O. Ostapenko, Cand. Sc. (Eng.), Assist. Professor

ENERGY EFFICIENCY OF ENERGY SUPPLY SYSTEMS, BASED ON COMBINED COGENERATION HEAT PUMP INSTALLATIONS AND PEAK SOURCES OF HEAT

The approach to evaluation of energy efficiency of energy supply systems (ESS), based on combined cogeneration heat pump installations (CHPI) and peak sources of heat (PSH), 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, dimensionless criterion of energy efficiency.*

Introduction

Taking into consideration the importance of the problem, put forward, in recent years a number of researches, dealing with the efficiency of combined CHPI application in thermal schemes of energy supply sources have been carried out [1 – 10]. In [1], the authors performed research, aimed at increase of energy efficiency of heat supply sources, using HPI with cogeneration drive. In [2], the comparative analysis of promising directions of energy efficiency increase of energy supply systems on the base of small power cogeneration installations is carried out; thermal schemes of integrated systems of complex energy supply are suggested. In research [3] authors evaluated economic efficiency of cogeneration and combined cogeneration heat pump installations with gas-piston and gas-turbine engines. In publication [4] the results of the study of the scheme of heat-electric power supply source (mini-TEP) with loads regulation on the base of heat pumps usage, are presented.

In [5 – 6] energy advantages and efficient real operation modes of HPI with electric and cogeneration drives, taking into account the impact of the drive energy sources of steam compressor heat pumps and losses of energy in the process of generation, supply and conversion of electric energy to HPI are determined. In research [7 – 8] methodical fundamentals of complex evaluation of energy efficiency of steam compressor heat pump plants (HPP) with electric and cogeneration drives, with the account of complex impact of variable operation modes of HPP, peak sources of heat of HPP, sources of HPP drive energy and with the account of energy losses in the process of generation, supply and conversion of electric energy are suggested. In studies [8 – 9] scientific fundamentals are proposed, complex evaluation of energy efficiency of steam compressor HPP with cogeneration drive taking into consideration complex impact of variable operation modes of HPP, peak sources of heat of HPP, 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 research [10] evaluation of ESS energy efficiency on the base of combined CHPI, determined the efficient operation modes of ESS, based on combined CHPI with the account of complex impact of variable operation modes, sources of drive energy of steam compressor HPI of various power levels, taking into consideration energy losses in the process of generation, supply and conversion of electric energy is carried out.

In the studies [1 – 10] authors did not perform evaluation of energy efficiency of ESS, based on combined CHPI and PSH, efficient operation modes of ESS, based on combined 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, taking into account losses of energy in the process of generation, supply and conversion of electric energy are not determined.

The aim of the research is evaluation of energy efficiency of energy supply systems, based on combined cogeneration heat pump installations and peak sources of heat, determination of efficient operation modes of energy supply systems, based on combined 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.

Main part

The given research contains the evaluation of energy efficiency of energy supply systems, based on combined cogeneration heat pump installations and peak sources of heat. The efficiency of energy supply systems, based on steam compressor HPI of small (up to 1 MW) and large power with cogeneration drive from gas-piston engine-generator (GPE) was investigated. Usage of cogeneration installations for heat pumps drive allows to avoid additional losses of electric energy in the process of its transmission and provides utilization of fuel gases heat after gas-fired engine, that provides better energy efficiency. Investigated ESS, based on combined CHPI and PSH can completely or partially ensure installation's needs in electric energy and provide heating and hot water consumers. Schemes of the energy supply systems, based on combined CHPI and PSH are given in [1, 11].

Energy efficiency of the given ESS is greatly determined by optimal distribution of loading between CHPI and PSH (for instance, hot-water fuel-fired boiler, electric boiler, solar collectors, etc.) within ESS. This distribution is characterized by the share of CHPI loading within ESS β, that is determined as a ratio of thermal capacity of CHPI to the capacity of ESS $\beta = Q_{CHPI}/Q_{ESS}$. For CHPI the value of thermal capacity is determined, taking into account the capacity of utilization equipment of cogeneration drive and is $Q_{CHPI} = Q_c + \Sigma Q_{ut}$, where $\mathrm{Q_c}$ – capacity of HPI condenser, $\Sigma \mathrm{Q_{ut}}$ – capacity of utilization equipment of HPI cogeneration drive.

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

It is suggested to perform complex evaluation of ESS energy efficiency, based on CHPI and PSH, 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, electric boiler, solar collectors, etc.),

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

It should be noted, that complex dimensionless criterion of ESS energy efficiency K_{ESS} may also be used for the selection of the most efficient peak source of heat for certain type of ESS.

In research [5, 10] dimensionless criterion of energy efficiency of steam compressor HPI with cogeneration drive was suggested. The given criterion was 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 the sources of drive energy of steam compressor HPI and taking into account energy losses in the process of generation, supply and conversion of electric energy to HPI. Taking into consideration of such approach, dimensionless criterion of energy efficiency of combined CHPI, according to [5, 10] will have the form:

$$K_{CHPI} = Q_{CHPI}/Q_h = \eta_{EGPE}\cdot\eta_{ED}\cdot\varphi^{CHPI}\cdot\eta_{hf}, \tag{2}$$

where Q_h – power, spent by gas-piston engine-generator for generation of electric energy for HPI drive, η_{EGPE} – efficient factor of gas-piston engine; η_{ED} – efficiency factor of electric motor with the account energy losses in motor control unit from [5], φ^{CHPI} – real coefficient of performance of CHPI from the research [10], η_{hf} – efficiency factor of the heat flow, that takes into consideration losses of energy and working substance in pipe lines and equipment of HPI.

