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COMPLEX EVALUATION OF ENERGY EFFICIENCY OF STEAM COMPRESSOR HEAT PUMP PLANTS WITH COGENERATION DRIVE

The approach, aimed at complex evaluation of energy efficiency of steam compressor heat pump plants (HPP) with electric drive, taking into account complex impact of variable operation modes of HPP, peak sources of heat of HPP, sources of drive energy of various levels of power of HPP, taking into account losses of energy in the process of generation, supply and conversion of electric energy.

Kew words: *complex evaluation, energy efficiency, heat pump plant, dimensionless criterion of energy efficiency, cogeneration drive.*

Introductions

In conditions of high cost of energy resources, increased electric energy demand in the peak consumption hours (especially in heating period) as a result of deficiency of the existing electric generation power in Ukraine and recurrent non-agreement of generation and consumption schedules, in order to reduce loading on energy system of Ukraine the technology of creation of energy generating capacities, based on combined cogeneration and heat pump installations (HPI) becomes very actual in modern conditions. This technology provides the application of combined cogeneration heat pump installations, enabling to decrease the consumption of natural or alternative gas by 30 – 45 %, as compared with boiler installations of the same capacity [1], and obtain cheaper at cost electric energy, comparing with the grid energy (by 30 – 40 %). Greater effect can be obtained on conditions of application of combined cogeneration-heat pump installations on the basis of existing municipal and industrial boiler houses – creation of heat pump plants with cogeneration drive of the compressors of heat pumps. Cogeneration drive of the compressors of heat pumps may be realized on the basis of gas engines-generators, manufactured by Ukrainian enterprises «Pervomayskdizelmach» and state enterprise «V. O. Malyshev plant».

Taking into consideration the actuality of the given problem, numerous investigations aimed at the study of the efficiency of usage of the heat pump installations in thermal schemes of energy supply sources were carried out [1 – 12]. In [1] the authors performed investigations, aimed at the increasing energy efficiency of heat supply sources, using HPI with electric and cogeneration drive, taking into account the impact of scheme solutions and operation modes. In [2] the comparative analysis of promising directions of increasing the efficiency of energy supply systems, based of small power cogeneration installations is performed, thermal schemes of integrated systems of complex energy supply are suggested. Studies of integrated systems of complex energy supply [2], realized on the base of solar collectors, geothermal sources of heat, heat pumps of compressor and absorption types, allowed on the base of numerical analysis, determine optimal conditions of their operation. In research [3], authors evaluated economical efficiency of cogeneration and combined cogeneration-heat pump installations with gas-piston and gas turbine engines. However, in research [3], authors suggested simplified approach to evaluation of HPI energy efficiency only by the coefficient of performance, that does not take into account all the losses of energy, connected with generation of heat in HPI. In [4] author performed the comparative analysis of technical-economic efficiency of heat pumps with the drive from gas-piston cogeneration installations and gas hot water boiler in the systems of hot water supply. Publication [5] contains the results of study of heat-electric power supply source scheme (mini-TEP) with regulated loads, based on the usage of heat pumps. In research [5] three variants of the thermal schemes are analyzed: scheme with cogeneration and heat pump installations, delivering electric energy into the grid, scheme with cogeneration and heat pump installations and storage battery tank, delivering electric energy into the grid, scheme with cogeneration and heat pump installations, without delivering electric energy into the grid. Heat source of HPI in this research is provided to use untreated sewage. In the research [5] authors suggested simplified approach to evaluation of HPI energy efficiency: the given approach does not take into consideration all energy losses, connected with production of heat in HPI. Thermal schemes, suggested in the research [5] may be used only to provide the needs of hot water supply and these schemes can provide only partially the power heating.

In [6] efficient real operation modes of HPI with electric and cogeneration drives, taking into account 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 determined. Energy advantages of steam compressor heat pumps with electric and cogeneration drive s usage are analyzed in the research [7].

In publications [8, 9] energy and economic preconditions of efficient integration of HPP into the systems of the heat supply of industrial enterprises and municipal utilities in Ukraine are determined. In [10] energy, ecological and economic efficiency of HPP with various types of compressor drive on natural and industrial sources of low temperature heat, taking into account variable operation modes of heat supply systems in wide range of HPI power change are evaluated. The results of study of HPP energy efficiency with various sources of heat, on conditions of variable operation modes are given in [11]. In [12] energy ecological efficiency of HPP with various types of compressor drive on natural and industrial sources of low temperature heat on condition of variable operation modes of heat supply systems is evaluated.

In [1 – 12] authors did not perform complex evaluation of energy efficiency of steam compressor HPP with cogeneration drive, taking into account complex impact of variable operation modes of HPP, peak sources of HPP heat, sources of drive energy of steam compressor HPP of different levels of power, taking into consideration energy losses in the process of generation, supply and conversion electric energy.

The aim of research is the development of methodic fundamentals and realization of complex evaluation of energy efficiency of steam compressor heat pump plants with cogeneration drive, taking into account complex impact of variable operation modes of HPP, peak sources of HPP heat, sources of drive energy of steam compressor HPP of various levels of power, taking into consideration energy losses in the process of generation, supply and conversion of electric energy.

Main part

In the research complex evaluation of energy efficiency of steam compressor HPP with HPI of small (up to 1 MW) and large power with cogeneration drive from gas-piston engine-generator (GPE). Cogeneration drive of heat pumps has advantages as compared with electric one, because it enables to avoid additional losses of energy in the process of its transmissions and provides utilization of fuel gases heat after gas-fired engine, and provides better energy efficiency HPP with cogeneration drive can partially or completely provides auxiliaries with electric energy. Scheme of the given HPP is presented in [1].

Energy efficiency of HPP is largely determined by optimal distribution of loading between heat pump installation and peak source of heat (for instance, hot-water fuel-fired boiler, electric boiler, solar collectors, etc.) within the frame of HPP. This distribution is characterized by the share of HPI loading within the frame of HPP β, that is determined as a relation of thermal capacity of HPI to the capacity of HPP $\beta = Q_{HPI}/Q_{HPP}$. For HPP with cogeneration drive, the value of HPI thermal capacity is determined, taking into account the capacity of utilization equipment of cogeneration drive $Q_{HPI} = Q_c + \Sigma Q_{ut}$, where Q_c – capacity of HPI condenser, ΣQ_{ut} – capacity of utilization equipment of HPI cogeneration drive.

