Spheres of high energy efficiency of energy supply systems with cogeneration heat pump installations of large power and peak fuel-fired boilers

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Abstract: The approach, aimed at determination of the spheres of high energy efficiency of energy supply systems (ESS) with cogeneration heat pump installations (CHPI) of large power and peak fuel-fired boilers (FB), 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 large power, with the account of energy losses in the process of generation, supply and conversion of electric energy, is suggested.

Key words: sphere of high energy efficient operation, energy supply system, cogeneration heat pump installation, peak fuel-fired boiler.

Introduction. Taking into consideration the actuality of the given problem, in recent years a number of investigations, dealing with the efficiency of usage combined cogeneration heat pump installations in thermal schemes of energy supply sources were carried out [1 – 11]. This technology provides the application of combined cogeneration heat pump installations, that enables to reduce the consumption of natural or alternative gas by 30 – 45 %, as compared with boiler installations of the equivalent capacity [1], and obtain cheaper at cost electric energy, as compared with the grid energy (by 30 – 40 %). Cogeneration drive of HPI compressors can be provided on the base of gas engines-generators, manufactured by Ukrainian enterprises.

Publications review on the subject. In research [2 –3] energy advantages are evaluated and efficient real operation modes of HPI with electric and cogeneration drives are determined, 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. In research [4 – 5] 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 HPP drive energy and with the account of energy losses in the process of generation, supply and conversion of electric energy are suggested. In [5 – 6] 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 research [7] 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 research [8] energy efficiency of ESS, based on combined CHPI and peak sources of heat (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 research [9] 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, is performed.

In accordance with [8 – 9], optimal distribution of loading between CHPI and PSH (for instance, hot-water fuel-fired boiler, electric boiler, solar collectors, etc.) within the frame of ESS largely determines energy efficiency of the above-mentioned ESS. Such distribution is characterized by the share of CHPI loading within the frame of ESS β, that is determined as the ratio of thermal capacity of CHPI to thermal capacity of ESS $\beta = Q_{CHPI}/Q_{ESS}$. In the paper [8] it is suggested to realize comprehensive assessment of ESS with CHPI and PSH energy efficiency by complex dimensionless criterion of energy efficiency:

$$\text{K}_{ESS} = (1-\beta)\cdot\text{K}_{PSH} + \beta\cdot\text{K}_{CHPI} \qquad (1)$$

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 CHPI within ESS energy efficiency from the researches [2, 7 – 8].

In research [8] spheres of energy efficiency operation of CHPI of various power levels, obtained on the base of the research [7] and determined and defined by CHPI energy efficiency dimensionless criterion K_{CHPI}, depending on real values of HPI coefficient of performance φ_r and efficient factor of gas-piston engine-generator (GPE) η_{EGPE}. Energy efficient operation modes of CHPI correspond to the condition $K_{CHPI} > 1$. High values of energy efficiency dimensionless criterion for ESS with CHPI, obtained in [8], confirm high energy efficiency of such combined energy supply systems. In [9] 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, intended for operation in heat supply systems.

In [1–9] the authors did not determine the areas of high energy efficiency of energy supply systems with combined CHPI and FB on conditions of optimal operation modes of CHPI.

Objective. Aim of the research is the determination of the areas of high energy efficiency of ESS with CHPI of large power and peak FB on conditions of optimal operation modes of CHPI, determination of energy efficient operation modes of ESS with CHPI and peak FB with the account of complex impact of variable operation modes, sources of drive energy for steam compressor HPI of large power, with the account of energy losses in the process of generation, supply and conversion of electric energy.

Materials and methods. The research contains the evaluation of high energy efficient operation modes of ESS with CHPI and peak FB. Energy efficiency of ESS with steam compressor HPI of large power (higher than 1 MW) with cogeneration drive from GPE was studied. Fuel-fired boiler houses were provided to be used as peak sources of heat in ESS. The investigated ESS with CHPI and FB can completely or partially provide auxiliary needs in electric energy and provide the consumers needs in heating and hot water supply. Schemes of the ESS with CHPI and peak FB are presented in works [1, 10]. Methodical fundamentals of energy efficiency evaluation of ESS with CHPI and FB are given in research [8].

