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ENERGY EFFICIENCY OF ENERGY SUPPLY SYSTEMS WITH COGENERATION HEAT PUMP INSTALLATIONS AND PEAK SOURCES OF HEAT IN HEAT SUPPLY SYSTEMS

The approach, aimed at assessment of energy efficiency of energy supply systems (ESS) with cogeneration heat pump installations (CHPI) and peak sources of heat (PSH) in heat supply systems, on conditions of optimal operation modes of CHPI, taking into consideration complex impact of variable operation modes, sources of drive energy for steam compressor heat pump installations (HPI) of various power levels, with the account of energy losses in the process of generation, supply and conversion of electric energy, is suggested.

Key words*: energy efficiency, energy supply system, cogeneration heat pump installation, peak source of heat, heat supply system, dimensionless criterion of energy efficiency.*

Introduction

Analysis of energy efficiency of combined CHPI application in thermal schemes of energy supply sources is carried out in a number of publications [1–11]. In [1] the study, aimed at increase of energy efficiency of heat supply sources, using HPI with cogeneration drive is performed. In [2] the comparative analysis of the directions of energy supply systems energy efficiency increase on the base of small power cogeneration installations is carried out and thermal schemes of the systems of complex energy supply are suggested. In [3] economic efficiency of cogeneration and combined cogeneration heat pump installations with gas-piston and gas-turbine engines is evaluated. In [4] schemes of heat-electric power supply source (mini-TEP) with loading regulation on the base of heat pumps usage are studied. In [5–6] energy advantages are evaluated, efficient real operation modes of HPI with electric and cogeneration drives with the account of the impact of drive energy sources of steam compressor heat pumps and energy losses in the process of generation, supply and conversion of electric energy to HPI are defined. In [7–8] methodical fundamentals of comprehensive assessment of energy efficiency of steam compressor heat pump plants (HPP) with electric and cogeneration drives, with the account of complex impact of HPP variable operation modes, peak sources of heat of HPP, sources of drive energy of HPP and with the account of energy losses in the process of generation, supply and conversion of electric energy are suggested. In [8–9] scientific fundamentals are suggested and comprehensive assessment of energy efficiency of steam compressor HPP with cogeneration drive with the account of complex impact of HPP variable operation modes, HPP peak sources of heat, sources of drive energy of steam compressor HPP of various power levels, with the account of energy losses in the process of generation, supply and conversion of electric energy is performed. In [10] the assessment of ESS energy efficiency on the base of combined CHPI are realized, efficient operation modes of ESS with the account of complex impact of variable operation modes, sources of drive energy of steam compressor HPI of various power levels, with the account of energy losses in the processes of generation, supply and conversion of electric energy are determined. In [11] energy efficiency of ESS, based on combined CHPI and PSH is evaluated, efficient operation modes of these ESS with the account of complex impact of variable operation modes, sources of drive energy for steam compressor HPI of various power levels, with the account of energy losses in the process of generation, supply and conversion of electric energy are determined.

In [1–11] the authors did not perform assessment of energy efficiency of ESS with CHPI and PSH in heat supply systems on conditions of optimal operation modes of CHPI; energy efficient operation modes of ESS with CHPI and PSH, with the account of complex impact of variable operation modes, sources of drive energy of steam compressor HPI of various power levels, with the account of energy losses in the process of generation, supply and conversion of electric energy are not determined.

Aim of research is assessment of energy efficiency of energy supply systems with combined CHPI and PSH for heat supply systems on conditions of optimal operation modes of CHPI, determination of energy efficient operation modes of ESS with CHPI and PSH, with the account of complex impact of variable operation modes, sources of drive energy for steam compressor HPI of various power levels, with the account of energy losses in the process of generation, supply and conversion of electric energy.

Main part

The research contains the evaluation of energy efficiency of energy supply systems with combined cogeneration heat pump installations and peak sources of heat for heat supply systems. Energy efficiency of energy supply systems with steam compressor HPI of small (up to 1 MW) and large power with cogeneration drive from gas-piston engine-generator (GPE) was studied. Usage of cogeneration installations for heat pumps drive allows provides better energy efficiency as it enables to avoid additional losses of electric energy in the process of its transport and provides utilization of fuel gases heat after gas-fired engine. The investigated ESS with combined CHPI and PSH can completely or partially provide auxiliary needs in electric energy and provide the consumers needs in heating and hot water supply. Schemes of the energy supply systems with combined CHPI and PSH are presented in works [1, 12].

Optimal distribution of loading between CHPI and PSH (for instance, hot-water fuel-fired boiler, electric boiler, solar collectors, etc.) within ESS to large extent determines energy efficiency of the given ESS. Such distribution is characterized by the share of CHPI loading within ESS β, that is determined as the ratio of thermal capacity of CHPI to thermal capacity of ESS $\beta = Q_{CHPI}/Q_{ESS}$. The value of CHPI thermal capacity is determined with the account of utilization equipment capacity of cogeneration drive and is $Q_{CHPI} = Q_c + \Sigma Q_{ut}$, where Q_c – capacity of HPI condenser, ΣQ_{ut} – capacity of utilization equipment of HPI cogeneration drive. Optimal values of β index for ESS with various sources of heat for CHPI in case of variable operation modes of heating network were determined on the base of analysis of the results of research, carried out [13-15].