Proceeding from the analysis of the research, carried out [10 – 12], optimal values of index β are determined for HPP with cogeneration drive at various sources of heat, in case of variable operation modes of heating systems. Each of theses modes corresponds to certain value of thermal power of HPP, HPI and part of HPI loading β. The results of study of energy efficiency of HPP with cogeneration drive, on condition of variable operation modes for various sources of low temperature heat are given in [11].

In our research energy efficiency of «Source of drive energy of HPP – HPP – heat consumer from HPP» system on the example of steam compressor heat pumps with cogeneration drive is analyzed. The advantage of such an approach is taking into consideration of energy losses in the process of generation, supply and conversion of electric energy to HPI and peak source of heat in order to determine the efficient operation modes of HPP with cogeneration drive.

Complex evaluation of energy efficiency of steam compressor HPP with cogeneration drive is suggested to carry out, applying complex dimensionless criterion of HPP energy efficiency:

$$K_{HPP} = (1-\beta)\cdot K_{PSH} + \beta \cdot K_{HPI}, \qquad (1)$$

where K_{PSH} – dimensionless criterion of energy efficiency of peak source of heat within the frame of HPP (hot-water fuel-fired boiler, electric boiler, solar collectors, etc.), K_{HPI} – dimensionless criterion of energy efficiency of steam compressor HPI with cogeneration drive within the frame of HPP.

Dimensionless criterion of energy efficiency of steam compressor HPI with cogeneration drive K_{HPI} is suggested in the research [6]. It is obtained on the basis of energy balance equation for the system «Source of drive energy of HPI – HPI – heat consumer from HPI», taking into 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.

For steam compressor HPI with cogeneration drive dimensionless criterion of energy efficiency will have the form [6]:

$$K_{HPI} = Q_{HPI}/Q_h = \eta_{EP}\cdot\varphi\cdot\eta_{hf}, \qquad (2)$$

where Q_h – power, spent by gas-piston engine-generator for generation of electric energy for HPI drive, η_{EP} – total efficiency factor of generation, supply and conversion of electric energy from [6], φ – coefficient of performance of steam compressor HPI, η_{hf} – efficiency factor of the heat flow, that takes into account energy losses and working substance in pipe lines and equipment of HPI.

For HPI with cogeneration drive total efficiency factor of generation, supply and conversion of electric energy, in accordance with [6], may be defined:

$$\eta_{EP} = \eta_{EGPE}\cdot\eta_{ED}, \qquad (3)$$

where η_{EGPE} – efficient factor of gas-piston engine; η_{ED} – efficiency factor of electric motor, taking into account energy losses in motor control unit from [6].

For steam compressor HPI with cogeneration drive dimensionless criterion of energy efficiency will have the form [6]:

$$K_{HPI} = Q_{HPI}/Q_h = \eta_{EP}\cdot\varphi\cdot\eta_{hf} = \eta_{EGPE}\cdot\eta_{ED}\cdot\varphi\cdot\eta_{hf}. \qquad (4)$$

On condition $K_{HPI} = 1$ heat pump installation supplies to the consumer the same thermal power that was consumed for generation of electric energy for HPI drive. The greater the value of this index is more efficient and competitive the heat pump will be.

In research [6] the method of determination of the spheres of efficient usage of steam compressor HPI with cogeneration drive by dimensionless index of HPI K_{HPI} energy efficiency, taking into consideration the impact of the sources of drive energy sources of steam compressor HPI and taking into consideration energy losses in the process of generation, supply and conversion of electric energy to HPI.

Dimensionless criterion of energy efficiency of peak source of heat – electric boiler –within the frame of HPP K_{PSH} can be obtained proceeding from the equation of energy balance for the systems

«Source of electric energy – electric boiler – heat consumer from HPP», taking into account the impact of the energy sources for peak source of heat (electric boiler) and taking into consideration energy losses in the process of generation and supply of electric energy to electric boiler.

In general case, for electric boiler as peak source of heat for HPP dimensionless criterion of energy efficiency has the form:

$$K_{PSH} = Q_{EB} / Q_h = \eta_{EP}^{b} \cdot \eta_{EB}, \quad (5)$$

where Q_{EB} – thermal capacity of hot-water electric boiler, that can be defined as: $Q_{EB} = Q_{HPP} - Q_{HPI}$; 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 is determined 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 [6]; η_{DG} – efficiency factor of distributive electric grids in Ukraine, from [6], η_{EB} – efficiency factor of the electric boiler.

For the case, when steam compressor HPP with cogeneration drive and peak electric boiler are used, then 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 cogeneration drive of HPI or by the above-mentioned formula for the cases of electric energy consumption from energy system on the base of conventional or alternative sources of electric energy.

Then, dimensionless criterion of energy efficiency of electric boiler as peak source of heat for HPP, for the cases of electric energy consumption from energy system will be defined:

$$K_{PSH}^{ES} = \eta_{EPP} \cdot \eta_{DG} \cdot \eta_{EB}. \quad (6)$$

In case of usage in electric boiler the electric energy from cogeneration drive of HPI, dimensionless criterion of energy efficiency of electric boiler as peak source of heat for HPP will be defined:

$$K_{PSH}^{EC} = \eta_{EGPE} \cdot \eta_{ED} \cdot \eta_{EB} = \eta_{EP}^{b} \cdot \eta_{EB}. \quad (7)$$

Dimensionless criterion of energy efficiency of peak source of heat – hot-water fuel-fired boiler – within the frame of HPP K_{PSH} can be obtained, proceeding from the equation of energy balance for the systems «Sources of electric energy and fuel – fuel-fired boiler –consumer of heat from HPP», taking into account the impact of the energy sources for peak source of heat (fuel-fired boiler) and taking into consideration energy losses in the process of generation and supply of electric energy to boiler (boiler house). In this case, consumption of electric energy by peak source of HPP heat – fuel-fired boiler – is not directly connected with the process of heat generation in the boiler and the portion of electric energy consumption by auxiliaries is very small, that is why it does not practically influence the values of K_{PSH} index.

