ADVANCED TECHNOLOGIES AND POWER INSTALLATIONS FOR THERMAL AND ELECTRIC ENERGY GENERATION

6.3. Heat and power supply units of low capacity

6.3.6. Estimation of thermal efficiency of small CHPPs

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Total annual fuel saving can be used as criterion of thermal efficiency. Annual fuel saving is estimated as a difference between total annual reference fuel consumption for combined thermal and electric power supply within a year from power units, installed in boiler-houses, and annual fuel consumption for separate supply of the same quantity of thermal and electric power. The economy results from replacement in a power system of condensing capacities with generation of electric power, based on thermal power supply:

$$\Delta B_s^{an} = B_{el.s}^{an} + B_{th.s}^{an} + B_c^{an}, \qquad (6.13)$$

where $B_{el.s}^{an}$ is annual consumption of reference fuel for electric power supply at separate electric and thermal power generation, t.r.f a year (tons of reference fuel a year)

$$B_{el.s}^{an} = E_r \cdot b_{rcpp}^{av}; \qquad (6.14)$$

E_r — annual electric power supply from a replacing condensing power plant (rcpp), kW/year;
b_{rcpp}^{av} — average specific consumption of conditional fuel for electric power supply from a condensing power plant [b_{rcpp}^{av} = = 0,355 kg/(kW·h)], is accepted based on statistics; $B_{th.s}^{an}$ — annual reference fuel consumption for thermal power supply from a boiler-house equal to thermal load of hot water supply Q_{hws}, from turbines, installed in a boiler-house,

$$B_{th.s}^{an} = Q_{hws} \cdot b_{th}^{av}; \qquad (6.15)$$

b_{th}^{av} — average specific equivalent fuel consumption for thermal power supply from a boiler-house [b_{th}^{av}=165 kg/(Gcal·h)], accepted on the basis of data provided in [1]; B_c^{an} — annual fuel consumption by electric power generating equipment of a boiler-house, t.r.f.

Total electric power supply from electricity generating equipment is estimated as a sum of electric power, supplied for each zone of characteristic load diagram for the heating period $Э_r^h$ and non-heating period $Э_r^{nh}$. For a non-heating period the calculation is performed for each zone of the diagram according to the characteristic day load diagrams and equipment characteristics:

$$Э_r = Э_r^h + Э_r^{nh}, \qquad (6.16)$$

Electric power supply for the heating system

$$Э_r^h = \sum_1^{\tau_{I-IV}} (N_i - N_{aux\,i}) \tau_{I-IV}, \qquad (6.17)$$

where N_i, $N_{aux\,i}$—capacity at generator outlet and capacity of auxiliary machines in a heating period, accordingly; $\tau_{I—IV}$ — duration of a heating period, h.

Electric power supply for the non-heating period

$$Э_r^{nh} = \sum_1^{n_{V+VI}} E_{V+VI} \cdot n_{V+VI}, \qquad (6.18)$$

Where E_{V+VI} —electric power supply during a day of a non-heating period; n_{V+VI} — quantity of days in a non-heating period.

Electric power during any day of the non-heating period

$$E_i = \int_0^T (N_i - N_{aux\,i}) dt, \qquad (6.19)$$

where N_t — capacity change at generator outlet in each moment [function of capacity change during a day is calculated based on turbine characteristics, depending on load diagrams (ref. Fig. 6.14)]; $N_{aux\,i}$— change in auxiliary capacity in every moment of a day; t — time of a day; T — duration of a day.

Thermal power supply is calculated similarly.

On the basis of the technique, described above, estimation of efficiency of electric and thermal power generation installations has been conducted. It was accepted for the calculation that installations are in operation during 8390 hours per year. The rest of the time is spent for maintenance of equipment and switching-off heating mains. Conditionally it was accepted that all these works are performed during the season VI when the daily average temperature reaches +18°C. As a result the season VI is reduced to τ = 2016 h. All calculations have been carried out for GT of NK-37 type and a steam turbine PR-6-34/1,0/0,1-1. Two cases are considered:

units are installed, using a principle of provision of total mid-annual load of hot water supply;

units are installed, using a principle of provision of calculated hot water load.

