Method of calculating the critical share of combined power generation at CHPP

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Annotation. The paper presents analysis of the value of absolute fuel saving due to combined heat and power generation as illustrated by the regional power supply system based on the steam turbine combined heat and power plants (CHPP) of the Volga region. It is established that the most part of the plants operate with negative fuel saving from cogeneration (heat extraction) due to high physical deterioration of the equipment, low initial steam parameters at certain CHPPs, low load of the turbine heat extractions, and large condensation power generation. Positive fuel saving can be obtained if the actual share of heat-extraction power generation (cogeneration) exceeds its critical value. The authors offer a method of determining the critical value of combined generation share depending on the total amount of electric power generated by CHPP. The paper contains calculations for determining the critical share of combined power generation for turbines T-55-130, T-110-130 and T-250-240. The method offered can be used when planning the load of CHPP turbines for ensuring the positive value of fuel saving due to combined heat and power generation at CHPPs.

In RF, thermal energy is supplied to the industrial and public utility consumers mainly by large CHPPs and boiler houses of different capacity [1]. The share of combined heat generation at CHPP amounts to 37% [2].

During the last 15–20 years due to decrease of steam demand of enterprises, aging of the equipment, high losses of heat in heating networks, and overrated thermal energy tariffs, a tendency of reduction of heat supply from CHPPs and construction of small-size boiler houses is observed. As a result, many regional CHPPs need to be operated with high condensation capacity, which results in reduction of the fuel saving achieved due to combined heat and power generation. Yet, fuel saving when generating heat and power is the most important national economic task specified by Federal Law No. 261 “On Energy Saving and Increasing Energy Efficiency” and Federal Law No. 190 “On Heat Supply”.

The value of absolute fuel saving can be determined by the difference of fuel consumption in a divided power layout (condensation thermal power plant (TPP) + boiler house) using the expression [3], kg of conventional fuel's:

\[ \Delta B_{fc} = N_{comb} \cdot (b_{TPP} \cdot \eta_{pp} - b_{heat,ex} \cdot \eta_{hnetw}) - N_{cond} \cdot (b_{cond} \cdot \eta_{pp} + Q_{ext} \cdot b_{boiler} - b_{heat} \cdot \eta_{hnetw}) \]  \tag{1}

where \( N_{comb}, N_{cond} \) – electric power generated in combined and condensation mode at CHPP, kW; \( b_{TPP}, b_{boiler} \) – specific fuel consumption for electric power output from TPP and local boiler houses, kg of conv. fuel/kWh, kg of conv. fuel/GJ; \( b_{heat,ex}, b_{cond}, b_{heat} \) – specific fuel consumption for output of electric power in heat-extraction (cogeneration) and condensation mode and heat from CHPP, kg of...
conv. fuel/kWh, kg of conv. fuel/GJ; \( \eta_{pp}, \eta_{hu \text{netw}} \) – efficiency of transport of electric power from TPP and CHPP heat networks; \( Q_{\text{ext}} \) – heat send out from CHPP turbine extraction, kW.

The relative fuel saving is determined by the expression, %:

\[
\Delta B_{\text{rel}} = \Delta B_{\text{ec}} \cdot 100/(B_{\text{CHPP}} + B_{\text{boiler}}).
\]

By the example of the regional power supply system consisting of six CHPPs located in the Volga region, the authors of paper [4] using the expressions (1) and (2) made annual calculations of \( \Delta B_{\text{ec}} \) and \( \Delta B_{\text{rel}} \) shown in Table 1.

**Table 1. Absolute and relative fuel saving due to combined heat and power generation at CHPP.**

| Index and unit of measurement | CHPP-1 | CHPP-2 | CHPP-3 | CHPP-4 | CHPP-5 | CHPP-6 |
|-------------------------------|--------|--------|--------|--------|--------|--------|
| Absolute fuel saving, mln of kg of conventional fuel/year | -3.6  | -62.5  | 22.6   | -43.3  | 110.1  | 6.4    |
| Relative fuel saving, %       | -6.6  | -13.4  | 8.6    | -9.7   | 13.5   | 3.0    |

As shown in table 1, certain CHPPs have negative fuel saving. The main reasons of the negative fuel saving are as follows:

- high physical depreciation of the equipment and resulting reduction of the equipment efficiency;
- low initial steam parameters at CHPP-1, CHPP-2;
- low thermal energy output load (use factor of the specified thermal capacity is 0.12-0.24);
- large condensation power generation.

For ensuring positive fuel saving due to combined heat and power generation, it is necessary to determine the critical value of share of heat-extraction power generation (cogeneration) when zero fuel saving is achieved.

The critical value of share of heat-extraction power generation (cogeneration) depending on the initial steam parameters was determined by professor Ye. Ya. Sokolov in [3]. The calculations were made upon condition that CHPP is operated according to the heat load curve. However, recently CHPPs have been widely involved in adjusting electric load curve with condensation power output that influences the amount of fuel saving due to heat extraction (cogeneration). In certain cases as shown in Table 1, such operation leads to the negative result. The present paper is aimed at developing the method of determining the critical value of combined generation share depending on the total amount of electric power generated by CHPP.

The share of power generation in the heat-extraction mode can be presented as

\[
\varphi = \frac{N_{\text{cond}}}{N},
\]

where \( N \) – total CHPP power load determined as the sum of \( N_{\text{comb}} \) and \( N_{\text{cond}} \), kW.