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

$$K_{PSH}^{FB} = Q_{FB} / Q_f = \eta_{FB}, \quad (8)$$

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

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

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

The suggested complex approach to energy efficiency evaluation of steam compressor HPP with cogeneration drive has a number of advantages:

— it allows to evaluate complex impact of variable operation modes of HPP, peak sources of heat of HPP, sources of drive energy of steam compressor HPP with cogeneration drive, taking into account energy losses in the process of generation, supply and conversion of electric energy;

— takes into account the operation modes of steam compressor HPI;

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

— takes into account the impact of drive energy sources of steam compressor HPP of various levels of power, taking into account energy losses in the process of generation, supply and conversion of electric energy to HPP;

— takes into account energy efficiency of steam compressor HPP of various levels of power with cogeneration drive;

— takes into consideration the impact of peak sources of heat of steam compressor HPP and kind of the energy consumed, taking into account 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 energy efficiency of HPP with the cogeneration drive, the selection of the most efficient peak source of heat for certain kind of steam compressor HPP can be performed;

— the suggested methodical fundamentals may be used for evaluation of energy efficiency of steam compressor HPP with various refrigerants and scheme solutions of HPI;

— allows to evaluate in a complex manner energy efficiency of considerable number of variants of steam compressor HPP with cogeneration drive.

The application of the suggested methodical fundamentals of complex evaluation of energy efficiency of HPP with cogeneration drive we will demonstrate on specific examples.

Figs. 1 – 4 show the results of complex evaluation of energy efficiency of small power HPP with cogeneration drive. The values of dimensionless criterion of energy efficiency of HPP with cogeneration drive K_{HPP} are shown for the cases of variable loading of HPI within the frame of HPP with the values of HPI loading share in the range of β = 0.1…1.0. Values of dimensionless criterion of energy efficiency of steam compressor HPI with cogeneration drive K_{HPI}, according to the research [6], are defined for the values of real coefficient of performance of HPI in the range φ_r = 0.83…6.23. HPP peak source of heat for such conditions is provided: electric boiler house with η_{EB} = 0.95 (Figs. 1 – 3) and hot water fuel-fired boiler house with η_{FB} = 0.85 (Fig. 4). By the formula (3), according to [6], for HPI of small power levels with cogeneration drive the value of total efficiency factor of generation, supply and conversion of electric energy to HPI is η_{EP} = 0.28.

Fig. 1 shows the values of dimensionless criterion of energy efficiency of small power HPP with cogeneration drive, on condition of electric energy consumption by peak source of heat (electric boiler) from energy system of Ukraine. In the given research, according to [6], the following values are taken into account: averaged value of efficiency factor of electric power plants in Ukraine η_{EP} = 0.383 and efficiency factor value of distributive electric grids in Ukraine η_{DG} = 0.875.

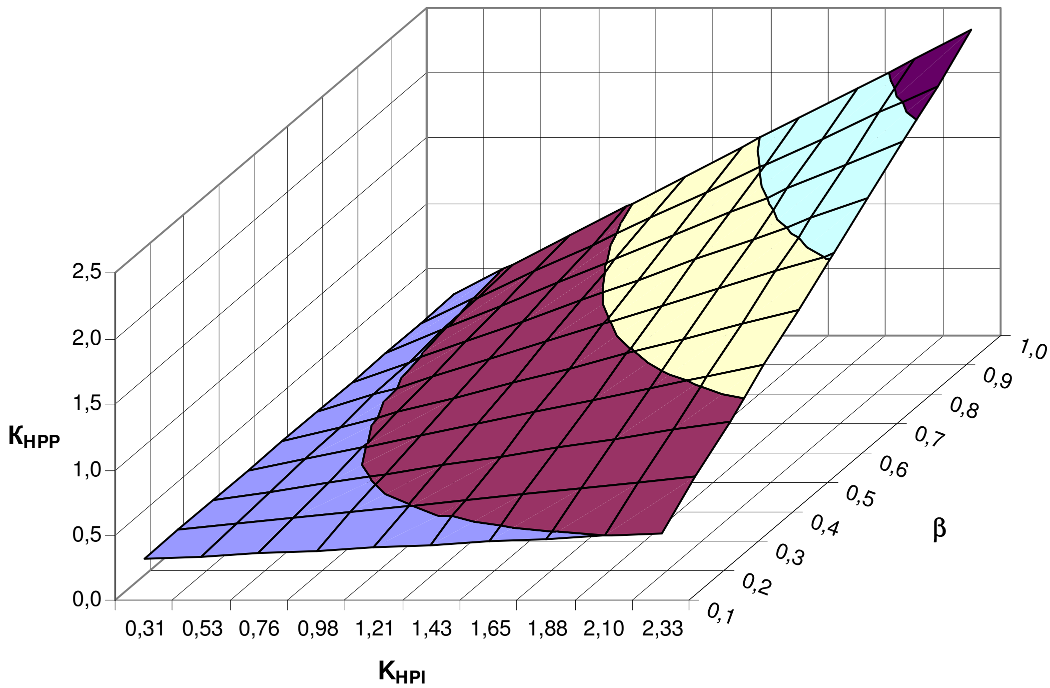

Fig. 1. Values of dimensionless criterion of energy efficiency of small power HPP with cogeneration drive, on condition of electric energy consumption by peak source of heat (electric boiler) from the energy system of Ukraine

Fig. 2 shows the values of dimensionless criterion of energy efficiency of small power HPP with cogeneration drive, on condition of electric energy consumption of peak source of heat (electric boiler) from SGI. According to [6] in the given research, the following values are taken into account: value of efficiency factor of SGI $\eta_{EPP} = \eta_{SGI} = 0.55$ and value of efficiency factor of distributive electric grids in Ukraine $\eta_{DG} = 0.875$.