On condition $K_{CHPI} = 1$ combined CHPI transfers 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.

Fig. 1 shows the area of energy efficient operation of small power CHPI, obtained on the base of the research [10] and determined according to dimensionless criterion of CHPI energy efficiency K_{CHPI}, depending on real values of HPI coefficient of performance φ_r and efficient factor of GPE η_{EGPE}. In the research, according to [5, 10], the value of electric motor efficiency with the account of energy losses in control unit of the motor η_{ED} = 0,8 is taken into consideration.

As it was mentioned above, efficient operation modes of CHPI correspond to the condition K_{CHPI} > 1. The obtained high values of dimensionless criterion of energy efficiency of ESS, based on CHPI of small power (see Fig.1) prove high energy efficiency of such combined systems of energy supply.

Fig. 2 shows the area of energy efficiency operation of large power CHPI, obtained on the base of the research [10] and determined by the dimensionless criterion of CHPI energy efficiency K_{CHPI}, depending on real values of HPI coefficient of performance φ_r and efficient factor of GPE η_{EGPE}. In the research, according to [5], the value of electric motor efficiency with the account of energy losses in control unit of the motor η_{ED} = 0,9 is taken into consideration.

Efficient operation modes of large power CHPI correspond to the condition K_{CHPI} > 1. As in the previous case, the obtained high values of dimensionless criterion of energy efficiency for ESS, based on large power CHPI prove high energy efficiency of such combined systems of energy supply.

Dimensionless criterion of energy efficiency of peak source of heat – electric boiler –within ESS K_{PSH} can be obtained on the basis of energy balance equation for the systems «Source of electric energy – electric boiler –consumer of heat from ESS», taking into account the impact of the energy sources for peak source of heat (electric boiler) and with the account of energy losses in the process of generation and supply of electric energy to electric boiler.

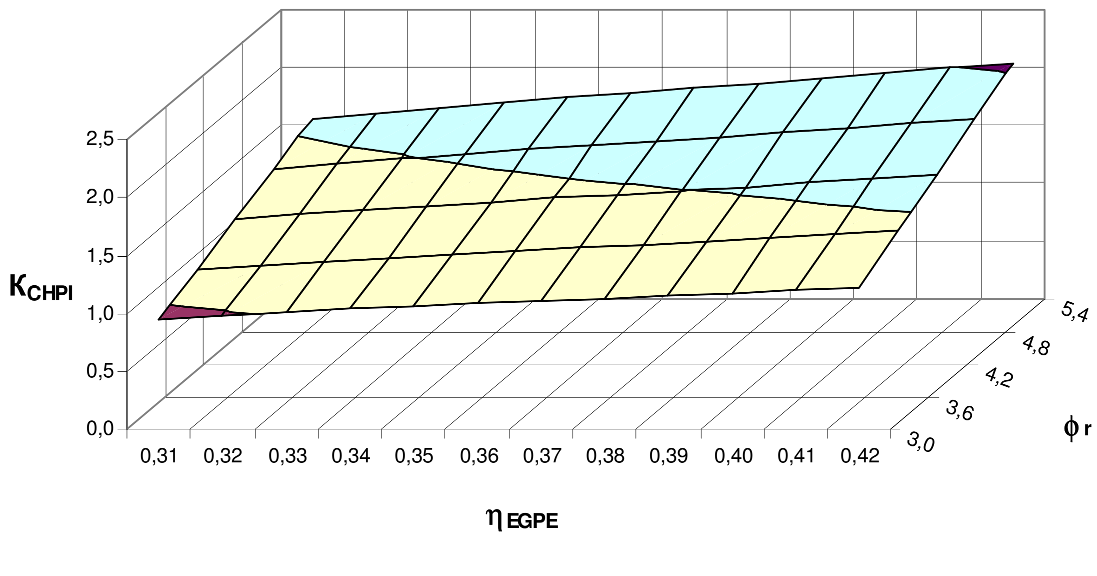

Fig. 1. Area of energy efficient operation of small power CHPI by dimensionless criterion of CHPI energy efficiency, depending on real values of HPI coefficient of performance and efficient factor of GPE