Areas of high energy efficiency of ESS with CHPI and FB can be determined from the dependences, suggested in the research [11 – 12], on conditions of K_{CHPI} > 1 and K_{ESS} > 1 [11]. If the above-mentioned conditions are realized, the investigated ESS with CHPI and FB can be recommended as high efficient energy supply systems that can be competitive with modern high-efficient electric and fuel-fired boilers in heat supply and energy supply systems.

In our study the areas of high energy efficiency of ESS with CHPI and FB are defined on conditions of optimal operation modes of CHPI on the base of the research, carried out [7 – 8].

Results and discussion. Application of the suggested approaches, aimed at determination of the areas of ESS with CHPI and FB high energy efficiency will be demonstrated on the specific examples. Figs. 1 – 2 shows the results of research, aimed at determination of the areas of high energy efficiency of ESS with CHPI and FB for energy efficient operation modes of CHPI, based on the results of the studies [7 – 8]. The values of dimensionless criterion of ESS with CHPI and FB energy efficiency for the cases of variable loading of CHPI within ESS on condition of CHPI share change within the range β = 0,1…1,0 are shown. As above mentioned, the areas of high energy efficiency of ESS with CHPI and FB can be determined on conditions of K_{CHPI} > 1 and K_{ESS} > 1 [11]. The research is carried out for energy efficient operation modes of CHPI with K_{CHPI}=1,1…2,1 (on conditions of maximum efficiency of GPE) and with K_{CHPI}=1,1…1,6 (on conditions of minimum efficiency of GPE), based on the results of the studies [7 – 8]. The above-mentioned values of CHPI K_{CHPI} energy efficiency criterion correspond to the values of real coefficient of performance of CHPI within the limits of $φ_r = 2,7…5,4$ for CHPI of large power, according to [8].

Fig. 1 shows the area of high energy efficiency of ESS with CHPI of large power and peak fuel-fired boiler house, on conditions of minimal efficiency of GPE and FB. In the given research, according to [2, 7], the following values are taken into account: value of GPE efficiency factor $η_{EGPE} = 0,31$ and value of electric motor efficiency with the account of energy losses in the control unit of electric motor $η_{ED} = 0,9$. Fuel-fired boiler house with $η_{FB} = 0,8$ is provided to be peak source of heat in ESS for these conditions. Value of dimensionless criterion of fuel-fired boiler energy efficiency will be $K_{PSH}^{FB} = η_{FB} = 0,8$. As it is seen from Fig. 1, the values of complex dimensionless criterion of ESS energy efficiency are $K_{ESS} = 1,0…1,3$ on condition on minimal efficient value of energy efficient criterion of CHPI $K_{CHPI} = 1,3$; for operation modes of ESS with $K_{CHPI} > 1,3$ the values of dimensionless criterion of ESS energy efficiency change within the limits of $K_{ESS} = 1,04...1,6$·
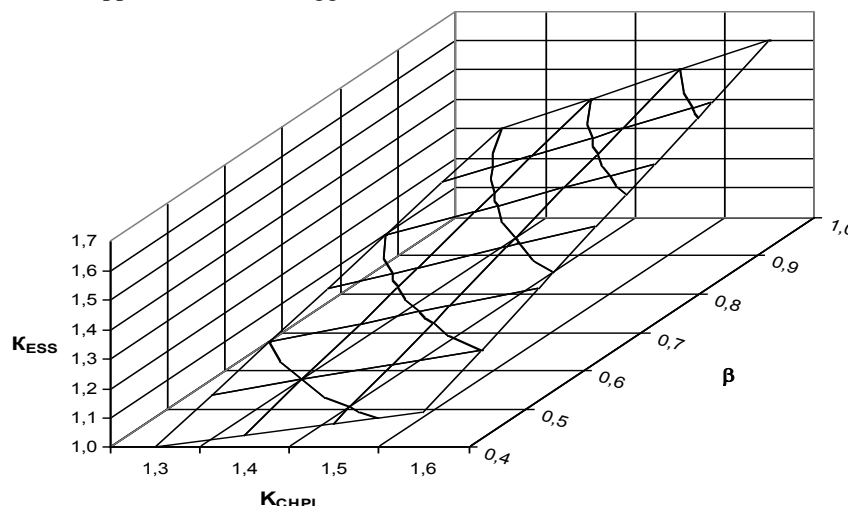