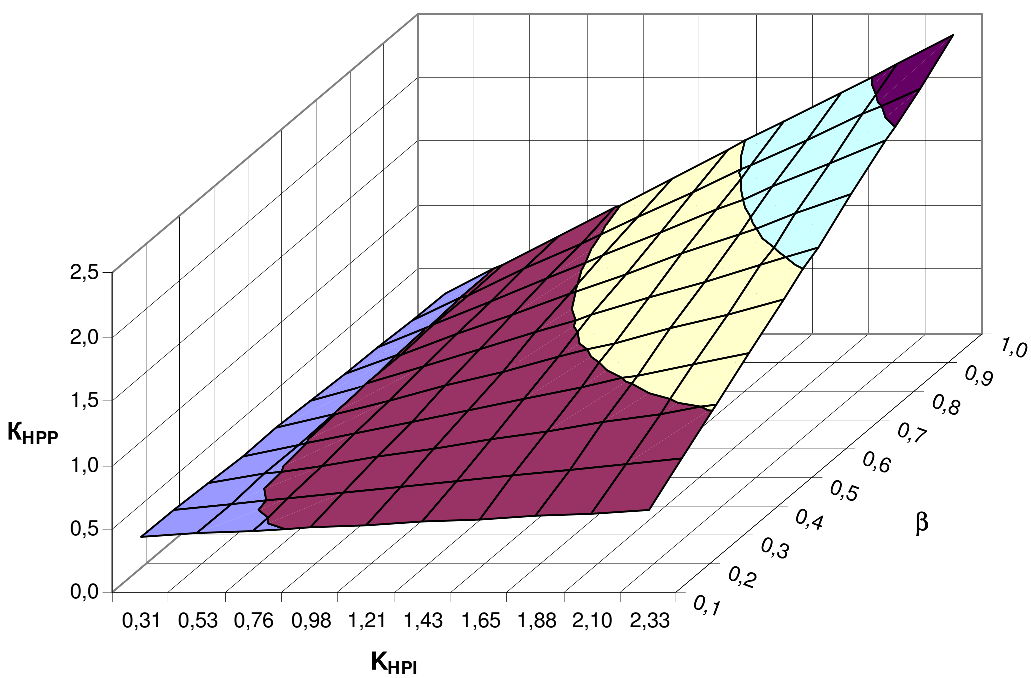

Fig. 2. Values of dimensionless criterion of energy efficiency of small power HPP with cogeneration drive, on condition

of electric energy consumption by peak source of heat (electric boiler) from SGI

Fig. 3 shows the values of dimensionless criterion of energy efficiency of small power HPP with cogeneration drive, on condition of electric energy consumption by peak source of heat (electric boiler) from cogeneration drive of HPI. In the given research, according to [6], the following values are taken into account: value of effective efficiency of small power GPE $\eta_{EGPE} = 0.35$ and the value efficiency factor of electric motor, taking into account energy losses in control unit of the motor, according to [6], η_{ED} =0.8.

Fig. 4 shows the values of dimensionless criterion of energy efficiency of small power HPP with cogeneration drive, on condition of using hot water fuel-fired boiler as HPP peak source of heat.

Fig. 5 shows the results of complex evaluation of energy efficiency of large power HPP with cogeneration drive. The values of dimensionless criterion of energy efficiency of HPP with cogeneration drive K_{HPP} are shown for the cases of variable loading of HPI within the frame of HPP with the values of HPI loading share in the range of β = .0.1…1.0. Values of dimensionless criterion of energy efficiency of steam compressor HPI with cogeneration drive K_{HPI}, according to the research [6], are determined for the values of real coefficient of performance of HPI in the range φ_r = 0.93…7,01.

Hot water fuel-fired boiler house with $\eta_{FB} = 0.85$ is provided as HPP peak source of heat for such conditions. By the formula (3), according to [6], for HPI of large levels of power with cogeneration drive, the value of total efficiency factor in the process of generation, supply and conversion of electric energy to HPI is $\eta_{EP} = 0.378$.

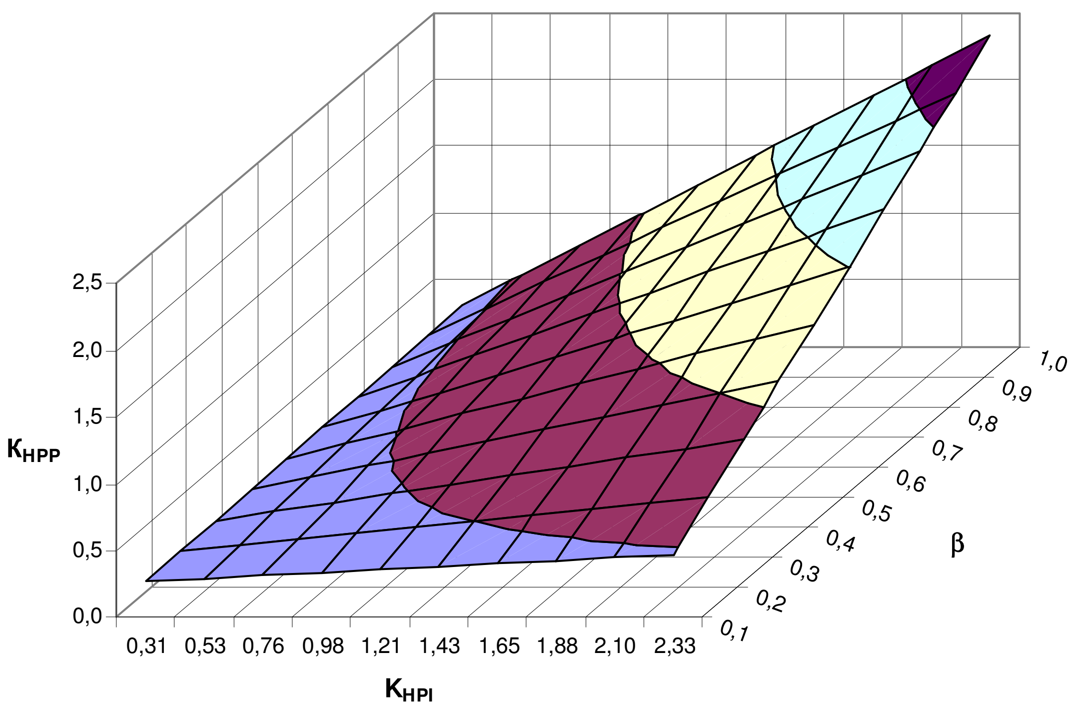

Fig. 3. Values of dimensionless criterion of energy efficiency of small power HPP with cogeneration drive, on condition of electric energy consumption by peak source of heat (electric boiler) from cogeneration drive of HPI