Fuel consumption in the divided power layout, kg of conv. fuel/s

\[
B = (N/Q_d \eta_{pp})\eta_{pp} + (Q_{\text{ext}}/Q_d \eta_{boiler}),
\]

where \( Q_d \) – combustion value of conventional fuel, kJ/kg; \( \eta_{pp} \) – CHPP efficiency on electric power output; \( \eta_{boiler} \) – boiler house efficiency on heat output.

Fuel consumption in the combined power layout (at CHPP without consideration of a peak-load boiler), kg of conv. fuel/s

\[
B_{\text{chpp}} = ((N_{\text{comb}} + Q_{\text{ext}})/Q_d \eta_{hu \text{netw}}) + (N_{\text{cond}}/Q_d \eta_{\text{cond}}),
\]

where \( \eta_{hu} \) – factor of effective use of fuel heat in a combined cycle; \( \eta_{\text{cond}} \) – efficiency on electric power output in a condensation cycle at CHPP.

The difference of fuel consumption in the divided and combined power layouts determines the value of absolute fuel saving, kg of conv. fuel/s:

\[
\Delta B_{\text{ec}} = B_{\text{di}} - B_{\text{chpp}}.
\]

The critical share of combined power generation is determined by the condition \( \Delta B_{\text{ec}} = 0 \). Then, inserting (4) and (5) into (6), we obtain
\[ \phi N \left( \frac{1}{\eta_{\text{cond}}} - \frac{1}{\eta_{\text{hu}} \eta_{\text{hnetw}}} \right) - N_{\text{cond}} \left( \frac{1}{\eta_{\text{cond}}} - \frac{1}{\eta_{\text{pp}} \eta_{\text{p}}} \right) + Q_{\text{extr}} \left( \frac{1}{\eta_{\text{boiler}}} - \frac{1}{\eta_{\text{hu}} \eta_{\text{hnetw}}} \right) = 0. \]  

(7)

Taking into account the expression (3) and following transformations, we have

\[ \phi_{cr} = \left( \frac{1}{\eta_{\text{cond}}} - \frac{1}{\eta_{\text{pp}} \eta_{\text{p}}} \right) - \frac{1}{\eta_{\text{boiler}}} \left( \frac{1}{\eta_{\text{hu}} \eta_{\text{hnetw}}} \right) \]  

(8)

where \( Y = \frac{N}{Q_{\text{extr}}} \) – factor equal to the ratio of electric power to heat sent out from the turbine extractions to consumers.

The obtained expression can be used for determining \( \phi_{cr} \) both for certain modes and in the annual period.

The numerical value of \( Y \) factor can be changed within 0.5 – 1.8. The lesser value is determined by the specific power generation with turbine heat consumption, and the larger one – depending on the ratio of electric power to heat send out from the turbine extractions.

Using the expression (8), the critical share of combined power generation was calculated for turbines T-55-130, T-110-130 and T-250-240. Depending on the combined power generation share, electrical efficiency of the turbine condensation capacity changes. The values of electrical efficiency of the condensation steam flow are determined based on the calculations of CHPP layouts with the specified turbine types and are given in Table 2. The value of the factor of fuel energy effective use in the heat extraction (cogen) mode varies within 0.89 – 0.92. The remaining data included in the expression (8) are taken as follows: \( \eta_{\text{pp}} = 0.4; \eta_{\text{p}} = 0.9; \eta_{\text{boiler}} = 0.92; \eta_{\text{hnetw}} = 0.85 \). The results of calculations are shown on figure 1.

### Table 2. Electric efficiency of condensation power generation of CHPP turbines.

| Mark of turbine | Share of heat extraction power generation (cogeneration) |
|----------------|-------------------------------------------------------|
|                | 0.2         | 0.4         | 0.6         | 0.8         |
| T-55-130       | 0.315       | 0.311       | 0.303       | 0.270       |
| T-110-130      | 0.320       | 0.318       | 0.311       | 0.290       |
| T-250-240      | 0.365       | 0.363       | 0.356       | 0.328       |

![Figure 1. Influence of Y factor on the critical share of combined power generation at CHPP.](image)
As shown on figure 1, the critical share of combined power generation is reduced with growth of Y factor. The higher the efficiency of the condensation power generation, the lesser $\phi_{cr}$. Therefore, for adjusting the electric load curve, cogeneration (heat extraction) plants with the highest $\eta_{\text{cond}}$ shall be involved first.

When planning heat and power generation load of the CHPP turbines, the actual value of the combined power generation share $\phi$ shall exceed the critical value $\phi_{cr}$ to ensure the positive fuel saving due to cogeneration (heat extraction). In the CHPP operating conditions the values Y and $\eta_{\text{cond}}$ are estimated based on the preliminary turbine load and data on the condensation steam flow efficiency.

Conclusions
1. The method of calculating the critical share of combined power generation of CHPP turbines is offered, which takes into account electrical load, heat send out from turbine extraction, condensation steam flow efficiency, and indices of energy efficiency of the divided power layout.
2. The method can be used when planning the load of CHPP turbines for ensuring the positive value of fuel saving due to combined heat and power generation at CHPPs.

References
[1] Orlov M Ye and Sharapov V I 2014 Improvement of Structure and Operation Techniques of the City CHPPs and Cogeneration Systems (Ulyanovsk, UISTU) p 352
[2] Rotov P V and Sharapov V I 2013 Adjustment of Load of the City Cogeneration Systems (Ulyanovsk: UISTU) p 309
[3] Sokolov Ye Ya 2001 Cogeneration and Heat Networks: Textbook for Higher Education (Moscow: MPEI Publ) p 472
[4] Nikolayev Yu Ye and Vdovenko I A 2018 Heat Supply News 3 18–21