Investigation of the regulatory range expansion at Krasnodar combined heat and power plant due to the partial displacement of regenerative extractions of the K-150-130 unit by steam from the backpressure turbine

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Abstract. The article describes a new way to increase the technical maximum load of Krasnodar CHPP. It involves the joint operation of block part turbo generators and additionally installed backpressure turbine with the displacement of steam extraction to high pressure regenerative heaters. We provided a detailed overview of the power plant equipment. We calculated the effectiveness of joint operation and shutdown of the high pressure feed water heater (HPFH) 1, 2. It showed that when implementing the proposed technical solution, the power increase in the technical maximum mode for each unit amounted to 7.8 MW. The total increase in the power plant is 43.6 MW. The joint operation scheme allows to increase the technical maximum of the power plant with higher energy efficiency: the specific consumption of reference fuel for electricity generation is 4 g r.f./kW*h, lower than when the HPFH 1, 2 is turned off. The economic effect of the applied solution was estimated for Krasnodar CHPP conditions. It was shown that the annual increase in net profit amounted to 33.7 million rubles, and the payback period of investments is 4.7 years.

1. Introduction
Krasnodar CHPP is a classic urban heat and power plant and the most powerful generating facility in the operating zone of the Kuban Regional Dispatching Office. In different years it had all kinds of equipment: from low-power steam-powered plants of non-block layout, that worked on coal, to one of the most modern combined-cycle plants with an electric efficiency of 58%. According to the satellite image of the Krasnodar CHPP (figure 1), one can trace the development trends of thermal power plants from the mid 20th century to the present day.

The construction of the Krasnodar CHPP took place in several stages. New equipment introduction: non-block part 1954-1961, block part 1962-1966, gas turbine units 1971-1976, CCP-410 October 8, 2011. The first of them is the non-block part or boiler-turbine workshop No. 1 (boiler-turbine shop BTS -1) - worked on steam parameters 90AA and 540 °C. It had cross connections in steam and water and consisted of 6 steam boilers with a total load of 1180 t/h and five turbine units with a total Sest.= 159 MW. Today turbines and some boilers are decommissioned. Two steam boiler units TP-15 remained in operation, using natural gas as the main fuel.
The block part was originally equipped with four K-150-130 units of the Kharkov Turbogenerator Plant with gas-oil boiler units TGM-94. The turbines are designed to operate with the following steam parameters: superheated steam in front of the shut-off valve P = 130 AA, t = 540 ° C; steam after overheating (before shut-off valves) P = 27.5 AA; t = 540 ° C; calculation vacuum 0.035 AA (26.5 ° C according to the vacuum recorder). Later, three turbine units were equipped with adjustable selection for heating and received the marking T-145 / 160-130. The regeneration system has also undergone a number of changes. The second selection was shut down, and the high-pressure feedwater heater No. 2 (HPFH 2) was switched to reduced steam from the first extraction. As we have already mentioned, they organized extraction for heating network water, namely by steam with a pressure of 4.6 at for peak boilers (PB) and 1.45 at for the main boiler (MB). The seventh selection is shut down, and its chamber is combined with the chamber of the sixth one, where the low-pressure heater No. 2 (LPH 2) is transferred. Besides, the distinction of this turbine unit is the use of a pair of different parameters for the deaerator (D) to operate. At a flow rate of fresh steam up to 400 t / h, steam is taken from the third extraction, when it comes to more than 400 t / h the steam is selected from the fourth one. The parameters of regenerative sampling at an electric load of 150 MW are given in table 1.

**Table 1. Characteristics of regenerative turbine extraction.**

| №  | Extraction place                      | P (AA) | t (°C) | Purpose               |
|----|--------------------------------------|--------|--------|-----------------------|
| 1  | After the 7th stage of the HP part    | 32.5   | 375    | HPFH 3                |
|    |                                       | 22.5   | 375    | HPFH 2                |
| 2  | Shut down                             |        |        |                       |
| 3  | After the 11th stage of the LP part   | 12.5   | 451    | HPFH 1 and D          |
| 4  | After the 13th stage of the LP part   | 7.6    | 384    | D                     |
| 5  | After the 15th stage of the LP part   | 4.6    | 322    | LPH 4 and PB 2, 3     |
| 6  | After 2 stages of the low pressure cylinder | 1.45 | 200   | LPH 3                 |
|    |                                       |        |        | LPH 2 and MB 1        |
| 7  | After 4 stages of the low pressure cylinder | 0.34 | 80    | LPH 1                 |

**Figure 1.** Satellite image of the Krasnodar CHPP territory:
1 - BTS -1 (non-block part), 2 - BTS -2 (block part), 3 - gas-turbine power unit building, 4 - CCP-410 combined-cycle plant building.
In the third stage, two gas turbine units GT-100-750-2 were operating. They are currently decommissioned and dismantled [1].