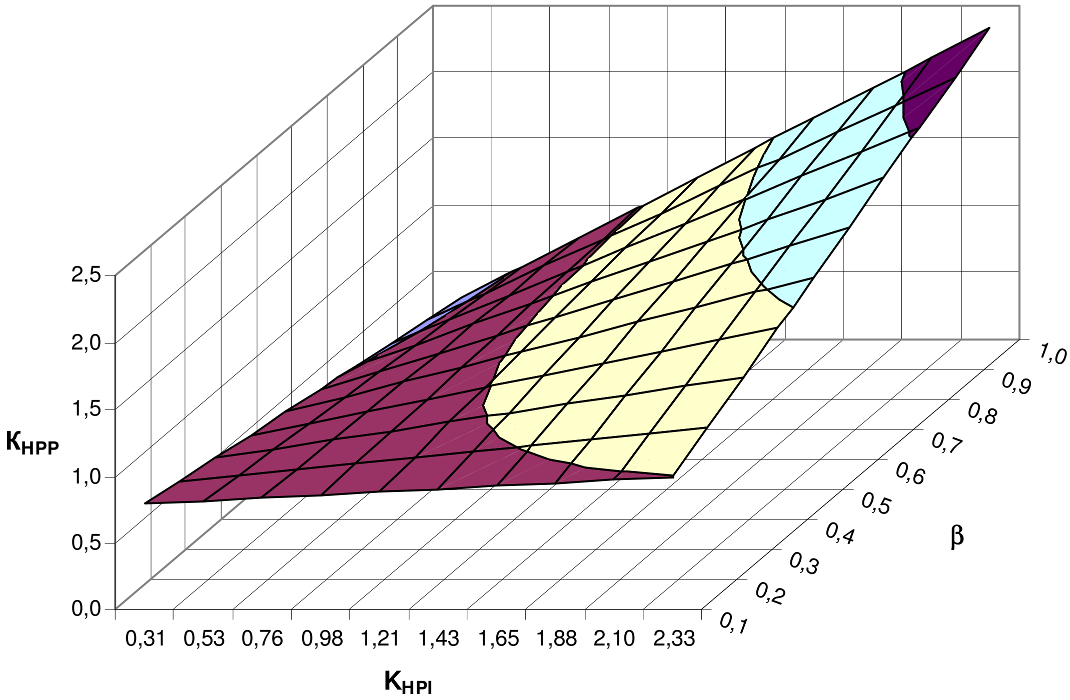

Fig. 4. Values of dimensionless criterion of energy efficiency of small power HPP with cogeneration drive, on condition of using hot water fuel-fired boiler as HPP peak source of heat

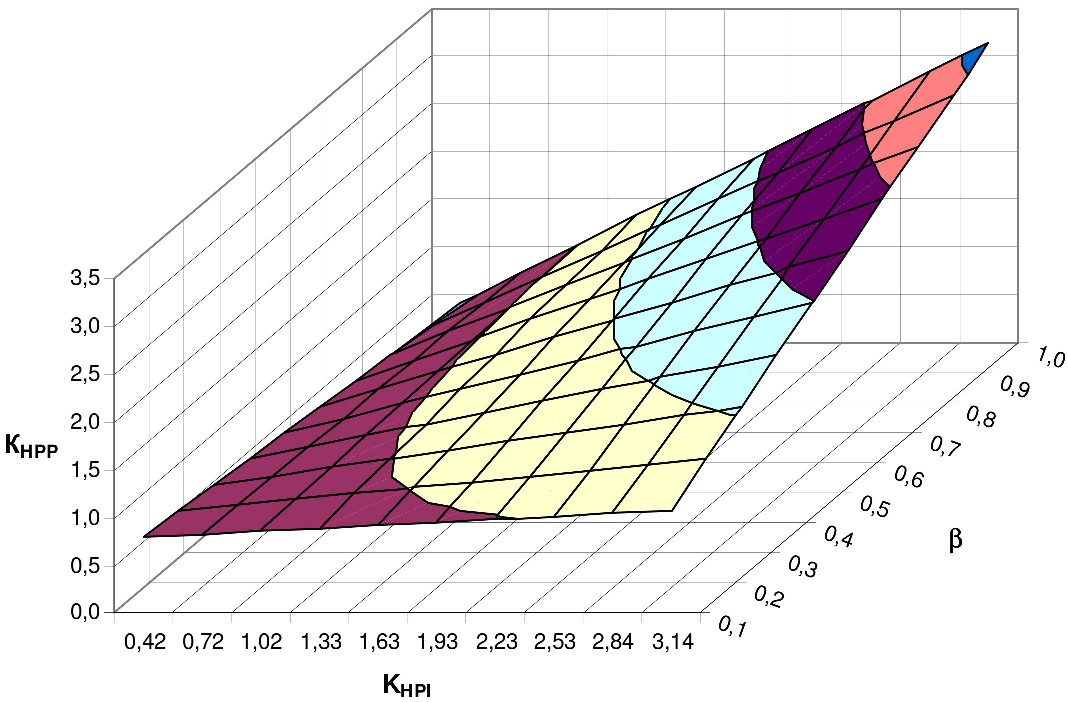

Fig. 5. Values of dimensionless criterion of energy efficiency of large power HPP with cogeneration drive, on condition of using hot water fuel-fired boiler as HPP peak source of heat

Comparing the results of research, shown in Figs. 1 – 3 and Figs. 4 – 5, the conclusions can be drawn, that usage of fuel-fired boiler as peak source of heat in cogeneration HPP has the advantages as compared with usage of peak electric boiler with different variants of electric energy sources, that is confirmed by greater values of dimensionless criterion of energy efficiency of peak source of heat within the frame of HPP K_{PSH} and dimensionless criterion of energy efficiency of HPP with cogeneration drive K_{HPP} for various operation modes of HPP operation. Proceeding from the analysis of the results of the research (Figs. 1 – 5) it was defined that for large power HPP with cogeneration drive and peak fuel-fired boiler greater values of dimensionless criterion of energy efficiency of HPP K_{HPP} are recorded for all the studied operation modes, as compared with other variants of HPP.

It is seen from Figs. 1 – 5 that for cases $K_{HPI} < K_{PSH}$ value of dimensionless criterion of energy efficiency of HPP with cogeneration drive K_{HPP} will decrease with the increase of HPI loading share β. For other cases value of dimensionless criterion of energy efficiency of HPP with cogeneration drive K_{HPP} will increase with the increase of the share of HPI load β.

Proceeding from the analysis of the results of research, carried out [10 – 12], optimal values of β index are defined for HPP on various sources of heat with different kinds of HPI compressor drive at variable operation modes of heating system.