In our research the energy efficiency of the system «Source of drive energy of CHPI – ESS with CHPI and PSH – consumer of the heat from ESS» is analyzed on the example of ESS with steam compressor CHPI and PSH. The advantage of this approach is the account of energy losses in the process of generation, supply and conversion of electric energy in CHPI and PSH in order to determine energy efficient ESS operation modes.

In [11] it is suggested to realize comprehensive assessment of ESS with CHPI and PSH energy efficiency by complex dimensionless criterion of energy efficiency:

$$K_{ESS} = (1-\beta) \cdot K_{PSH} + \beta \cdot K_{CHPI}, \tag{1}$$

where K_{PSH} – dimensionless criterion of energy efficiency of peak source of heat within ESS (hot-water fuel-fired boiler (FB), electric boiler (EB), solar collectors, etc.),

K_{CHPI} – dimensionless criterion of combined CHPI within ESS energy efficiency.

In research [5, 10-11] dimensionless criterion of energy efficiency of steam compressor HPI with cogeneration drive K_{CHPI} was suggested. This criterion is obtained on the base of energy balance equation for the system «Source of drive energy of HPI – HPI – heat consumer from HPI», with the account the impact of drive energy sources of steam compressor HPI and with the account of energy losses in the process of generation, supply and conversion of electric energy to HPI. On condition $K_{CHPI} = 1$ combined CHPI supplies to the ESS the same thermal power that was used for generation of electric energy for HPI drive. The greater is the value of this index, the more efficient and competitive ESS with CHPI will be.

In research [11] spheres of energy efficiency operation of CHPI of various power levels are defined, that were obtained on the base of the research [10] and determined by CHPI energy efficiency dimensionless criterion $К_{CHPI}$, depending on real values of HPI coefficient of performance φ_r and efficient factor of GPE η_{EGPE}. As it was mentioned above, energy efficient operation modes of CHPI correspond to the condition $К_{CHPI} > 1$. High values of dimensionless criterion of energy efficiency of ESS with CHPI, obtained in [11], affirm high energy efficiency of such combined energy supply systems.

Dimensionless criterion of energy efficiency of peak source of heat – electric boiler –within ESS $К_{PSH}$, according to [11], obtained on the base of energy balance equation for the systems «Source of electric energy – electric boiler – heat consumer from ESS», with the account the impact of the energy sources for peak electric boiler and with the account of energy losses in the process of generation and supply of electric energy to electric boiler. In research [11] assessment of energy efficiency of peak electric boiler in ESS, in case of electric energy usage from CHPI and for the cases of electric energy consumption from energy system, based on conventional or alternative sources of electric energy on the base of steam-gas installations, gas-turbine installations, solar power plants of thermodynamic cycle, wind energy plants is carried out.

Dimensionless criterion of energy efficiency of peak source of heat – hot-water fuel-fired boiler – within ESS $К_{PSH}$, according to [11], obtained on the base of energy balance equation for the systems «Sources of electric energy and fuel – fuel-fired boiler – heat consumer from ESS» with the account of the impact of the energy sources for peak fuel-fired boiler and with the account of energy losses in the process of generation and supply of electric energy to the boiler (boiler house). In this case, consumption of electric energy by peak source of heat in ESS – fuel-fired boiler – is not directly connected with the process of heat generation in the boiler and the share of electric energy consumption for auxiliary needs is not great, that is why, it does not greatly influence the value of $К_{PSH}$ index.

In research [11] it is noted that in case of usage of the alternative peak sources of heat in ESS (for instance, solar collectors for ESS of small power) the value of dimensionless criterion of energy efficiency of peak source of heat for ESS $К_{PSH}$ will equal the efficiency of the alternative peak source of heat η_{APSH} or the efficiency of additional system with alternative peak source of heat η^{s}_{APSH}.

It should be noted, that complex dimensionless criterion of energy efficiency of ESS $К_{ESS}$ from the formula (1) can be used for the selection of the most efficient peak source of heat for certain type of ESS and efficient operation modes of ESS.

From the research [11] it is determined that for the cases of $К_{CHPI} < К_{PSH}$ the value of dimensionless criterion of ESS $К_{ESS}$ energy efficiency will decrease with the increase of the share of CHPI β load. For other cases the value of dimensionless criterion of ESS $К_{ESS}$ energy efficiency will increase with the growth of the share of CHPI β loading.

Methodical fundamentals of energy efficiency assessment of ESS with CHPI and PSH are considered in details in the research [11].

