

Areas of high energy efficiency of energy supply systems with cogeneration heat pump installations of small power and peak electric boilers in heat supply systems

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Abstract: The approach, aimed at determination of the areas of high energy efficiency of energy supply systems (ESS) with cogeneration heat pump installations (CHPI) of small power and peak electric boilers (EB) in heat supply systems (HSS), 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 small power, with the account of energy losses in the process of generation, supply and conversion of electric energy, is suggested.

Key words: area of high energy efficient operation, energy supply system, cogeneration heat pump installation, peak electric boiler, heat supply system

Introduction. In recent years a number of investigations, dealing with the efficiency of usage combined cogeneration heat pump installations in thermal schemes of heat and energy supply sources were carried out [1 – 12]. The application of combined CHPI 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 [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 ESS with combined CHPI and PSH, on conditions of optimal operation modes of CHPI for heat supply systems 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 $\beta = Q_{\text{CHPI}}/Q_{\text{ESS}}$. 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:

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

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 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 $K_{\text{CHPI}} > 1$. 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 electric 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 [1–12] the authors did not determine the areas of high energy efficiency of ESS with CHPI of small power and peak EB in HSS, 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 small power and peak EB in HSS, on conditions of optimal operation modes of CHPI; determination of high energy efficient operation modes of ESS with CHPI and peak EB in HSS, with the account of complex impact of variable operation modes, sources of drive energy for steam compressor HPI of small 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 of small power and peak EB in HSS. Energy efficiency of ESS with steam compressor HPI of small power (up to 1 MW) with cogeneration drive from GPE was studied. Electric boiler houses

were provided to be used as peak sources of heat in ESS. The investigated ESS with CHPI and EB 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 EB for heat supply systems are presented in works [1, 10]. Methodical fundamentals of energy efficiency evaluation of ESS with CHPI and EB are given in research [8]. Areas of high energy efficiency of ESS with CHPI of small power and peak EB in HSS 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 EB 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 of small power and peak EB for heat supply systems 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 small power CHPI and EB high energy efficiency for heat supply systems 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 small power CHPI and EB in HSS, for energy efficient operation modes of CHPI, based on the results of the studies [7 – 8]. The values of the dimensionless criterion of energy efficiency of ESS with small power CHPI and EB in HSS is studied for the cases of seasonal variable loading of CHPI within ESS for optimal values of CHPI loading share the range of $\beta = 0,16 \dots 0,63$ [13 – 14], that corresponds to temperature modes of heat supply system operation. As above mentioned, the areas of high energy efficiency of ESS with CHPI and EB 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 $K_{CHPI} = 1,1 \dots 2,1$ (on conditions of maximum efficiency of GPE) and with $K_{CHPI} = 1,1 \dots 1,6$ (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 $\varphi_r = 3,0 \dots 5,4$ for CHPI of small power, according to [8].

Fig. 1 shows the area of high energy efficiency of ESS with CHPI of small power and peak electric boiler house for heat supply, on conditions of minimal efficiency of GPE and EB, with the consumption of electric energy by electric boiler from CHPI.

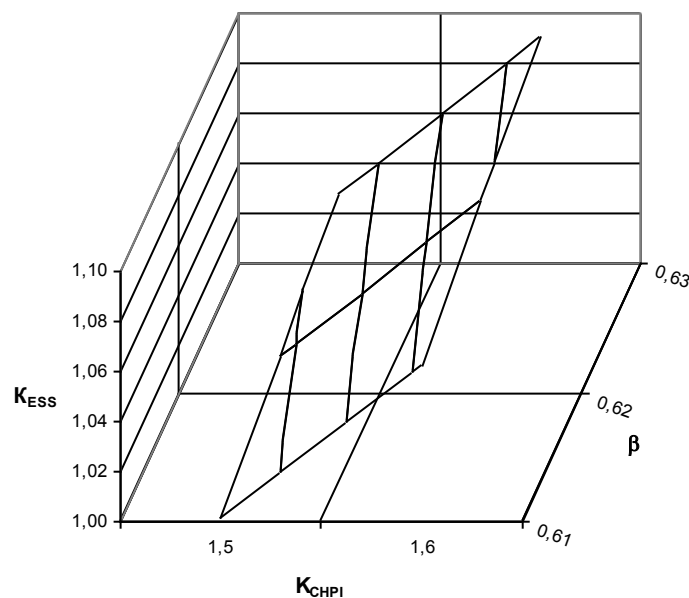


Fig. 1 – Area of high energy efficiency of ESS with CHPI of small power and peak electric boiler house for heat supply, on conditions of minimal efficiency of GPE and EB, with the consumption of electric energy by electric boiler from CHPI

In the given research, according to [2, 7], the following values are taken into account: 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 these conditions. The value of dimensionless criterion of energy efficiency of electric boiler for the cases of electric energy consumption from CHPI will be $K_{PSH}^{EC} = 0,223$.

