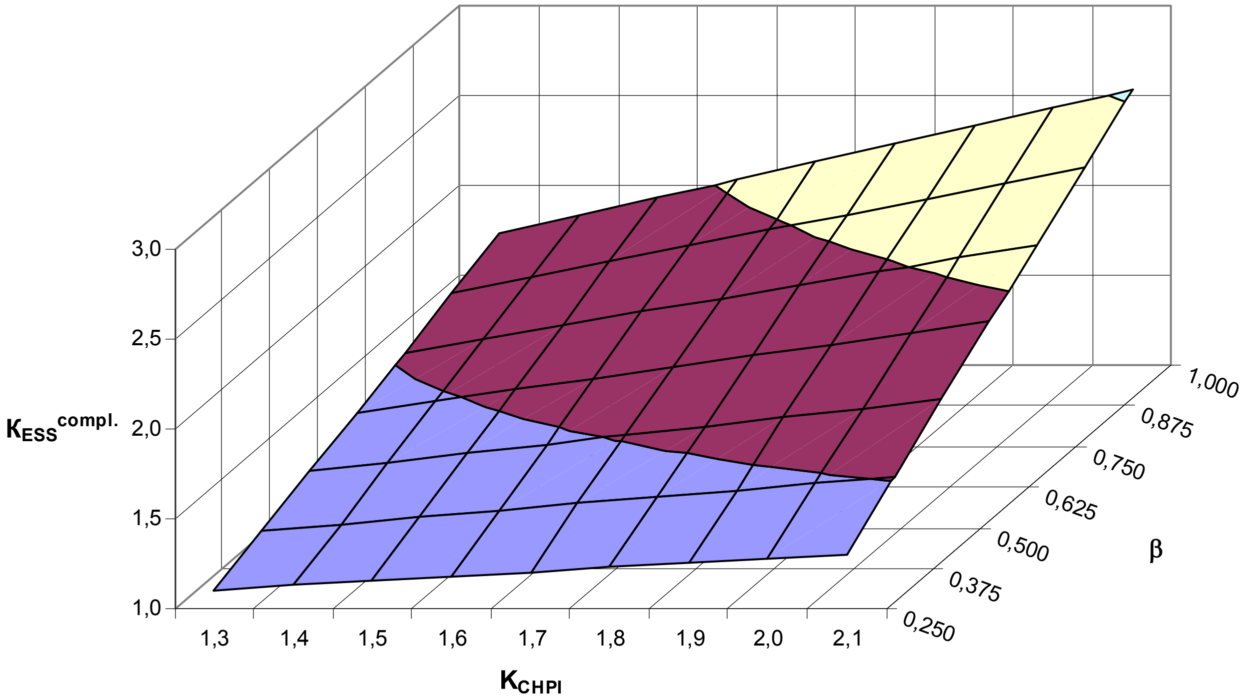

Fig. 4. Area of energy efficient operation of ESS, determined for wide range of CHPI efficiency change by the efficiency index of ESS with CHPI and PSH, with the account of the component that takes into consideration ecological efficiency and without the account of the component that takes into consideration economic efficiency

Fig. 5 shows the area of energy efficient operation of ESS, determined for CHPI high efficient operation modes, by the efficiency index of ESS with CHPI and PSH from the formula (1), on conditions of maximum efficiency of GPE and peak fuel-fired boiler with the account of the component, that takes into consideration economic efficiency and without the account of the component, that takes into consideration ecological efficiency. This area is determined on the conditions of high efficient operation of CHPI with K_{CHPI} =1,7…2,1 and contracted range of CHPI load share change in ESS within the limits of β = 0,125…1,0.

Fig. 6 shows the area of energy efficient operation of ESS, determined for wide range of CHPI efficiency change. As in the previous case, this area is determined by the efficiency index of ESS with CHPI and PSH from the formula (1), on conditions of maximum efficiency of GPE and peak fuel-fired boiler, with the account of the component that takes into consideration economic efficiency and without the account of the component that takes into consideration ecological efficiency. This area is determined on conditions of energy efficient operation of CHPI with K_{CHPI} =1,3…2,1 and contracted range of CHPI load share change in ESS within the range of β = 0,25…1,0.

Dependences, shown in Fig. 5 and 6, are determined on the condition of $K_{ESS} > 1$. As compared with the similar dependences in Fig. 1 and 2, in Fig. 5 and 6 the impact of the component of economic efficiency on the value of energy-ecological-economic efficiency of ESS index can bee seen.