The suggested approach, aimed at assessment of energy efficiency of ESS with CHPI and PSH for heat supply systems has a number of advantages:

— it takes into account variable operation modes of ESS for heat supply during the year with the change of loading share between steam compressor CHPI and peak source of heat in ESS;

— it enables to evaluate the complex impact of variable operation modes of ESS, peak sources of heat of ESS, sources of drive energy of steam compressor CHPI with the account of energy losses in the process of generation, supply and conversion of electric energy;

— it takes into consideration the impact of the sources of drive energy of steam compressor CHPI of various power levels, with the account of energy losses in the process of generation, supply and conversion of electric energy in CHPI and ESS;

— it takes into consideration the impact of peak sources of heat for ESS and type of the energy, consumed by them with the account of energy losses in the process of generation and supply of energy to peak sources of heat;

— as a result of complex approach to ESS energy efficiency assessment the selection of the most efficient PSH for certain type of ESS at the operation in heat supply systems can be made;

— methodical fundamentals, suggested [11], and the results of research, presented in the given paper can be used for assessment of ESS energy efficiency on the base of steam compressor CHPI with various refrigerants, sources of low temperature heat and scheme solutions;

— it enables to evaluate comprehensively energy efficiency of considerable number of variants of ESS with CHPI and PSH for heat supply systems.

The application of the suggested approaches for evaluation of energy efficiency of ESS with CHPI and PSH we will demonstrate on specific examples.

In Figs. 1-6 the results of energy efficiency evaluation of ESS with CHPI and PSH for optimal values of the share of CHPI β loading, are shown. The values of dimensionless criterion of ESS with CHPI and PSH energy efficiency for the cases of variable loading of CHPI within ESS are shown here. The research is performed for the cases of seasonal variable loading of CHPI within ESS for optimal values of CHPI loading share in the range β = 0,16…0,63 [12-15], that corresponds to temperature modes of heat supply system operation. The research is carried out for energy efficient operation modes of CHPI with K_{CHPI}=1,1…2,1. Values of CHPI K_{CHPI} energy efficiency criterion correspond to the values of real coefficient of performance CHPI within the limits of φ_r = 3,0…5,4 for small power CHPI and φ_r = 2,7…5,4 for CHPI of large power, according to [11].

Fig. 1 shows the values of dimensionless energy efficiency criterion of ESS with CHPI of small power on the condition of electric energy consumption by peak source of heat (electric boiler) from energy system of Ukraine. In the given research, according to [5], the following values are taken into account: averaged value of the efficiency factor of Ukrainian electric power plants η_{EPP} = 0,383 and efficiency factor value of distributive electric grids in Ukraine η_{DG} = 0,875. In these conditions, electric boiler house with η_{EB} = 0,95 is provided to be peak source of heat in ESS. It should be noted, that in case of electric boiler efficiency change in the range η_{EB} = 0,9…0,95 the value of dimensionless criterion of electric boiler energy efficiency for the cases of electric energy consumption from energy system will be $K_{PSH}^{ES} = 0{,}302...0{,}318$. For the investigated ESS operation modes for heat supply systems the values of complex dimensionless criterion of ESS energy efficiency will be $K_{ESS} = 0{,}44...1{,}44$ on condition of β = 0,16…0,63 and may be $K_{ESS} = 2{,}1$ [11] on condition of β = 1.

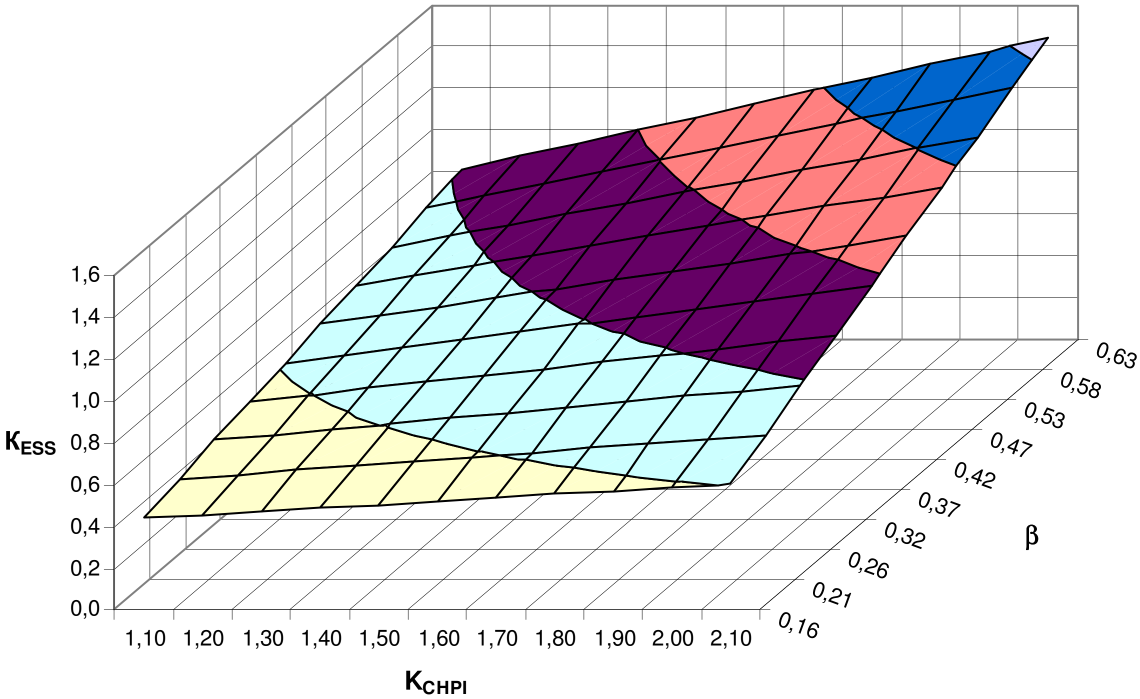

Fig. 1 – Values of dimensionless criterion of energy efficiency of ESS with small power CHPI, on condition of electric energy consumption by peak electric boiler from the energy system of Ukraine