Figs. 6 – 9 show the results of complex evaluation of energy efficiency of small power HPP with cogeneration drive for optimal values of load share of HPI β. The values of dimensionless criterion of energy efficiency of HPP with cogeneration drive K_{HPP} are shown for the cases of variable loading of HPI within the frame of HPP. The research is carried out for the cases of seasonal variable loading of HPI within the frame of HPP for optimal values of HPI load share in the range of β = 0,16…0,63 [10 – 12], that corresponds to temperature operation modes of heat supply system. Values of energy efficiency criterion of HPI with cogeneration drive K_{HPI} corresponds to the values of real coefficient of performance of HPI within the range φ_r = 0.83…6.23. Peak source of heat for HPP for these conditions are provided: electric boiler house with η_{EB} = 0.95 (Figs. 6 – 8) and hot water fuel-fired boiler house with η_{FB} = 0.85 (Fig. 9). By the formula (3), according to [6], for HPI of small power levels with cogeneration drive the value of total efficiency factor of generation, supply and conversion of electric energy to HPI is η_{EP} = 0.28.

Fig. 6 shows the values of dimensionless criterion of energy efficiency of small power HPP with cogeneration drive for optimal values of HPI load share β, on condition of electric energy consumption by peak source of heat (electric boiler) from energy system of Ukraine. In the given research, according to [6], 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.

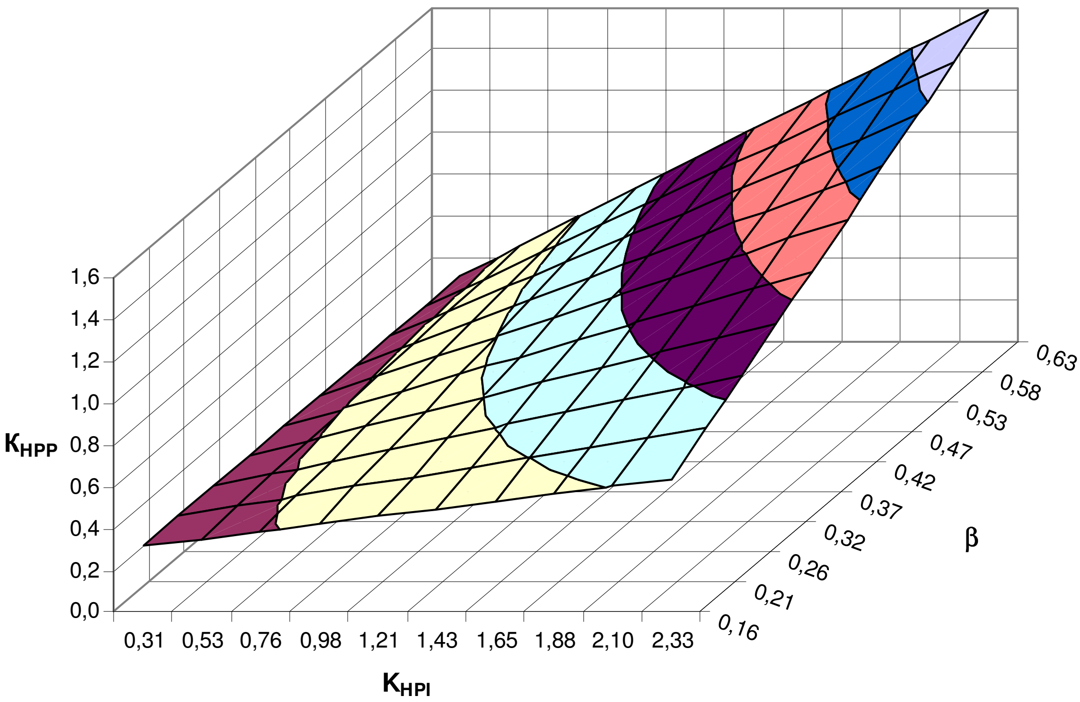

Fig. 6. Values of dimensionless criterion of energy efficiency of small power HPP with cogeneration drive for optimal values of HPI load share, on condition of electric energy consumption by peak electric boiler from the energy system of Ukraine

Fig. 7 shows the values of dimensionless criterion of energy efficiency of small power HPP with cogeneration drive for optimal values of HPI load share β, on condition of electric energy consumption by peak source of heat (electric boiler) from SGI. According to [6] in the given research, the following values are taken into account: value of efficiency factor of SGI $\eta_{EPP} = \eta_{SGI} = 0.55$ and value of efficiency factor of distributive electric grids in Ukraine $\eta_{DG} = 0.875$.

Fig. 8 shows the values of dimensionless criterion of energy efficiency of small power HPP with cogeneration drive for optimal values of HPI load share β, on condition of electric energy consumption by peak source of heat (electric boiler) from cogeneration drive of HPI. In the given research, according to [6], the following values are taken into account: value of effective efficiency factor of small power GPE $\eta_{EGPE} = 0.35$ and the value efficiency factor of electric motor, taking into account energy losses in control unit of the motor, according to [6], $\eta_{ED} = 0.8$.

Fig. 9 shows the values of dimensionless criterion of energy efficiency of small power HPP with cogeneration drive for optimal values of HPI load share β, on condition of usage hot water fuel-fired boiler as HPP peak source of heat.