At last they mounted a combined-cycle plant CCP-410. It is a three-circuit binary combined cycle gas plant consisting of a gas turbine unit M701F4 manufactured by Mitsubishi Heavy Industries, Ltd (Japan), a waste heat boiler EMA-003-KU (Ep-307/353 / 41.5-12.6 / 3.1 / 0.5-565 / 560/250) manufactured by EMAlliance OJSC and a T-135 / 145-12.4 type steam turbine manufactured by Ural Turbine Works CJSC.

Thus, today the Krasnodar CHPP is the largest power generating facility in the Kuban Regional Dispatching Office. Its installed electric capacity is 1,025 MW. However, in the context of the energy-deficient energy system, which is the Kuban Regional Dispatching Office (consumption exceeds the generation by more than two times), there is a request to expand the regulatory range, namely to increase the technical maximum of the CHPP.

One of the key ways to pass peak loads is to temporarily disable regenerative extraction on HPFH, as a way to pass peak loads. Its application has long been studied [2, 3]. But turning off the HPFH leads to a decrease in electrical efficiency. To eliminate this negative aspect, various schemes were proposed for displacing steam of regenerative extractions by using the heat of flue gases from additionally installed gas turbine plants [1, 4, 5]. These solutions are associated with high investment costs due to the need to purchase and install gas turbine units and gas-water heaters of feed water. There are suggestions to use solar energy to heat the feed water of steam turbine power units [6-8]. The authors of the article expressed ideas on using dry steam from a combined-cycle plant to displace steam going to the HPFH if this equipment is located at the same power station [9, 10]. Previously, scientists Sherstobitov I.V. and Biryukov B.V. developed schemes for the joint operation of steam turbine blocks of super- and subcritical parameters [11–13]. Thus, there are a number of ways to displace steam going to HPFH in order to increase the technical maximum of a power plant.

2. Proposed solution, methodology and results of thermodynamic efficiency calculation

In this study, we propose a scheme for the joint operation of four power units of the Krasnodar CHPP with an additional counterpressure turbine. To displace steam from HPFH 1 and 2, we consider the unit R-12-8.8 / 3.1-1 manufactured by the Kaluga Turbine Plant (nominal parameters of superheated steam: 8 MPa, 535 °C, its consumption is 182 t / h; behind the turbine: 3.05 MPa, 399 °C). We have chosen this unit due to the close steam parameters of the backpressure turbine and the first extraction, as well as the possibility of using steam from the TP-15 boiler for a non-block part. The latter will allow more rational operation of existing equipment and reduce investment costs for modernization. Condensate is heated in the LPH of the power units before being fed to the deaerator of the non-block part. For the study, the condensation mode was selected in order to use the generalized thermal diagram of the power units (extractions for district heating are not conventionally shown). The schematic diagram of joint operation is shown in figure 2 (for simplicity, only one block K-150-130 is shown).

The calculation is carried out according to the classical method described by Ryzhkin V.Ya. [14]. Before starting, we accept the following assumptions:

- the calculation is carried out in condensation mode, at an outdoor temperature of +15 °C and a steam flow rate at the inlet of condensing turbines of 127.9 kg / s (460 t / h), which corresponds to 150 MW when operating in the conditions of the Krasnodar CHPP;
- the relative internal efficiency of the turbines is assumed constant;
- we do not take into account the effect of changes in steam flow on its parameters in the flow part of the turbines;
- we do not take into account the effect of changes in steam flow on the vacuum in the condenser;
- we do not take into account steam losses in the cycle and boiler blowdowns.
Figure 2. Schematic diagram of the joint operation of the steam turbine unit K-150-130 of the Krasnodar CHPP with the displacement of the extraction on the HPFH 2 with steam from the R-12-8.8 / 3.1-1 turbine:

1 – steam boiler of a power unit; 2 – superheater of the power unit; 3 – high pressure cylinder; 4 – intermediate superheater; 5 – low pressure cylinder; 6 – power unit power generator; 7 – condenser; 8 – condensate pump; 9 – LPH 1; 10 – LPH 2; 11 – LPH 3; 12 – LPH 4; 13 – deaerator of the power unit; 14 - power unit electric pump; 15 – HPFH 1; 16 – HPFH 2; 17 – HPFH 3; 18 – steam boiler backpressure turbine; 19 – superheater of the backpressure turbine; 20 – backpressure turbine; – electric generator backpressure turbine; 22 – deaerator backpressure turbine; 23 – power pump backpressure turbine; 24 - HPFH counterpressure turbine.