Areas of energy efficient operation of investigated ESS can be determined from the dependences, suggested in the given research, on conditions $K_{CHPI} > 1$ and $K_{ESS} > \eta_{FB}$ (or $K_{ESS} > \eta_{EB}$) [11]. If the above-mentioned conditions are realized, the investigated ESS with CHPI and PSH can be recommended as highly efficient systems of energy supply, that can be competitive with modern highly-efficient electric and fuel-fired boilers in the systems of heat supply and energy supply. Fig. 2 shows the area of energy efficient operation of ESS of small power CHPI on condition of electric energy consumption by peak electric boiler from energy system of Ukraine, in case of operation in heat supply systems.

Fig. 3 shows the values of dimensionless criterion of energy efficiency of ESS with CHPI of small power, on condition of minimal efficiency of GPE and PSH, with the consumption of electric energy by peak source of heat (electric boiler) from CHPI. In the given research, according to [5, 10], the following values are taken into consideration: value of GPE efficiency factor $\eta_{EGPE} = 0{,}31$ and value of electric motor efficiency with the account of energy losses in the control unit of electric motor $\eta_{ED} = 0{,}8$. Electric boiler house with $\eta_{EB} = 0{,}9$ is provided to be peak source of heat in ESS for such conditions. Value of dimensionless criterion of energy efficiency of electric boiler for the cases of electric energy consumption from CHPI will be $K_{PSH}^{EC} = 0{,}223$. For the investigated operation modes of ESS for heat supply systems the values of complex dimensionless criterion of ESS energy efficiency is $K_{ESS} = 0{,}36...1{,}09$ on condition of $\beta = 0{,}16…0{,}63$ and may be $K_{ESS} = 2{,}1$ [11] on condition of $\beta = 1$.

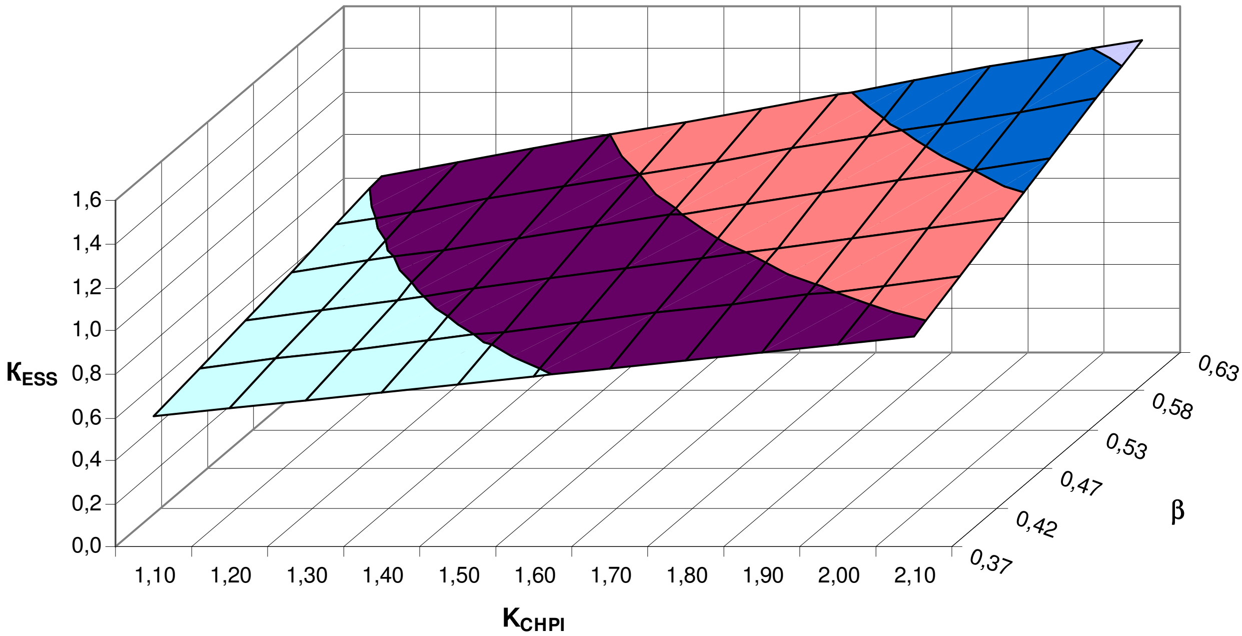

Fig. 2 – Area of energy efficient operation of ESS with CHPI of small power on condition of electric energy consumption by peak electric boiler from energy system of Ukraine