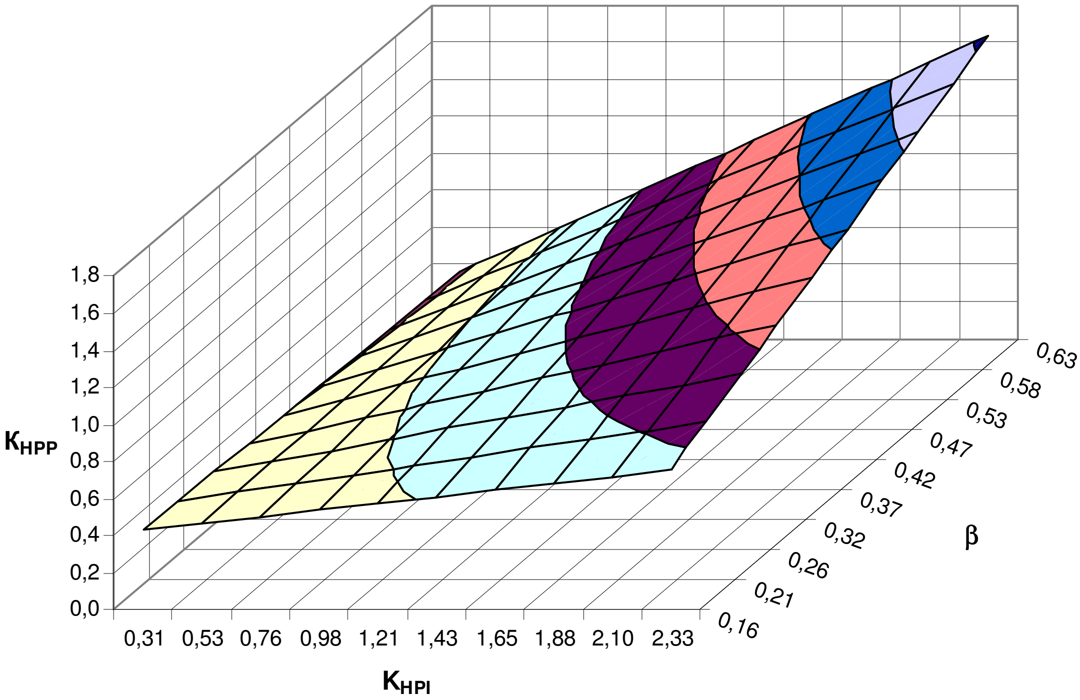

Fig. 7. Values of dimensionless criterion of energy efficiency of small power HPP with cogeneration drive for optimal values of HPI load share, on condition of electric energy consumption by peak electric boiler from SGI

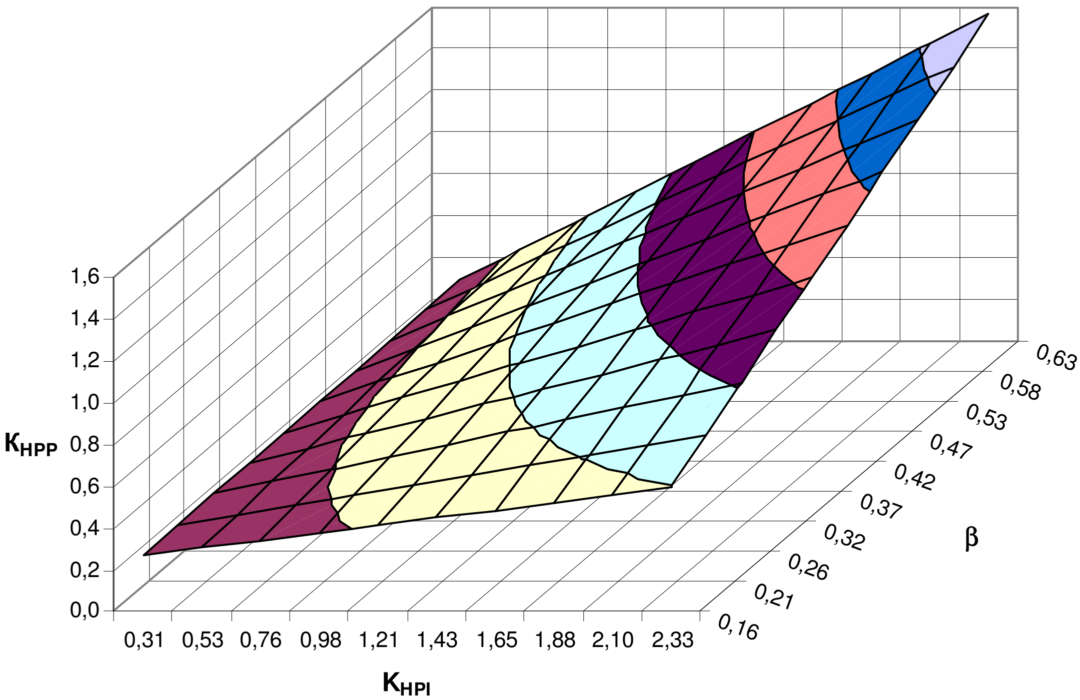

Fig. 8. Values of dimensionless criterion of energy efficiency of small power HPP with cogeneration drive for optimal values of HPI load share, on condition of electric energy consumption by peak electric boiler from cogeneration drive of HPI

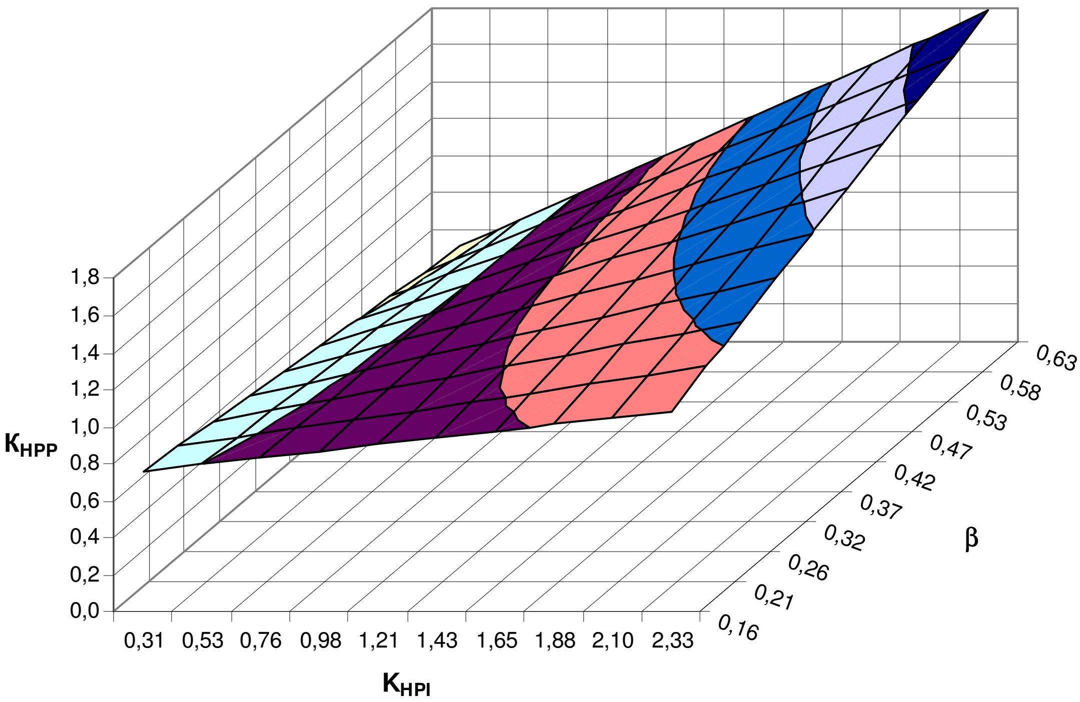

Fig. 9. Values of dimensionless criterion of energy efficiency of small power HPP with cogeneration drive for optimal values of HPI load share, on condition of usage hot water fuel-fired boiler as HPP peak source of heat

Figs. 10 shows the results of complex evaluation of energy efficiency of large power HPP with cogeneration drive for optimal values of HPI β load share. The values of dimensionless criterion of energy efficiency of HPP with cogeneration drive K_{HPP} are shown for the cases of seasonal variable loading of HPI within the frame of HPP for optimal values of HPI load share in the range of β = 0.16…0.63 [10 – 12], that corresponds to temperature operation modes of heat supply system.