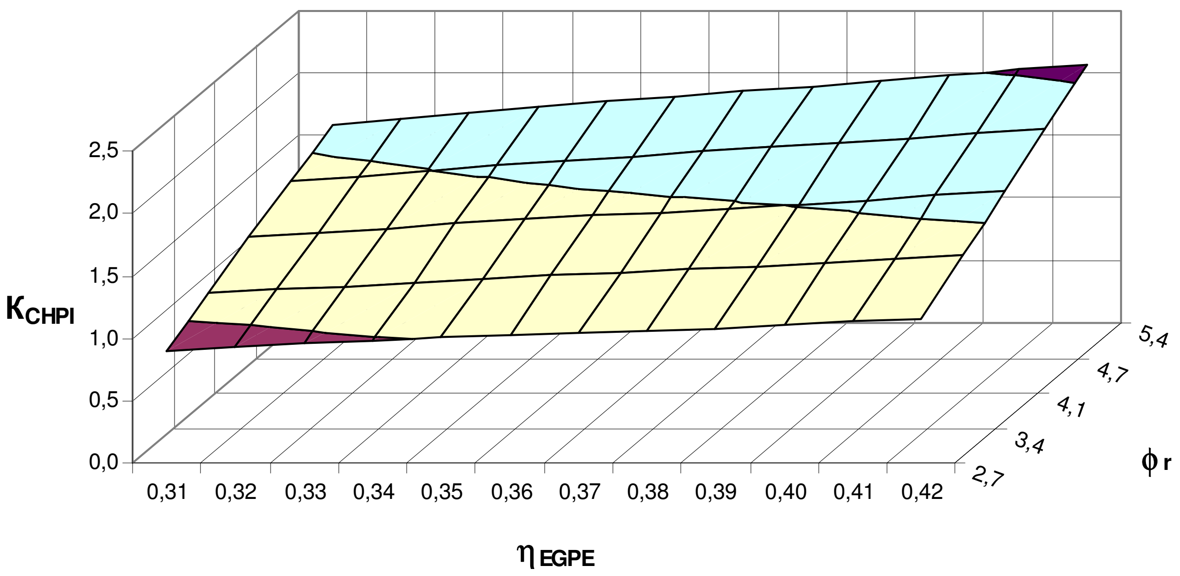

Fig. 2. Area of energy efficient operation of large power CHPI by dimensionless criterion of CHPI energy efficiency, depending on real values of HPI coefficient of performance and efficient factor of GPE

In general case, for electric boiler as peak source of heat for ESS dimensionless criterion of energy efficiency will have the form:

$$K_{PSH} = Q_{EB} / Q_h = \eta_{EP}^b \cdot \eta_{EB}\,, \tag{3}$$

where Q_{EB} – thermal capacity of hot-water electric boiler, that can be defined as: $Q_{EB} = Q_{ESS} - Q_{CHPI}$; Q_h – power, spent by electric power station for generation of electric energy, η_{EP}^b – total efficiency of generation and supply of electric energy to electric boiler, defined by the formula: $\eta_{EP}^b = \eta_{EPP} \cdot \eta_{DG}$, where η_{EPP} – averaged value of the efficiency factor of electric power plants in Ukraine or alternative sources of electric energy for HPI (on the base of steam-gas installations (SGI), gas-turbine installations (GTI), solar power plants of thermodynamic cycle (SPP), wind energy plants (WEP)), from the research [5]; η_{DG} – efficiency factor of distributive electric grids in Ukraine, from [5], η_{EB} – efficiency factor of the electric boiler.

For the cases of ESS application with peak electric boiler, total efficiency factor of generation and supply of electric energy to electric boiler may be defined as $\eta_{EP}^b = \eta_{EGPE} \cdot \eta_{ED}$ in case of usage of electric energy from CHPI or according to the formula, mentioned above, for the cases of electric energy usage from energy system on the basis of conventional or alternative sources of electric energy. Then, dimensionless criterion of energy efficiency of electric boiler as peak source of heat for ESS, for the cases of electric energy consumption from energy system, will be defined:

$$K_{PSH}^{ES} = \eta_{EPP} \cdot \eta_{DG} \cdot \eta_{EB}\,. \tag{4}$$

In case of usage of electric energy from CHPI in electric boiler, dimensionless criterion of energy efficiency of electric boiler as peak source of heat for ESS will be defined as:

$$K_{PSH}^{EC} = \eta_{EGPE} \cdot \eta_{ED} \cdot \eta_{EB} = \eta_{EP}^b \cdot \eta_{EB}\,. \tag{5}$$

Dimensionless criterion of energy efficiency of peak source of heat – hot-water fuel-fired boiler –

within ESS K_{PSH} may be obtained on the base of energy balance equation for the systems «Sources of electric energy and fuel – fuel-fired boiler –consumer of heat from ESS» with the account of the impact of the energy sources for peak source of heat (fuel-fired boiler) and taking into account energy losses in the process of generation and supply of electric energy to the boiler (boiler house). In this case, electric energy consumption 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 portion of electric energy consumption for auxiliary needs is rather small and does not considerably influence the value of K_{PSH} index.

For fuel-fired boiler as a peak source of heat for ESS dimensionless criterion of energy efficiency will have the form:

$$K_{PSH}^{FB} = Q_{FB} / Q_f = \eta_{FB}, \quad (6)$$

where Q_{FB} – thermal capacity of hot-water fuel-fired boiler, that can be defined as: $Q_{FB} = Q_{ESS} - Q_{CHPI}$; Q_f – power, spent for generation of heat energy from burning fuel in the boiler, η_{FB} – efficiency of hot-water fuel-fired boiler or fuel-fired boiler house (for ESS of large power).

For the cases of usage the alternative peak sources of heat in ESS (for instance, solar collectors for small power ESS) the value of dimensionless criterion of energy efficiency of peak source of heat for ESS K_{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_{APSH}^{s}.