As it is seen from Fig. 1, the values of complex dimensionless criterion of ESS energy efficiency are $K_{ESS} = 1,0...1,03$ on condition of minimal efficient value of energy efficient criterion of CHPI $K_{CHPI} = 1,5$; for operation modes of ESS with $K_{CHPI} > 1,5$ the values of dimensionless criterion of ESS energy efficiency change within the limits of $K_{ESS} = 1,06...1,09$. For the investigated operation modes of ESS for heat supply systems the values of the complex dimensionless criterion of ESS energy efficiency are $K_{ESS} = 1,0...1,09$ on condition of $\beta = 0,61...0,63$ and it can reach the value of $K_{ESS} = 1,6$ [9, 11] on condition of $\beta = 1$.

As it is seen from Fig. 1, on conditions of $K_{CHPI} > 1,5$ and $K_{ESS} > 1$ [11], dependence, shown in Fig. 1, determine area of high energy efficiency of ESS with CHPI of small power and peak electric boiler (boiler house), on conditions of minimal efficiency of GPE and EB, with the consumption of electric energy by electric boiler from CHPI. On these conditions, the above-mentioned ESS can be recommended as high efficient systems of energy supply, as their efficiency exceeds energy efficiency of high efficient electric and fuel-fired boilers.

Fig. 2 shows the area of high energy efficiency of ESS with CHPI of small power and EB for heat supply, on conditions of maximal efficiency of GPE and EB, with the consumption of electric energy by peak electric boiler from CHPI. 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 $\eta_{ED} = 0,8$. Electric boiler house with $\eta_{EB} = 0,95$ is provided to be peak source of heat in ESS for these conditions. The value of dimensionless criterion of electric boiler energy efficiency for the cases of electric energy consumption from CHPI will be $K_{PSH}^{EC} = 0,319$. As it is seen from Fig. 2, the values of complex dimensionless criterion of ESS energy efficiency are $K_{ESS} = 1,01...1,19$ on condition of minimal efficient value of energy efficient criterion of CHPI $K_{CHPI} = 1,7$; for operation modes of ESS with $K_{CHPI} > 1,7$ the values of dimensionless criterion of ESS energy efficiency change within the limits of $K_{ESS} = 1,06...1,44$.