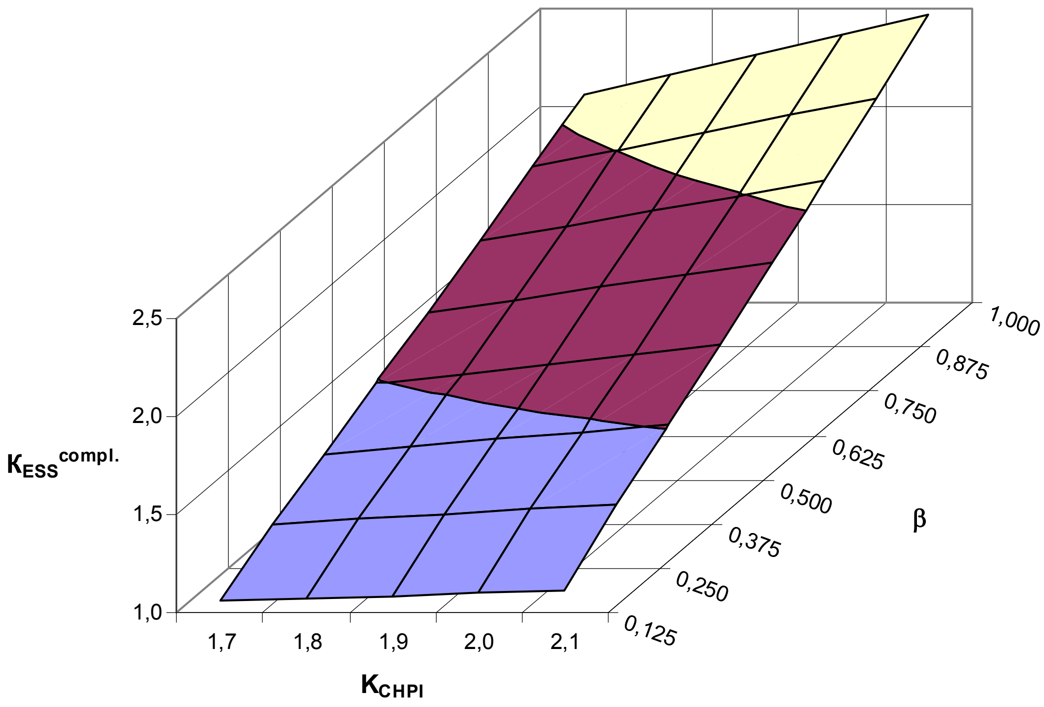

Fig. 5. Area of energy efficient operation of ESS, determined for high efficient operation modes of CHPI by the efficiency index of ESS with CHPI and PSH, with the account of the component that takes into consideration economic efficiency and without consideration of the component, that takes into consideration ecological efficiency

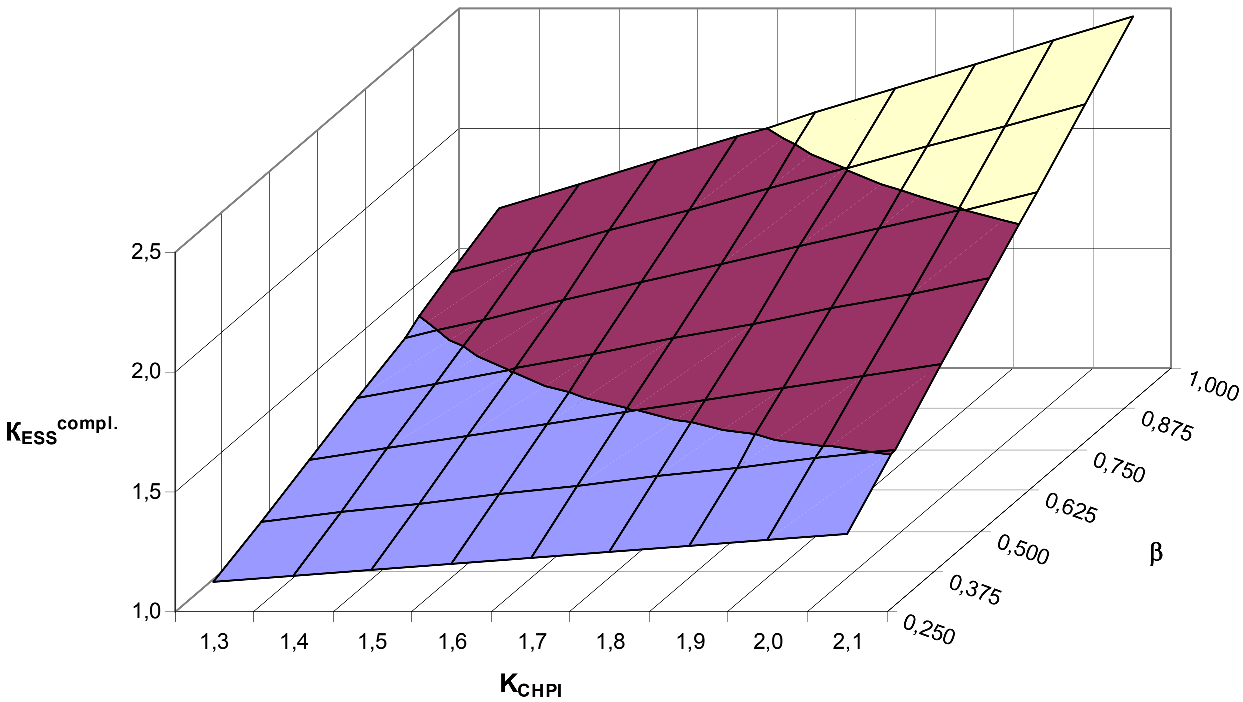

Fig. 6. Area of energy efficient operation of ESS, determined for wide range of CHPI efficiency change by the efficiency index of ESS with CHPI and PSH, on conditions of maximum efficiency of GPE and peak fuel-fired boiler, with the account of the component that takes into account economic efficiency and without consideration of the component that takes into account ecological efficiency

Fig. 7 shows the area of energy-economical efficient and ecologically safe operation of ESS, using the heat of sewage water, with CHPI of large power and peak gas-fired boiler from the study [10]. This area is determined by the index of energy-ecological-economic efficiency of ESS with CHPI and PSH from the formula (1).