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

The suggested approach to evaluation of ESS energy efficiency on the base of CHPI and PSH has a number of advantages:

— it allows 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 allows to evaluate the impact of variable operation modes of 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 account energy efficiency of ESS, based on CHPI of various power levels;

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

— it takes into consideration operation modes and energy efficiency of steam compressor CHPI of various power levels;

— it takes into consideration the impact of peak sources of heat for ESS and kind 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 evaluation of ESS energy efficiency it is possible to select the most efficient peak source of heat for certain type of ESS;

— the suggested methodical fundamentals may be used for evaluation of ESS energy efficiency on the base of steam compressor CHPI with various refrigerants, sources of low temperature heat and scheme solutions;

— it allows to comprehensively evaluate energy efficiency of greater part of ESS variants, based on CHPI and PSH.

The application of the suggested approaches to evaluation of energy efficiency of energy supply systems, based on CHPI and PSH we will demonstrate on specific examples.

Figs. 3 – 7 show the results of complex evaluation of energy efficiency of ESS, based on CHPI and PSH. The values of dimensionless criterion of ESS energy efficiency K_{ESS} on conditions of CHPI load share change in the range of β = 0,1…1,0 are shown here. The research is performed for energy efficient operation modes of CHPI with K_{CHPI} =1,1…2,1.

Fig. 3 shows the values of dimensionless criterion of energy efficiency of ESS, based on CHPI of small power, on 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 efficiency factor of electric power plants in Ukraine η_{EPP} = 0,383 and efficiency factor value of distributive electric grids in Ukraine η_{DG} = 0,875. Electric boiler house with η_{EB} = 0,95 is provided to be peak source of heat in ESS for these conditions. 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 the values of complex dimensionless criterion of ESS energy efficiency are $K_{ESS} = 0{,}396...1{,}92$ on condition of β = 0,1…0,9 and $K_{ESS} = 2{,}1$ on condition of β = 1.

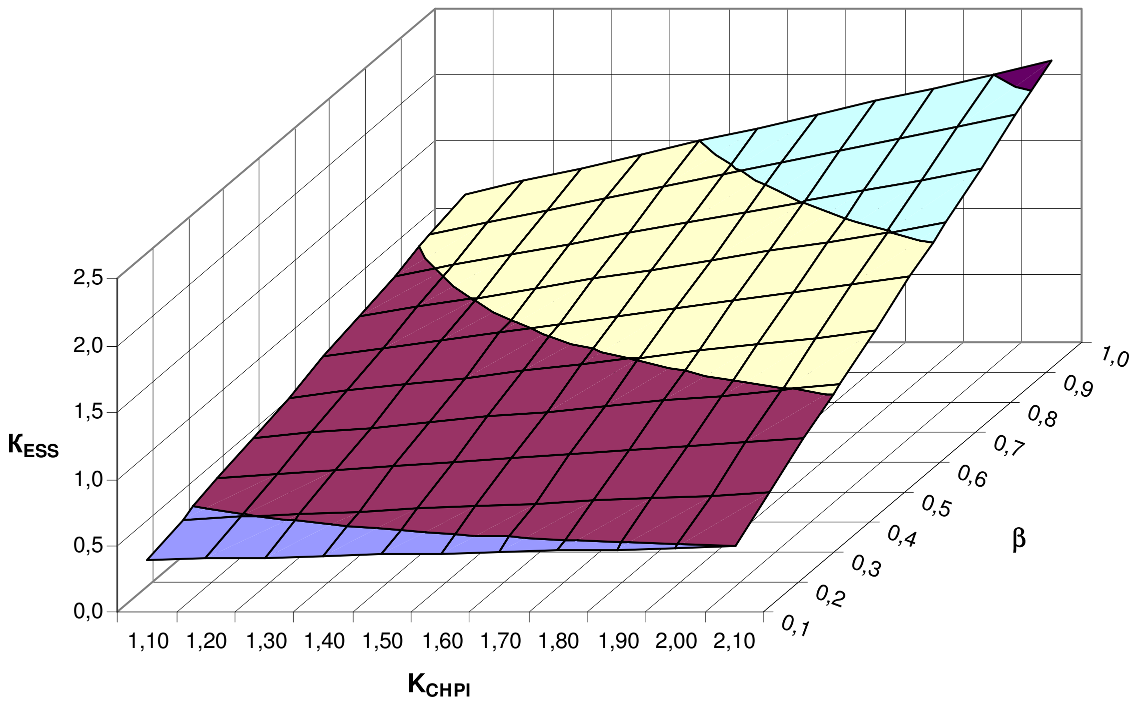

Fig. 3 – Values of dimensionless criterion of energy efficiency of ESS, based on CHPI of small power, on condition of electric energy consumption by peak electric boiler from energy system of Ukraine

Fig. 4 shows the values of dimensionless criterion of energy efficiency of small power ESS, 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, in accordance with [5, 10] the following values are taken into account: value of GPE efficiency factor η_{GPE} = 0,31 and value of electric motor efficiency, taking into account of energy losses in the control unit of electric motor η_{ED} = 0,8. For such conditions electric boiler house with η_{EB} = 0,9 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 $K_{PSH}^{EC} = 0{,}223$. For the investigated operation modes of ESS the values of complex dimensionless criterion of energy efficiency of ESS will be

$K_{ESS} = 0{,}31...1{,}46$ on condition of $\beta = 0{,}1 \ldots 0{,}9$ and $K_{ESS} = 1{,}6$ on condition of $\beta = 1$.