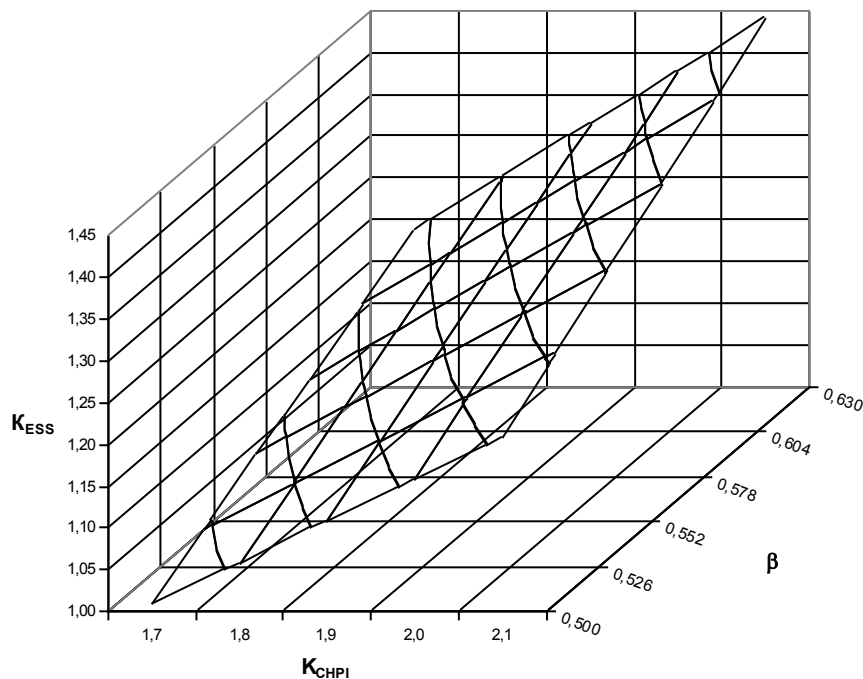


Fig. 2 – Area of high energy efficiency of ESS with CHPI of small power and EB for heat supply, on conditions of maximal efficiency of GPE and EB, with the consumption of electric energy by peak electric boiler from CHPI

For the investigated operation modes of ESS with CHPI of small power and EB for heat supply systems the values of the complex dimensionless criterion of ESS energy efficiency are $K_{ESS} = 1,01...1,44$ on

condition of $\beta = 0,5 \dots 0,63$ and it can reach the value of $K_{ESS} = 2,1$ [8 – 9, 11] on condition of $\beta = 1$.

As it is seen from Fig. 2, on conditions of $K_{CHPI} > 1,7$ and $K_{ESS} > 1$ [11], dependence, shown in Fig. 2, determine area of high energy efficiency of ESS with CHPI of small power and peak electric boiler (boiler house), on conditions of maximal efficiency of GPE and electric boiler (boiler house). On such conditions, the above-mentioned ESS can be recommended as high efficient energy supply systems, as their efficiency almost 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.

The area of high efficient operation of ESS with CHPI of small power and EB, on condition of electric energy consumption by peak electric boiler from energy system of Ukraine, in the process of operation in heat supply systems, is determined in research [12]. In our research it is determined that ESS with small power CHPI and peak electric boilers will be high energy efficient, if the share of CHPI load in ESS will be $\beta > 0,5 \dots 0,61$ (depending on the levels of energy efficiency of GPE and EB). However, such operation modes of ESS will be provided on condition of high efficient operation of CHPI with energy efficiency index of $K_{CHPI} > 1,5 \dots 1,7$ (depending on various ESS elements energy efficiency). These conditions correspond to the results of the 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 for heat supply, as even in case of minimal efficiency of GPE and electric boiler, energy efficiency of ESS 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 small power CHPI and EB in HSS, on conditions of optimal operation modes of CHPI are determined; energy efficient operation modes of ESS with CHPI and EB in HSS, with the account of complex impact of variable operation modes, sources of drive energy for steam compressor HPI of small 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 small power CHPI and EB in HSS 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 EB in ESS;
- it enables to determine areas and modes of high energy efficient operation of ESS with small power CHPI and EB for heat supply, 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 small power CHPI and EB with different scheme solutions for heat supply systems.

Under conditions of $K_{CHPI} > 1,5 \dots 1,7$ (depending on various ESS elements energy efficiency) and $K_{ESS} > 1$ the areas of high energy efficiency and high energy efficient operation modes of ESS with CHPI of small power and peak electric boilers, for various ESS elements energy efficiency are determined. It is determined that ESS with small power CHPI and peak electric boilers for heat supply will be high energy efficient, if the share of CHPI load in ESS will be $\beta > 0,5 \dots 0,61$ (depending on the levels of energy efficiency of GPE and EB). Under these conditions the above-mentioned ESS can be recommended as high efficient energy supply systems, as their efficiency almost 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 малой мощности и пиковыми электрическими котлами в системах теплоснабжения

О. П. Остапенко

Аннотация: Предложен подход по определению областей высокой энергоэффективности систем энергоснабжения (СЭ) с когенерационно-теплонасосными установками (КТНУ) малой мощности и пиковыми электрическими котлами (ЭК) в системах теплоснабжения, при условиях оптимальных режимов работы КТНУ, с учетом комплексного влияния переменных режимов работы, источников приводной энергии для парокompрессионных теплонасосных установок (ТНУ) малой мощности, с учетом потерь энергии при генерировании, снабжении и преобразовании электрической энергии.

Ключевые слова: область высокой энергоэффективности, система энергоснабжения, когенерационно-теплонасосная установка, пиковый электрический котел, система теплоснабжения