Results of the calculations are shown in Tabs. 6.22 and 6.23.

Analysis of estimation results, presented in Tabs. 6.22 and 6.23, shows that installation in a boiler-house of the power generating equipment, working on the combined cycle within a year, gives an essential fuel saving in a power system. Fuel saving is determined as reduction of its consumption for generation and supply of electric power.

Therefore, significant fuel saving is reached when considerable electric power generation at thermal supply is provided. Fuel saving at identical thermal supply is directly proportional to the factor of electric power generation at thermal consumption and to overall performance of the generating unit.

Estimation results, presented in Tab. 6.22, show that annual fuel saving, referred to thermal supply unit for a gas turbine NK-37, installed in a boiler-house is 3 times higher, than for a steam turbine PT-6-3,4/1,0/0,1-1. It is explained by the fact that electric power generation at thermal supply of the given gas turbine is 3 times higher, than of the non-condensing turbine.

At the same time, efficiency of utilization of fuel heat is higher for non-condensing turbines than for gas turbines.

The estimation of build-up options, using thermal efficiency is not definite. For a choice of an optimum alternative, technical and economic calculations are required which would consider all factors. In particular, service life of a gas turbine is, as a rule, equal or less than 100 000 hours and for aeroderivative gas turbines is even less— 40 000 hours, while steam turbines with initial parameters $p_0 \leq 3,5$ MPa and $t_0 \leq 440$ °C can serve above 300 000 hours.

Table 6.22. **Calculation of annual fuel saving when installing electric generating equipment in boiler-houses based on provision of average annual hot water supply load**

Characteristics	PT-6-3,4/1,0/0,1-1	GT-NK-37
Electric power supply in season periods, MW·h:		
I	949,4	5160,0
II	4046,2	21990,0
III	11746,6	60222,4
IV	10361,0	49928,2
V	5753,36	20620,2
VI	7933,2	27048,6
Thermal power supply in season periods, MW:		
I	4532,2	5650,2
II	19314,5	25068,6
III	56072,8	74160,8
IV	49458,9	66455,8
V	25973,4	35253,4
VI	35822,4	48615,6
Electric power supply during 1 day of a non-heating period, MW·h:		
V	89,34/107,2	310,85/408,4
VI	89,34/107,2	295,05/389,2
Thermal power supply during 1 day of a non-heating period, MW:		
V	388,48/493,9	544,9/663,4
VI	399,48/493/9	544,9/663,4
Annual electric power supply, MW·h	40789,7	184969,4
Annual thermal power supply, MW	191174,2	255194,4
Total annual consumption of reference fuel by electric power generating units, t/year	32828,9	67463,0
Total annual consumption of reference fuel for electric power supply from a replacing condensing thermal power plant, t/year	14480,3	65664,0
Total annual consumption of reference fuel for thermal power supply from a replacing boiler-house, t/year	27122,7	36205,57
Annual equivalent fuel saving, t	8774,1	34406,0
Coefficient of fuel heat utilization	0,868	0,801

Analysis of estimation results, presented in Tab. 6.14, shows possibility of growth of electric power generation in a boiler-house, up to increase in thermal supply from steam turbines up to the calculated level of hot water supply. In climatic zones of the North and the central European part of Russia such increase is possible, as during all heating period the full load of equipment is provided. Only in a summer, non-heating period part of equipment needs to be removed into a stand-by mode because it is impossible to provide loading of all power generating equipment in a co-generation cycle. Application of such equipment in an independent mode, for example, gas turbines is economically inexpedient.

Withdrawal of part of equipment into a stand-by mode for the whole non-heating period allows to keep thermal efficiency indicators at a high level and provide significant fuel saving.