Fig. 5 shows the values of dimensionless criterion of energy efficiency of small power ESS, on condition 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, in accordance with [5, 10] the following values are taken into consideration: value of GPE efficiency factor $\eta_{GPE} = 0{,}42$ and value of electric motor efficiency, taking into account of energy losses in the control unit of electric motor $\eta_{ED} = 0{,}8$. Electric boiler house with $\eta_{EB} = 0{,}95$ is provided in these conditions 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 the values of complex dimensionless criterion of energy efficiency of ESS will be $K_{ESS} = 0{,}39...1{,}92$ on condition of $\beta = 0{,}1 \ldots 0{,}9$ and $K_{ESS} = 2{,}1$ on condition of $\beta = 1$.

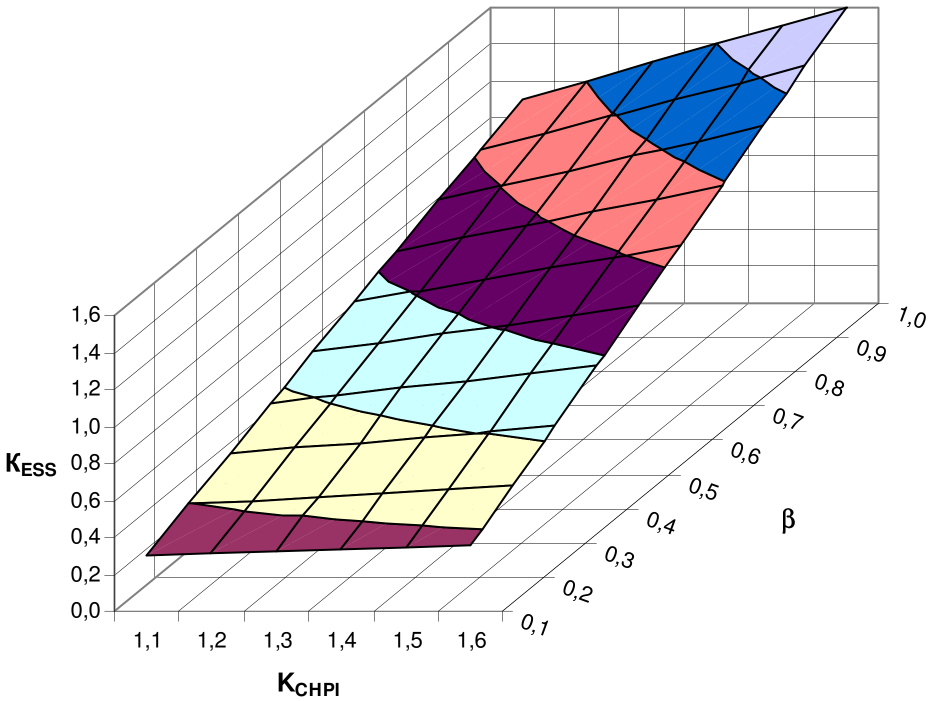

Fig. 4. Values of dimensionless criterion of energy efficiency of small power ESS, on condition of minimal efficiency of GPE and PSH, with the consumption of electric energy by peak electric boiler from CHPI

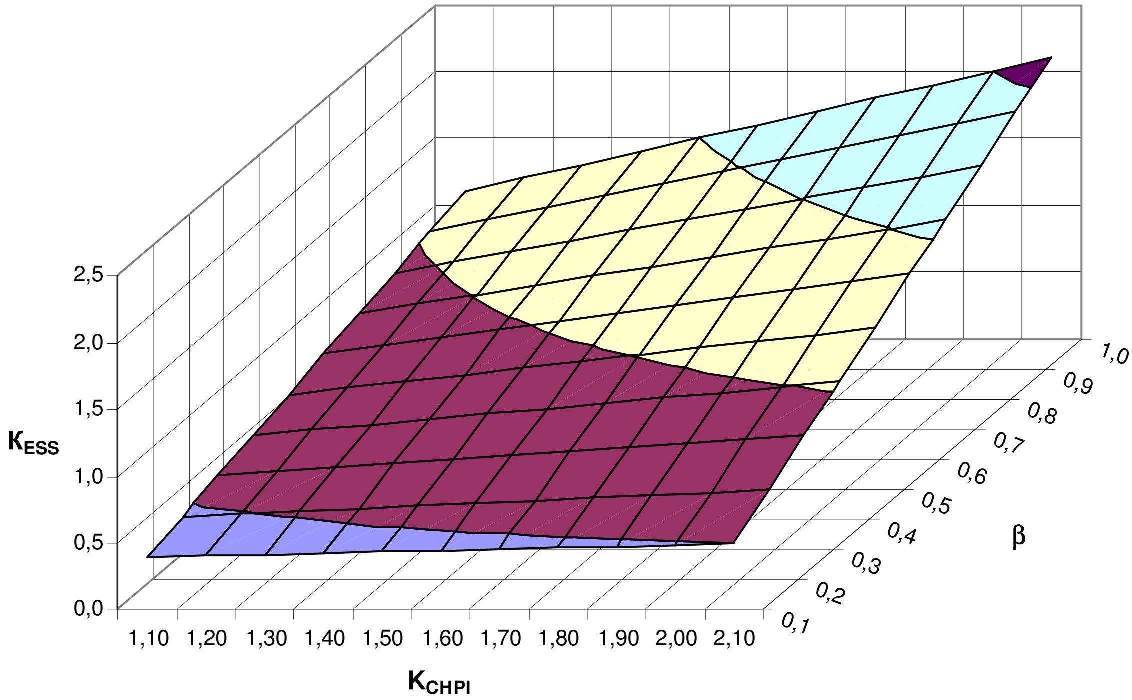

Fig. 5. Values of dimensionless criterion of energy efficiency of small power ESS, on condition of maximum efficiency of GPE and PSH, with the consumption of electric energy by peak electric boiler from CHPI