Fig. 1. Area of high energy efficiency of ESS with CHPI of large power, on conditions of minimal efficiency of GPE and peak fuel-fired boiler

As it is seen from Fig. 1, on conditions of $K_{CHPI} > 1,3$ and $K_{ESS} > 1$ [11], dependence, shown in Fig. 1, determine area of high energy efficiency of ESS with CHPI of large power and peak fuel-fired boiler (boiler house), on conditions of minimal efficiency of GPE and fuel-fired boiler (boiler house). On these conditions, the above-mentioned ESS can be recommended as high efficient systems of energy supply, as their efficiency almost two times exceeds energy efficiency of high efficient electric and fuel-fired boilers. Such ESS could be competitive with modern high efficient electric and fuel-fired boilers in the systems of heat and energy supply.

Fig. 2 shows the area of high energy efficiency of ESS with CHPI of large power and peak fuel-fired boiler, on conditions of maximum efficiency of GPE and FB. In the given research, according to [2, 7], the following values are taken into account: value of GPE efficiency factor $\eta_{EGPE} = 0,42$ and value of electric motor efficiency with the account of energy losses in the control unit of electric motor $\eta_{ED} = 0,9$. Fuel-fired boiler house with $\eta_{FB} = 0,9$ is provided to be peak source of heat in ESS for these conditions. The value of dimensionless criterion of fuel-

fired boiler energy efficiency will be $K_{PSH}^{FB} = 0,9$. As it is seen from Fig. 2, the values of complex dimensionless criterion of ESS energy efficiency are $K_{ESS} = 1,06...1,3$ on condition on minimal efficient value of energy efficient criterion of CHPI $K_{CHPI} = 1,3$; for operation modes of ESS with $K_{CHPI} > 1,3$ the values of dimensionless criterion of ESS energy efficiency change within the limits of $K_{ESS} = 1,12...2,1$.

As it is seen from Fig. 2, on conditions of $K_{CHPI} > 1,3$ and $K_{ESS} > 1$ [11], dependence, shown in Fig. 2, determine area of high energy efficiency of ESS with CHPI of large power and peak fuel-fired boiler (boiler house), on conditions of maximal efficiency of GPE and fuel-fired boiler (boiler house). On such conditions, the above-mentioned ESS can be recommended as high efficient energy supply systems, as their efficiency more than two times exceeds energy efficiency of high efficient electric and fuel-fired boilers. The studied ESS can be competitive with modern high efficient electric and fuel-fired boilers in heat and energy supply systems.
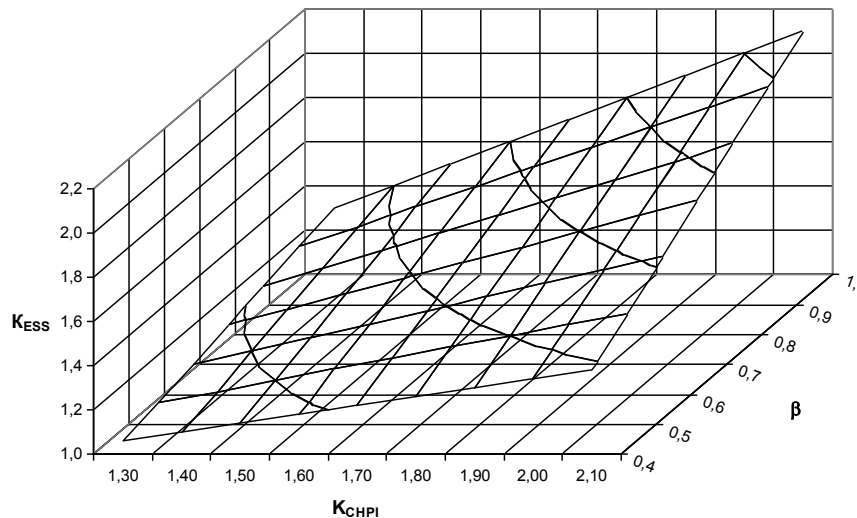