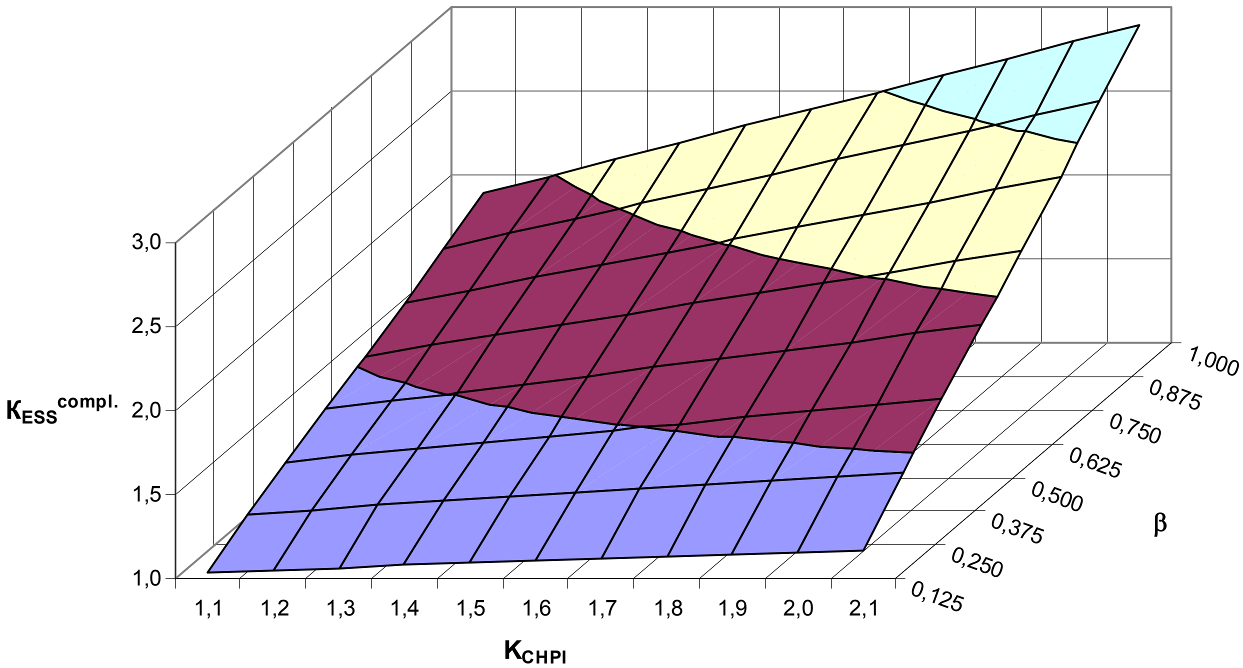

Fig. 7. Area of energy-economical efficient and ecologically safe operation of ESS, using sewage water heat, with CHPI of large power and peak fuel-fired boiler, on conditions of maximum efficiency of GPE and peak fuel-fired boiler [10]

Comparing the results of the research, shown in Fig. 1-6 and 7, the impact of the components of energy, economic efficiency and ecological safety on the value of the complex index of energy-ecological-economic efficiency of ESS with CHPI and PSH can be determined.

Method of complex assessment of energy-ecological-economic efficiency of energy supply systems with cogeneration heat pump installations and peak sources of heat, suggested in the study [10], stipulates profound approach to the assessment of energy transformations in the elements of ESS, that enables to provide the substantiated determination of high energy efficient, ecologically safe and economically grounded operation modes of ESS with CHPI and PSH on conditions of the following variables: operation modes of ESS and its elements, levels of energy efficiency of ESS elements, refrigerants, sources of drive en energy and topological composition of ESS. On the base of the results of the research the impact of the components of energy, economic efficiency and ecological safety on the value of the complex index of energy-ecological-economic efficiency of ESS with CHPI and PSH is illustrated.

Conclusions

Substantiation of the method of complex assessment of energy-ecological-economic efficiency of energy supply systems with cogeneration heat pump installations and peak sources of heat that has profound approach to the assessment of energy transformations in ESS elements is performed, the given method enables to provide the grounded definition of high energy efficient, ecologically safe and economically substantiated operation modes of ESS with CHPI and PSH on conditions of different variables: operation modes of ESS and its elements, levels of energy efficiency of ESS elements, refrigerants, sources of drive energy and topological composition of ESS. On the base of the results of the research the impact of the components of energy, economic efficiency and ecological safety on the value of the complex index of energy-ecological-economic efficiency of ESS with CHPI and PSH is illustrated.

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