Fig. 6 shows the values of dimensionless criterion of ESS 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 operation modes of ESS the values of complex dimensionless criterion of energy efficiency of ESS will be $K_{ESS} = 0{,}83...1{,}97$ on condition of β = 0,1…0,9 and $K_{ESS} = 2{,}1$ on condition of β = 1.

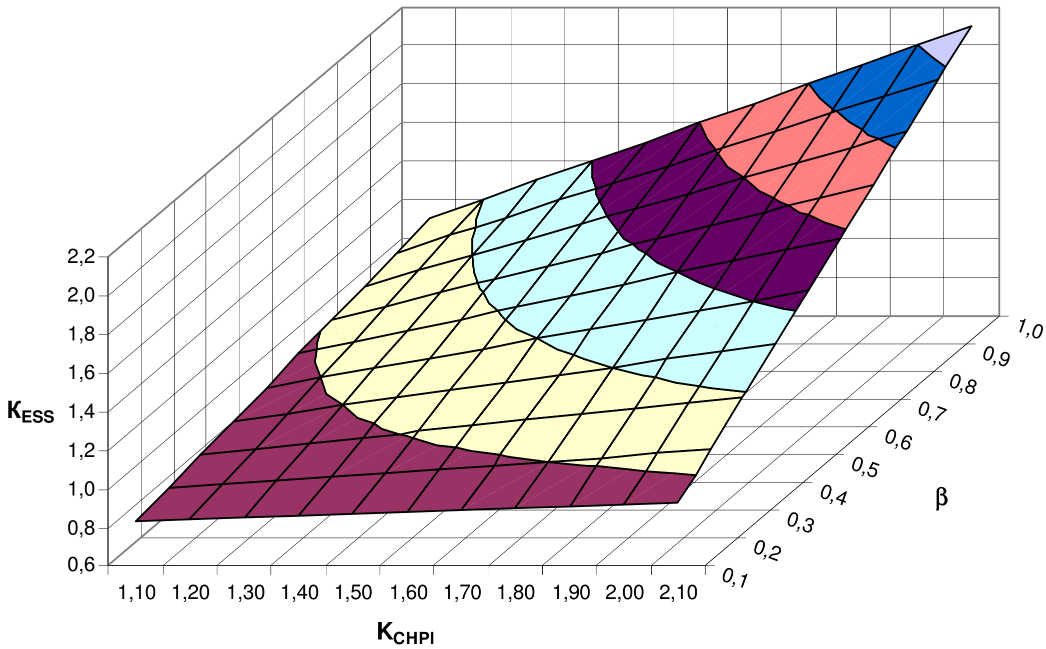

Fig. 6. Values of dimensionless criterion of ESS for energy efficiency operation modes of CHPI, on conditions of minimal efficiency of peak hot-water fuel-fired boiler

Fig. 7 shows the values of dimensionless criterion of ESS for energy efficiency 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 $K_{PSH}^{FB} = \eta_{FB}$=0,9. For the investigated operation modes of ESS the values of complex dimensionless criterion of energy efficiency of ESS will be $K_{ESS} = 0{,}92...1{,}98$ on condition of β = 0,1…0,9 and $K_{ESS} = 2{,}1$ on condition of β = 1.