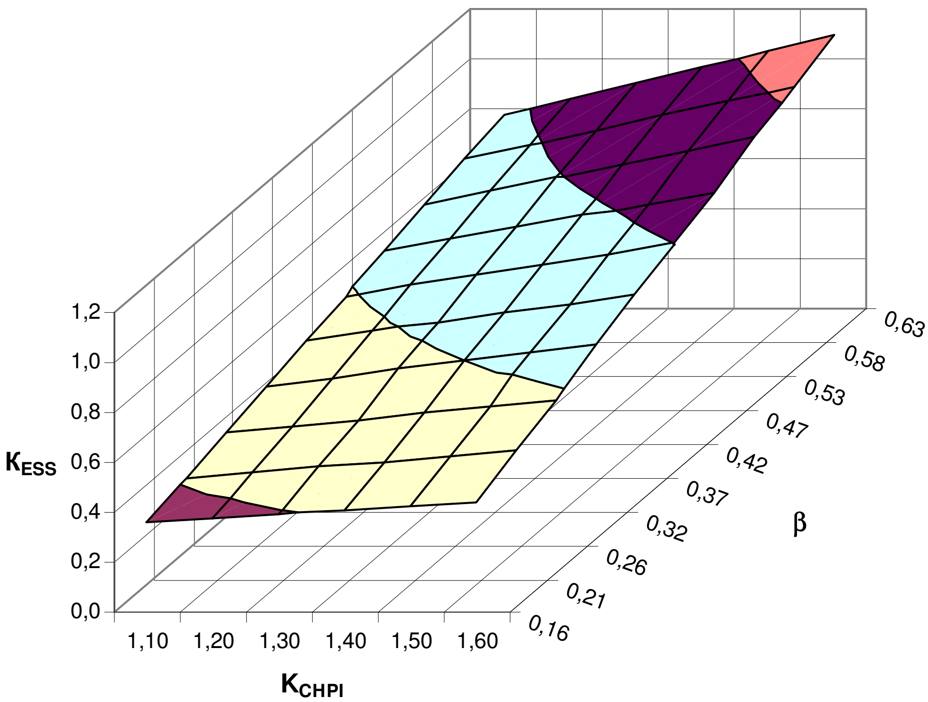

Fig. 3 – Values of dimensionless criterion of energy efficiency of ESS with CHPI of small power on conditions of minimal efficiency of GPE and PSH and electric energy consumption by peak electric boiler from CHPI

Fig. 4 shows the values of dimensionless criterion of energy efficiency of ESS with CHPI of small power on conditions of maximum efficiency of GPE and PSH, with the consumption of electric energy by peak source of heat (electric boiler) from CHPI. In the given research, according to [5, 10] the following values are taken into account: value of GPE efficiency factor η_{EGPE} = 0,42 and value of electric motor efficiency with the account of energy losses in the control unit of electric motor η_{ED} = 0,8. For these conditions, electric boiler house with η_{EB} = 0,95 is provided to be peak source of heat in ESS. Value of dimensionless criterion of electric boiler energy efficiency for the cases of electric energy consumption from CHPI will be $K_{PSH}^{EC} = 0{,}319$. For the investigated operation modes of ESS for heat supply systems the values of complex dimensionless criterion of ESS energy efficiency are $K_{ESS} = 0{,}444...1{,}441$ on condition of β = 0,16…0,63 and may be $K_{ESS} = 2{,}1$ [11] on condition of β = 1. It should be noted that the obtained values of the index of ESS energy efficiency in Fig. 4 slightly differ from the values of energy efficiency index for ESS with CHPI of small power and electric energy consumption by peak electric boiler from energy system of Ukraine, as it is shown in Fig. 1.