According to the research [6], in this case, the values of energy efficiency criterion of HPI with cogeneration drive K_{HPI} corresponds to the values of real coefficient of performance of HPI in the range of φ_r = 0.93…7.01. Peak source of heat for HPP in these conditions will be hot water fuel-fired boiler house with η_{FB} = 0.85. By the formula (3), according to [6], for HPI of large power levels with cogeneration drive the value of total efficiency factor of generation, supply and conversion of electric energy to HPI is η_{EP} = 0.378.

Proceeding from the analysis of the results of the research (Figs. 6 – 10) it was determined, that in case of optimal operation modes, for large power HPP with cogeneration drive and peak fuel-fired boiler, greater values of dimensionless criterion of energy efficiency of HPP K_{HPP} are recorded, as compared with other investigated variants of HPP.

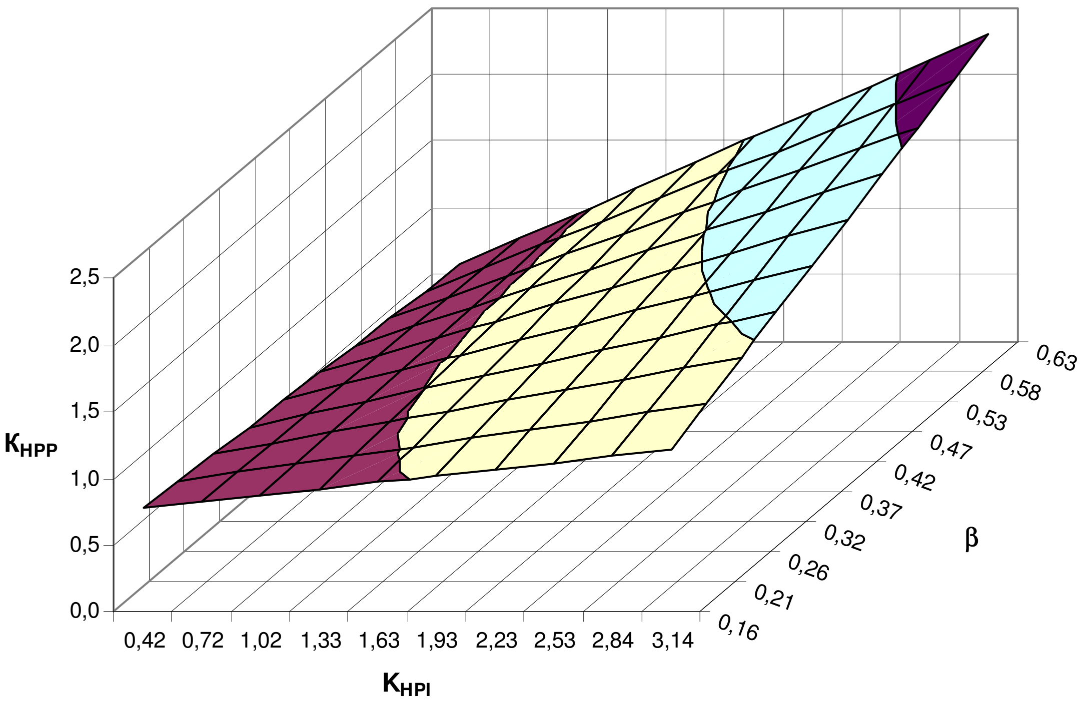

Fig. 10 – Values of dimensionless criterion of energy efficiency of large power HPP with cogeneration drive for optimal values of HPI load share, on condition of usage hot water fuel-fired boiler as HPP peak source of heat

To carry out complex evaluation of energy efficiency of different variants of HPP with cogeneration drive, besides the above-mentioned approaches, we propose to use the results of researches [6 – 12].

Conclusions

The approach, aimed at complex evaluation of energy efficiency of steam compressor heat pump plants with cogeneration drive, taking into account complex impact of variable operation modes of HPP, peak sources of heat for HPP, sources of drive energy for HPP of various levels of power, taking into consideration energy losses in the process of generation, supply and conversion of electric energy, is suggested.

Methodical fundamentals have been developed, complex evaluation of energy efficiency of steam compressor HPP with cogeneration drive, taking into account complex impact of variable operation modes of HPP, peak sources of heat of HPP, general drive energy of steam compressor HPP of various levels of power, taking into account energy losses in the process of generation, supply and conversion of electric energy, has been carried out.

The suggested complex approach aimed at evaluation of energy efficiency of steam compressor HPP with cogeneration drive has a number of advantages:

— it allows to evaluate complex impact of variable operation modes of HPP, peak sources of heat of HPP, sources of drive energy of steam compressor HPP with cogeneration drive, taking into account losses of energy in the process of generation, supply and conversion of electric energy;

— takes into consideration operation modes of steam compressor HPI;

— takes into consideration variable operation modes of HPP for heat supply during the year with the change of load distribution between steam compressor HPI and HPP peak source of heat;

— takes into consideration the impact of drive energy sources of steam compressor HPPof various levels of power, taking into account energy losses in the process of generation, supply and conversion of electric energy to HPP;

— takes into considerations energy efficiency of steam compressor HPP of various levels of power with cogeneration drive;

— takes into consideration the impact of peak sources of heat of steam compressor HPP and kind of the energy, consumed by them, taking into consideration 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 energy efficiency of HPP with the cogeneration drive, the choice of the most efficient peak source of heat for certain type of steam compressor HPP can be made;

— the suggested methodical fundamentals may be used for evaluation of energy efficiency of steam compressor HPP with various refrigerants and scheme solutions of HPI;

— it allows to evaluate in a complex manner energy efficiency of numerous variants of steam compressor HPP with cogeneration drive.

To carry out complex evaluation of energy efficiency of different variants of HPP with cogeneration drive, besides the above-mentioned approaches, we propose to use the results of researches [6-12].

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