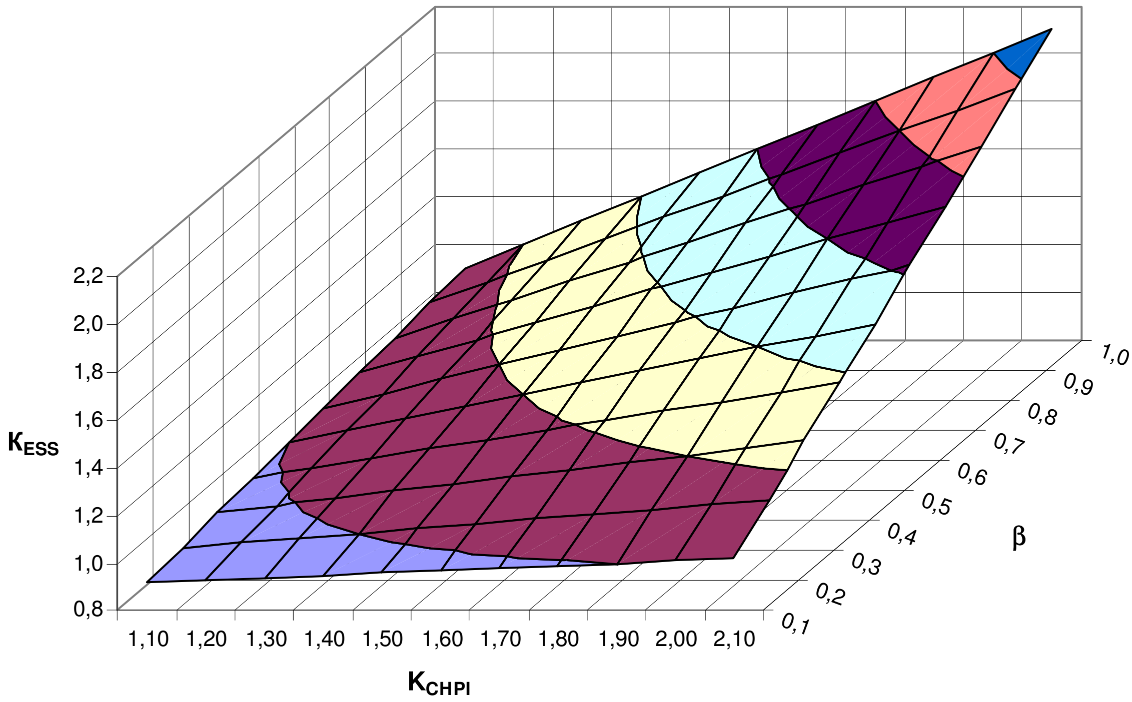

Fig. 7. Values of dimensionless criterion of ESS for energy efficiency operation modes of CHPI, on conditions of maximum efficiency of peak hot-water fuel-fired boiler

Comparing the results of research, shown in Figs. 3 – 7, the conclusion can be made that for ESS, based on CHPI and PSH for values of CHPI load share $\beta > 0{,}7$ the efficiency and type of peak source of heat perform minor influence of ESS energy efficiency on condition of energy efficient operation modes of CHPI. For other operation modes of ESS their energy efficiency and compatibility will greatly determine the type and efficiency of PSH, on condition of energy efficient operation modes of CHPI.

It is defined that the values of dimensionless index of energy efficiency of PSH within ESS are: K_{PSH}^{ES} =0,302…0,318 for electric boiler on condition of usage the electric energy from energy system; K_{PSH}^{EC} =0,223…0,319 for electric boiler for small power ESS on condition of usage the electric energy from CHPI; K_{PSH}^{FB} =0,8…0,9 for peak hot-water fuel-fired boiler within ESS.

Comparing the results of research, shown in Figs. 3 – 7, the conclusion can be made that usage of fuel-fired boiler as peak source of heat in ESS is for more efficient than the usage of peak electric boiler with different variants of electric energy sources, that is proved be greater values of dimensionless criterion of energy efficiency of peak source of heat within ESS K_{PSH} and dimensionless criterion of ESS energy efficiency K_{ESS} for various operation modes.

ESS, based on CHPI and peak electric boilers, suggested in the research, will be far more efficient than modern high efficient electric and fuel-fired boilers, if the load share of CHPI in ESS is $\beta > 0{,}4$.

Proceeding from the analysis of the results of research (Figs. 6 – 7) it is determined that far greater values of dimensionless criterion of ESS energy efficiency K_{ESS} are registered for ESS, based on CHPI and peak fuel-fired boilers for all investigated operation modes, as compared with other variants of ESS and modern high efficient electric and fuel-fired boilers. Energy efficiency of these ESS almost two times exceeds the efficiency of modern high efficient electric and fuel-fired boilers (see Figs. 6-7).

It is determined, that for the cases of $K_{CHPI} > 1$ and $K_{ESS} > \eta_{FB}$ (or $K_{ESS} > \eta_{EB}$), ESS, based on CHPI and PSH, suggested in the given paper, can be recommended as high efficient systems of energy supply, that could be competitive with modern high efficient electric and fuel-fired boilers.

On the base of the suggested approaches to evaluation of energy efficiency of ESS with CHPI and PSH and above-mentioned conditions the efficient operation modes of ESS are determined 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.

For evaluation of energy efficiency of different variants of ESS, based on CHPI and PSH, besides the above-mentioned approaches, we suggest using the results from the studies [1, 5 – 10].

Conclusions

Methodical fundamentals are elaborated, the evaluation of energy efficiency of energy supply systems, based on combined CHPI and PSH is performed, efficient operation modes of energy supply systems, based on combined 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, taking into consideration energy losses in the process of generation, supply and conversion of electric energy are determined.

The suggested approach to evaluation of ESS energy efficiency on the base of CHPI and PSH has a number of advantages:

— it allows 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 allows to evaluate the impact of variable operation modes of 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 account energy efficiency of ESS, based on CHPI of various power levels;

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

— it takes into consideration operation modes and energy efficiency of steam compressor CHPI of various power levels;

— it takes into consideration the impact of peak sources of heat for ESS and kind 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 evaluation of ESS energy efficiency it is possible to select the most efficient peak source of heat for certain type of ESS;

— the suggested methodical fundamentals may be used for evaluation of ESS energy efficiency on the base of steam compressor CHPI with various refrigerants, sources of low temperature heat and scheme solutions;

— it allows to comprehensively evaluate energy efficiency of greater part of ESS variants, based on CHPI and PSH.