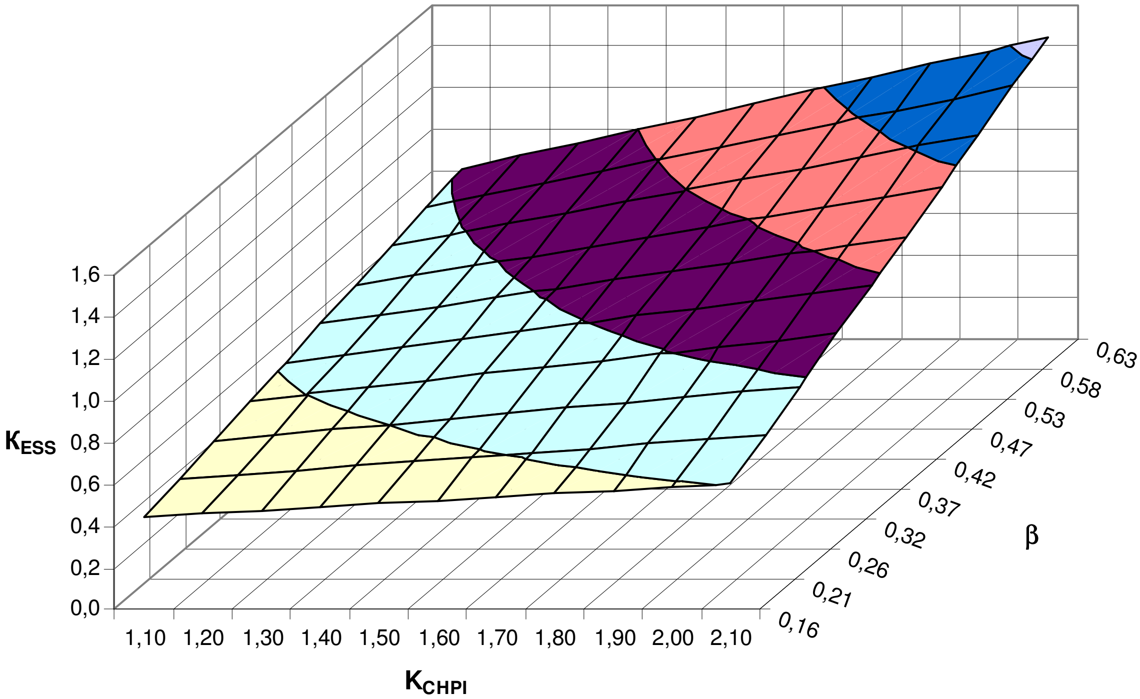

Fig. 4 – Values of dimensionless criterion of energy efficiency of ESS with CHPI of small power, on conditions of maximum efficiency of GPE and PSH and electric energy consumption by electric boiler from CHPI

Fig. 5 shows the values of dimensionless criterion of ESS energy efficiency for energy efficiency operation modes of CHPI, on conditions of minimal efficiency of peak hot-water fuel-fired boiler. Value of dimensionless criterion of energy efficiency of hot-water fuel-fired boiler will be $K_{PSH}^{FB} = \eta_{FB}$ =0,8. For the investigated modes of ESS operation for heat supply systems the values of complex dimensionless criterion of ESS energy efficiency are $K_{ESS} = 0{,}848...1{,}619$ on condition of β = 0,16…0,63 and may be $K_{ESS} = 2{,}1$ [11] on condition of β = 1.

As it is seen from Fig. 5, on conditions of K_{CHPI} > 1 and K_{ESS} > η_{FB} [11] dependence, shown in Fig. 5, defines the area of energy efficient operation of ESS with CHPI and peak fuel-fired boiler, on conditions of its minimal efficiency. This ESS can be recommended as high efficient system of energy supply, as its efficiency 2 times exceeds energy efficiency of fuel-fired boiler. Such ESS could be competitive with modern high efficient electric and fuel-fired boilers in the systems of heat and electric energy supply.

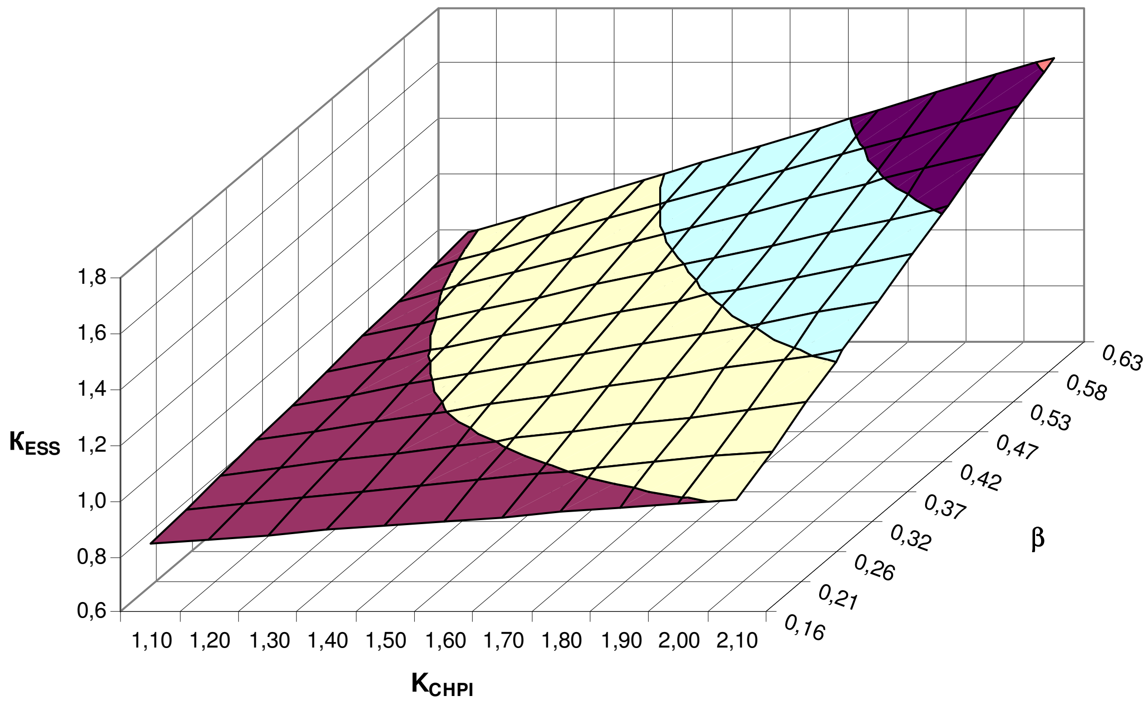

Fig. 5 – Values of dimensionless criterion of ESS energy efficiency for energy efficient operation modes of CHPI, on conditions of minimal efficiency of peak fuel-fired boiler

Fig. 6 shows the values of dimensionless criterion of ESS energy efficiency for energy efficient operation modes of CHPI, on conditions of maximum efficiency of peak hot-water fuel-fired boiler. Value of dimensionless criterion of energy efficiency of hot-water fuel-fired boiler will be $К_{PSH}^{FB} = \eta_{FB}$ =0,9. For the investigated operation modes of ESS for heat supply systems, the values of complex dimensionless criterion of ESS energy efficiency are $К_{ESS} = 0{,}932...1{,}656$ on condition of $\beta = 0{,}16\ldots0{,}63$ and may be $К_{ESS} = 2{,}1$ [11] on condition of $\beta = 1$.