Three modes were selected for comparison: operation of the K-150-130 unit in the conditions of the Krasnodar CHPP; also with disabled first regenerative extraction (HPFH 2 and 3 do not work); also with the displacement of steam of the first extraction on four blocks (steam from R-12-8.8 / 3.1-1). The calculation results are given in table 2.
Table 2. The results of thermal calculation of the proposed solution.

| Parameter                                                   | Nominal mode K-150-130 | Disabled extraction mode K-150-130 | Extraction mode K-150-130 | P-12-8,8/3,1 |
|-------------------------------------------------------------|------------------------|-----------------------------------|---------------------------|--------------|
| Feed water temperature (°C)                                | 299                    | 181                               | 299                       | 220          |
| Steam flow rate at turbine inlet (kg / s)                  | 127.9                  |                                    |                           |              |
| Steam consumption for HPFH 7 and HPFH 8 (kg / s)           | 11.3                   | 4.25                              | 7.02                      | 5.60         |
| Steam flow rate to deaerator (kg / s)                      | 2.44                   | 3.27                              | 2.45                      | 0.85         |
| Steam consumption for LPH 4 (kg / s)                       | 7.02                   | 7.66                              | 7.77                      | 6.19         |
| Steam consumption for LPH 1 (kg / s)                       | 6.78                   | 7.40                              | 7.5                       | 6.19         |
| Steam flow to condenser (kg / s)                           | 90.5                   | 98.7                              | 100.1                     | –            |
| Steam consumption for HPFH anti-pressure turbine (kg / s)  | –                      | –                                 | –                         | 3.97         |
| Estimated electrical power generated in the turbine (MW)   | 150.0                  | 156.5                             | 157.8                     | 12.2         |
| Changes in the efficiency of TPP for gross electricity production (%) | –                     | – 1.4                             | – 0.7                     |              |
| Change in specific consumption of reference fuel for electricity generation (g r.f. / kW * h) | –                     | + 11                              | + 6                       |              |

The use of steam displacement of the first extraction from K-150-130 power units by steam from a backpressure turbine as a way to increase the technical maximum of a power plant is energetically more profitable than turning off HPFH 1 and 2. Moreover, the maximum electric power of each power unit increases by 7.8 MW. The value of the technical maximum of the entire power plant increases by 43.6 MW.

3. Methodology and results of calculating the economic effect

Let us evaluate the economic effect of the proposed solution. We accept the following assumptions and initial data:
- reconstruction involves the installation of R-12-8,8 / 3,1-1, laying steam and condensate pipelines, construction of an automation system, commissioning activities;
- the economic effect of replacing the extraction with HPFH 1, 2 is taken into account only during the period of work at the technical maximum (we will take an average of 5 hours / day for a year). In this case, all additionally generated electricity will be sold;
- an increase in electric capacity will be taken into account when calculating payments for installed capacity;
- according to the data published on the official website of LUKOIL-Kubanenergo LLC, in the second quarter of 2019, the tariff rate for installed capacity was 115099.25 rubles / (MW * months), for electric energy supplied by steam turbine units - 1409.25 rub. / (MW * h).
- the reconstruction cost is assumed to be 238 million rubles, based on the unit costs of equipping a mini-CHP plant based on small steam turbine plants for the Kaluga Turbine Plant, listed in Appendix 3 to the program “Modernization of the Russian Electric Power Industry for the Period Until 2020” ($300 US / kW).

The calculation was carried out according to guideline documentation 53-34.1-09.321-2002. “Methodology for rapid assessment of the economic efficiency of energy-saving measures at thermal power plants”. We used simple criteria of economic efficiency (without taking into account the time factor). The results of a rapid assessment of the economic efficiency of the proposed solution are shown in table 3.
**Table 3.** Results of express evaluation of the proposed solution.

| Parameter                                                                 | Value       |
|---------------------------------------------------------------------------|-------------|
| Growth in retained earnings from payments for installed capacity (million rubles / year) | 60.2        |
| Annual increase in electricity supply (million kW * h / year)              | 48.8        |
| Growth in retained earnings from increased supply (million rubles / year)  | 112.0       |
| The increase in depreciation (million rubles / year)                       | 16.8        |
| Increase in operating costs (million rubles / year)                        | 113.3       |
| Income tax increase (million rubles / year)                               | 8.1         |
| Annual net profit growth (million rubles / year)                           | 33.7        |
| Investment payback period (years)                                         | 4.7         |

**Conclusion**

The application of the joint operation scheme of four steam power units K-150-130 and a backpressure turbine R-12-8.8 / 3.1-1 allows to increase the maximum electric power in condensing mode of each power unit by 7.8 MW. The value of the technical maximum of the entire power plant is increased by 43.6 MW.

The specific consumption of reference fuel for electricity generation after reconstruction is slightly increased (by 6 g r.f. / kW * h), which is lower than for shut down of extraction on HPFH 1 and 2. Moreover, the energy boiler operates at a feed temperature close to the nominal temperature water inlet.

Evaluation of the economic effect of the applied solution for the conditions of the Krasnodar CHPP showed that the annual increase in net profit amounted to 33.7 million rubles, and the payback period of investments is 4.7 years.

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