Proceeding from the analysis of the results of the research, it is determined that for ESS, based on CHPI and PSH for the values of CHPI load share $\beta > 0{,}7$ the efficiency and the type of peak source of heat have minor impact on energy efficiency of ESS on condition of energy efficient modes of CHPI operation. For other operation modes of ESS their energy efficiency and competitiveness will be determined to greater extent by the type and efficiency of PSH, on condition of energy efficient operation modes of CHPI. ESS, based on CHPI and peak electric boilers, suggested in the research, will be far more efficient than modern high efficient electric and fuel-fired boilers, if the load share of CHPI in ESS is $\beta > 0{,}4$.

It is determined, that for ESS, based on CHPI and peak fuel-fired boilers greater values of dimensionless criterion of ESS energy efficiency K_{ESS} are registered for all investigated operation modes, as compared with other variants of ESS and modern high efficient electric and fuel-fired boilers. Energy efficiency of these ESS almost two times exceeds the efficiency of modern high efficient electric and fuel-fired boilers.

For the cases of $K_{CHPI} > 1$ and $K_{ESS} > \eta_{FB}$ (or $K_{ESS} > \eta_{EB}$), ESS, based on CHPI and PSH, suggested in the given paper, can be recommended as high efficient systems of energy supply, that may be competitive with modern high efficient electric and fuel-fired boilers.

On the base of the suggested approaches to evaluation of energy efficiency of ESS with CHPI and PSH and above-mentioned conditions the efficient operation modes of ESS are determined 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.

For evaluation of energy efficiency of different variants of ESS, based on CHPI and PSH, besides the above-mentioned approaches, we suggest using the results from the studies [1, 5 – 10].

REFERENCES

1. Ткаченко С. Й. Парокомпресійні теплонасосні установки в системах теплопостачання. Монографія / С. Й. Ткаченко, О. П. Остапенко. – Вінниця: УНІВЕРСУМ-Вінниця. – 2009. – 176 с.

2. Баласанян Г. А. Ефективність перспективних інтегрованих систем енергозабезпечення на базі установок когенерації малої потужності (теоретичні основи, аналіз, оптимізація) : автореф. дис. д-ра техн. наук : 05.14.06 «Технічна теплофізика і промислова теплоенергетика» / Г. А. Баласанян. – Одеса, 2007. – 36 с.

3. Билека Б. Д. Экономичность когенерационных и комбинированных когенерационно-теплонасосных установок с газопоршневыми и газотурбинными двигателями / Б. Д. Билека, Р. В. Сергиенко, В. Я. Кабков // Авиационно-космическая техника и технология. – 2010. – №7 (74). – С. 25 – 29.

4. Сафьянц С. М. Исследование схемы источника теплоэлектроснабжения с регулированием нагрузок на базе использования тепловых насосов / С. М. Сафьянц, Н. В. Колесниченко, Т. Е. Веретенникова // Промышленная теплотехника. – 2011. – Т. 33, № 3. – С. 79 – 85.

5. Енергетична ефективність парокомпресійних теплових насосів з електричним та когенераційним приводами [Електронний ресурс] / О. П. Остапенко, В. В. Лещенко, Р. О. Тіхоненко // Наукові праці ВНТУ. – 2014. – № 4. – Режим доступу до журн.: http://praci.vntu.edu.ua/index.php/praci/article/view/421/419.

6. Енергетичні переваги застосування парокомпресійних теплових насосів з електричним та когенераційним приводами [Електронний ресурс] / О. П. Остапенко, В. В. Лещенко, Р. О. Тіхоненко // Наукові праці ВНТУ. – 2015. – № 1. – Режим доступу до журн.: http://praci.vntu.edu.ua/index.php/praci/article/view/437/435.

7. Остапенко О. П. Методичні основи комплексного оцінювання енергетичної ефективності парокомпресійних теплонасосних станцій з електричним та когенераційним приводом / О. П. Остапенко // Наукові праці ОНАХТ. – 2015. – Вип. 47. – Т. 2. – С. 157 – 162.

8. Ostapenko O. P. Scientific basis of evaluation energy efficiency of heat pump plants: monograph / O. P. Ostapenko. – Saarbrücken, LAP LAMBERT Academic Publishing, 2016. – 62 p.

9. Комплексна оцінка енергетичної ефективності парокомпресійних теплонасосних станцій з когенераційним приводом [Електронний ресурс] / О. П. Остапенко // Наукові праці ВНТУ. – 2015. – № 3. – Режим доступу до журн.: http://praci.vntu.edu.ua/index.php/praci/article/view/2/2.

10. Енергетична ефективність систем енергозабезпечення на основі комбінованих когенераційно-теплонасосних установок [Електронний ресурс] / О. П. Остапенко, В. В. Лещенко, Р. О. Тіхоненко // Наукові праці ВНТУ. – 2015. – № 4. – Режим доступу до журн.: http://praci.vntu.edu.ua/index.php/praci/article/view/454/452.

11. Остапенко О. П. Холодильна техніка та технологія. Теплові насоси : навчальний посібник / О. П. Остапенко. – Вінниця : ВНТУ, 2015. – 123 с.

Ostapenko Olga – Cand. Sc. (Eng.), Assistant Professor with the Department of Heat Power Engineering, ostapenko1208@gmail.com.

Vinnytsia National Technical University.