As in the previous case, on conditions of $К_{CHPI} > 1$ and $К_{ESS} > \eta_{FB}$ [11] dependence, shown in Fig. 6, determines the area of energy efficient operation of ESS with CHPI and peak fuel-fired boiler, on conditions of its maximum efficiency. This ESS can be recommended as high efficient energy supply system, as it efficiency is almost 2 times exceeds the energy efficiency of high efficient fuel-fired boiler. Such ESS could be competitive with modern high efficient electric and fuel-fired boilers in heat and energy supply systems.

In research [11] it is determined that for ESS with CHPI and PSH for the values of CHPI loading share $\beta < 0{,}7$ energy efficiency and competitiveness of ESS greatly determine by the type and efficiency of PSH, on condition of energy efficient operation modes of CHPI. This condition corresponds to optimal values of CHPI loading share in the range of $\beta = 0{,}16\ldots0{,}63$ for heat supply systems operation. That is why, type and efficiency of PSH, on condition of energy efficient operation modes of CHPI in ESS, will greatly determine energy efficiency of ESS for heat supply systems.

In research [11] values of dimensionless index of PSH energy efficiency for ESS are determined; they are [11]: $К_{PSH}^{ES} = 0{,}302\ldots0{,}318$ for electric boiler on condition of electric energy usage from energy system; $К_{PSH}^{EC} = 0{,}223\ldots0{,}319$ for electric boiler for ESS of small power, on condition of usage the electric energy from CHPI; $К_{PSH}^{FB} = 0{,}8\ldots0{,}9$ for peak hot-water fuel-fired boiler within ESS. On the base of the analysis of these indices, the conclusion can be drawn that the usage of fuel-fired boiler as peak source of heat in ESS for the systems of heat supply is much more efficient than the usage of peak electric boiler with different variants of electric energy sources.

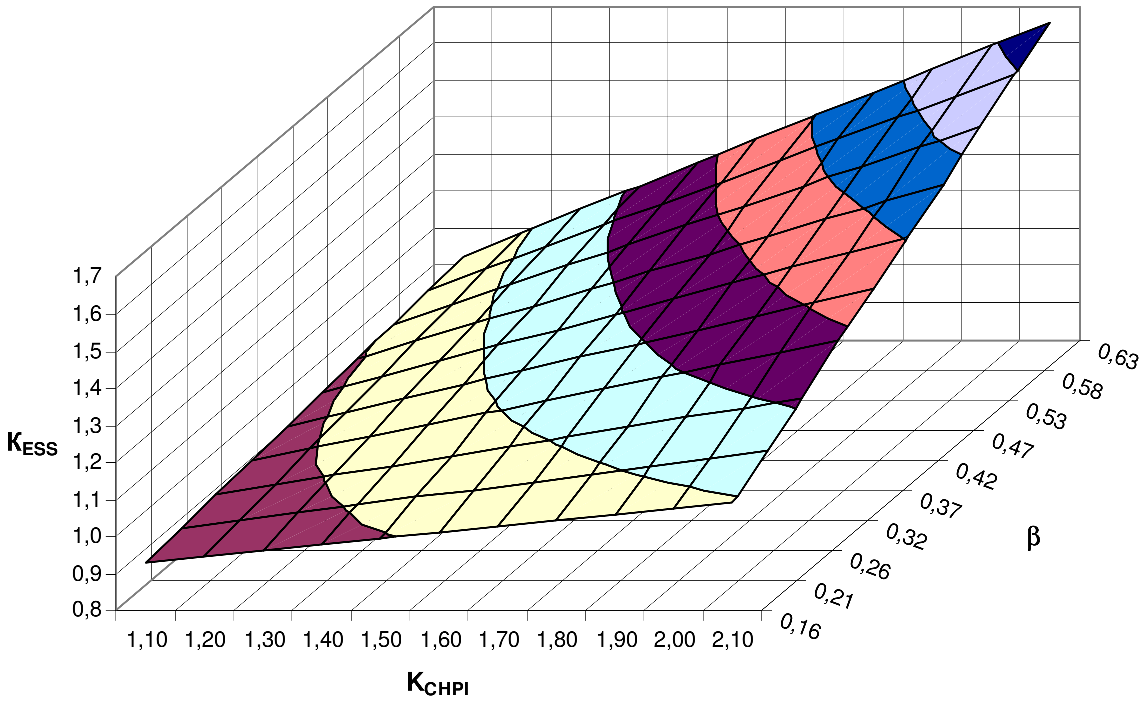

Fig. 6 – Values of dimensionless criterion of ESS energy efficiency for energy efficient operation modes of CHPI, on conditions of maximum efficiency of peak fuel-fired boiler

As it is seen from Fig. 2, ESS with CHPI and peak electric boilers, suggested in research, will be energy efficient, if the share of CHPI loading in ESS is $\beta > 0{,}4$. If this condition is realized, modern high efficient electric and fuel-fired boilers will be less energy efficient than the above-mentioned ESS.