Table 6.23. **Estimation of annual fuel saving in case of installation of electric power generating equipment on the basis of provision of total calculated hot water supply load**

Characteristics	2xPT-6-3,4/1,0/0,1-1	2xGT-NK-37
Electric power supply in season periods, MW·h:		
I	1898,8	10320,0
II	8092,4	43980,0
III	23493,2	120448,8
IV	20722,0	99856,4
V	5753,36	20620,2
VI	7933,2	27048,6
Thermal power supply in season periods, MW:		
I	9064,4	11300,4
II	38629,0	50137,2
III	112145,6	148321,6
IV	98917,8	132911,6
V	25973,4	35253,4
VI	35822,4	48615,6
Electric power supply during 1 day of a non-heating period, MW·h:		
V	89,34/107,2	310,85/408,4
VI	89,34/107,2	295,05/389,2
Thermal power supply during 1 day of a non-heating period, MW:		
V	388,48/493,9	544,9/663,4
VI	399,48/493,9	544,9/663,4
Annual electric power supply, MW·h	67892,96	322274
Annual thermal power supply, MW	320552,6	426539,8
Total annual consumption of reference fuel by electric power generating units, t/year	54831,18	114604,2
Total annual consumption of reference fuel for electric power supply from a replacing condensing thermal power plant, t/year	24102,0	114407,27
Total annual consumption of reference fuel for thermal power supply from a replacing boiler-house, t/year	52891,18	70379,07
Annual equivalent fuel saving, t	22162	70182,14
Coefficient of fuel heat utilization	0,8702	0,8011

To calculate an average fuel saving for Russia, estimation of possible scales of installation of various types of steam and gas turbines as boiler-houses build-up has been performed. The installation was assumed only for a hot water supply load. Results of the estimations are presented in Tab. 6.24.

Analysis of the estimation results shows that it is possible to install electric capacities N_{el} = 14,26 thousands MW at the existing boiler-houses, based on steam turbines. Installation of gas turbines in small boiler-houses is complicated, therefore, possibility of installing gas turbines was considered only for boiler-houses with a capacity above 50 MW. Total installed capacity of gas turbines in that case can make N_{GT} = 24,7 thousand MW.

And the maximum possible installed capacity of steam and gas turbines for the whole Russia will make N^{tot} = 28,6 thous. MW. As a result, installation of electric power generating equipment in boiler-houses yields fuel saving due to replacement of electric power generation at condensing power plants, equipped with steam turbines. Results of calculations are shown in Tab. 6.25.

Thus, installation of steam turbines in boiler-houses for generation of electric power on hot water supply loading yields reference fuel saving ΔB_{ST} = 17,422 million t/year or in conversion to gas fuel ΔB^{gas}_{ST} = 15,245 billion m^3/year.

At installation of gas turbines this economy increases, as generation of electric power increases on the same loading of hot water supply. In this case the total economy of reference fuel will make ΔB_{GT} = 33,991 million t/year in conversion to gas fuel ΔB^{gas}_{GT} = 29,742 billion m^3/year.

Combination of steam and gas turbines yields more complete use of hot water supply loading. In this case the total reference fuel saving will make ΔB_{tot} = 36,271 million t/year or in conversion to gas fuel ΔB^{gas}_{total} = 31,737 billion m^3/year.

Table 6.24. **Estimation of possible scale of electric power generating equipment in boiler-houses**

Boiler-house type	Installed capacity, thous. MW	Capacities, suitable for build-up, thous. MW	Capacity, thous. MW	
			Steam turbines	Gas turbines
Centralized heat supply	85	85	4,28	10,2
Decentralized heat supply, capacity higher than 50 MW	121,6	121,6	6,08	14,5
Decentralized heat supply, capacity less than 50 MW	236,7	118,9	3,9	-
In total	443,3	325,5	14,26	24,7

Table 6.25. **Generation of electric power and fuel saving by electric power generating equipment, installed in boiler-houses**

Turbine type	Electric power generation at the installed capacity $Э_г$, billion kW·h/year	Fuel saving, mln t.r.f./year
Steam turbines (N_{rat} = 14,26 thous. MW)	81,0355	17,422
Gas turbines (N_{rat} = 24,7 thous. MW)	182,7479	33,991
Gas turbines and steam turbines N_{rat}^{tot}= 28,6 thous. MW)	193,3532	36,271