Fig. 2 – Area of energy efficiency of ESS with CHPI of large power, on conditions of maximum efficiency of GPE and peak fuel-fired boiler

It is determined, that ESS with CHPI and peak fuel-fired boilers, suggested in the research, will be high energy efficient, if the share of CHPI loading in ESS will be $\beta > 0,4$ and the value of energy efficient criterion of CHPI will be $K_{CHPI} > 1,3$; that corresponds to the results of research, shown in Figs. 1-2. At these conditions the areas of high energy efficiency of the above-mentioned ESS are determined. Under realization of these conditions, modern high efficient electric and fuel-fired boilers will be inferior by energy efficiency to the above-mentioned ESS.

Under such conditions, the above-mentioned ESS can be recommended as high efficient energy supply systems, as even in case of minimal efficiency of GPE and boiler, energy efficiency of ESS almost two times exceeds energy efficiency of high efficient electric and fuel-fired boilers. This ESS can be competitive with modern high efficient electric and fuel-fired boilers in the systems of heat and energy supply.

Conclusions. Areas of high energy efficiency of ESS with CHPI and FB, on conditions of optimal operation

modes of CHPI are determined; energy efficient operation modes of ESS with CHPI and FB with the account of complex impact of variable operation modes, sources of drive energy for steam compressor HPI of large power, with the account of energy losses in the process of generation, supply and conversion of electric energy are determined.

The suggested approach, aimed at determination of the areas of high energy efficiency of ESS with CHPI and FB has a number of advantages:
− it takes into account variable operation modes of ESS with the change of load distribution between steam compressor CHPI and peak FB in ESS;
− it enables to determine areas and modes of high energy efficient operation of ESS with CHPI and FB, at which energy efficiency of the studied ESS almost two times exceeds energy efficiency of modern high energy efficient electric and fuel-fired boilers;
− it allows to develop recommendations, aimed at high energy efficient operation of ESS with CHPI and FB with different scheme solutions.

Under conditions of $K_{CHPI} > 1,3$ and $K_{ESS} > 1$ and modes of energy efficient operation of CHPI, areas of high energy efficiency and high energy efficient operation modes of ESS with CHPI of large power and peak fuel-fired boilers, for various ESS elements energy efficiency are determined. It is determined, that ESS with CHPI and peak fuel-fired boilers, suggested in the research, will be high energy efficient, if the share of CHPI loading in ESS will be $\beta > 0,4$ and the value of energy efficient criterion

of CHPI will be $K_{CHPI} > 1,3$. If this condition is realized, modern high efficient electric and fuel-fired boilers will be inferior by their energy efficiency to the above-mentioned ESS. Under these conditions the above-mentioned ESS can be recommended as high efficient energy supply systems, as their efficiency more than two times exceeds energy efficiency of high efficient electric and fuel-fired boilers.

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Области высокой энергоэффективности систем энергоснабжения с когенерационно-теплонасосными установками большой мощности и пиковыми топливными котлами
О. П. Остапенко
Аннотация: Предложен подход по определению областей высокой энергоэффективности систем энергоснабжения (СЭ) с когенерационно-теплонасосными установками (КТНУ) большой мощности и пиковыми топливными котлами (ТК), при условиях оптимальных режимов работы КТНУ, с учетом комплексного влияния переменных режимов работы, источников приводной энергии для парокомпрессионных теплонасосных установок (ТНУ) большой мощности, с учетом потерь энергии при генерировании, снабжении и преобразовании электрической энергии.

Ключевые слова: область высокой энергоэффективности, система энергоснабжения, когенерационно-теплонасосная установка, пиковый топливный котел.