On the base of the analysis of research results (Fig. 1-6) it is determined, that energy efficiency of ESS with CHPI and peak fuel-fired boilers almost two times exceeds the energy efficiency of modern high efficient electric and fuel-fired boilers for operation in heat supply systems.

It is determined, that on conditions $К_{CHPI} > 1$ and $К_{ESS} > \eta_{FB}$ (or $К_{ESS} > \eta_{EB}$) [11], areas of energy efficient operation of the investigated ESS for heat supply systems can be determined from the dependences, suggested in the given research (see Fig. 1-6). If the above-mentioned conditions are realizes, investigated ESS with CHPI and PSH can be recommended as high efficient energy supply systems, that can be competitive with modern high efficient electric and fuel-fired boilers in heat and energy supply systems.

The suggested approaches of assessment of ESS with CHPI and PSH energy efficiency allow to define energy efficient ESS operation modes with the account of complex impact of variable operation modes, sources of drive energy of steam compressor CHPI of various power levels, with the account of energy losses in the process of generation, supply and conversion of electric energy.

In order to evaluate of energy efficiency of different variants of ESS with CHPI and PSH for heat supply systems, we suggest, besides the above-mentioned approaches, to use the results of the research [1, 5-11, 13-15].

Conclusions

Methodical fundamentals are developed, assessment of energy efficiency of energy supply systems with combined CHPI and PSH on conditions of optimal operation modes of CHPI for heat supply systems is performed, energy efficient operation modes of ESS with CHPI and PSH, with the account of complex impact of variable operation modes, sources of drive energy for steam compressor HPI of various power levels, with the account of energy losses in the process of generation, supply and conversion of electric energy are determined.

The suggested approach, aimed at assessment of energy efficiency of ESS with CHPI and PSH for heat supply systems has a number of advantages:

— it takes into account variable operation modes of ESS for heat supply during the year with the change of loading share between steam compressor CHPI and peak source of heat in ESS;

— it enables to assess complex impact of variable operation modes of ESS, peak sources of heat of ESS, sources of drive energy of steam compressor CHPI with the account of energy losses in the process of generation, supply and conversion of electric energy;

— it takes into account the impact of the sources of drive energy of steam compressor CHPI of different power levels, with the account of energy losses in the process of generation, supply and conversion of electric energy in CHPI and ESS;

— it takes into consideration the impact of peak sources of heat for ESS and type of the energy, consumed by them with the account of energy losses in the process of generation and supply of energy to peak sources of heat;

— as a result of complex approach to assessment of ESS energy efficiency the selection of the most efficient PSH for certain type of ESS for operation in heat supply systems can be made;

— methodical fundamentals, suggested [11], and the results of research, given in this paper, may be used for assessment of energy efficiency of ESS on the base of steam compressor CHPI with different refrigerants, sources of low temperature heat and scheme solutions;

— it enables to assess comprehensively energy efficiency of the greater part of variants of ESS with CHPI and PSH for heat supply systems.

On the base of research results analysis, it is defined that in case of energy efficient operation modes of CHPI and optimal values of loading share of CHPI β = 0,16…0,63 in ESS the type and efficiency of PSH greatly determine energy efficiency of ESS for heat supply systems.

ESS with CHPI and peak electric boilers, suggested in the research, will be energy efficient, if the share of CHPI loading in ESS will be $\beta > 0{,}4$. On this condition modern high efficient electric and fuel-fired boilers would be inferior by energy efficiency to the above-mentioned ESS. It is determined that energy efficiency of ESS with CHPI and peak fuel-fired boilers almost two times exceeds the energy efficiency of modern high efficient electric and fuel-fired boilers for operation in heat supply systems.

It is determined, that on conditions $K_{CHPI} > 1$ and $K_{ESS} > \eta_{FB}$ (or $K_{ESS} > \eta_{EB}$) from the dependences, suggested in the given research (see Fig. 1-6), areas of energy efficient operation of the investigated ESS for heat supply systems can be determined. On these conditions, the investigated ESS with CHPI and PSH can be recommended as high efficient energy supply systems, that can be competitive with modern high efficient electric and fuel-fired boilers in heat and energy supply systems.

The suggested approaches, aimed at energy efficiency assessment of ESS with CHPI and PSH allow to define energy efficient operation modes of ESS with the account of complex impact of variable operation modes, sources of drive energy for steam compressor HPI of different power levels, with the account of energy losses in the process of generation, supply and conversion of electric energy.

In order to evaluate of energy efficiency of different variants of ESS with CHPI and PSH for heat supply systems, besides the above-mentioned approaches, we suggest to use the results from the research [1, 5-11, 13-15].

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