Analysis of the possibility of modernization of the state district power station by building the combined cycle plant

D S Balzamov1, E Yu Balzamova2, V V Bronskaya3, T V Ignashina3 and O S Kharitonova4,5

1Department of Power Supply of Enterprises and Energy Resource Saving Technologies, Kazan State Power Engineering University, 51 Krasnoselskaya Street, Kazan, 420066, Russia
2Department of Economics and Organisation Production, Kazan State Power Engineering University, 51 Krasnoselskaya Street, Kazan, 420066, Russia.
3Department of Chemical Process Engineering, Kazan National Research Technological University, 68 Karl Marx Street, Kazan 420015, Russia
4Department of Chemical Technology of Petroleum and Gas Processing, Kazan National Research Technological University, 68 Karl Marx Street, Kazan 420015, Russia

E-mail: olga.220499@mail.ru

Abstract. A priority task for the development of the energy industry is the replacement of the spent estimated lifetime of the generating equipment by new capacities taking into account progressive technologies. Nowadays, combined cycle technology shows itself to good advantage and provides excellent efficiency for any competing gas turbine systems that are likely to be available for large-scale electricity and heat production. In this article the possibility of modernization of the SDPS by building the combined cycle plant is considered.

1. Introduction
Today, the best solutions in the energy industry is the technology of combined cycle gas turbines. Combined cycle power stations are highly efficient that allows energy producers to obtain much more energy from the same amount of natural gas. Energy conversion rates for combined cycle plant (CCP) are high, ranging from 50% to 60% [1-6].

![Figure 1. CCP configuration.](image-url)
The possibility of modernization of the SDPS by construction of combined cycle plant with a capacity of 110 MW with the output of electric energy to an open switchgear of 110 kV and the thermal energy for heating needs.

The CCP configuration is shown in figure 1.

The thermal capacity of the steam turbine with controlled selection is 75 Gcal/h. In order to improve the efficiency of use of gas turbine exhaust gases, it is necessary to provide for the installation of boiler-utilizer of network water gas heaters (NWGH) that allows to produce additionally about 5 - 6 Gcal/h. Thus, the total generation of thermal energy by the combined cycle plant is 80 - 81 Gcal/h, that partially covers the need for thermal energy in the residential district, the main building and the industrial area of SDPS (the thermal load at the specified temperature of the external air of -34°C is -168 Gcal/h).

2. Methods
The thermal scheme of the SDPS with the installation of CCP-110 allows to provide consumers with thermal energy as efficiently as possible [7-9].

The estimated cost of the CCP-110 construction project at the SDPS is presented in table 1.

| № | Type of work, equipment, costs | Price, mln. rub. (excl. VAT) |
|---|--------------------------------|-----------------------------|
| 1 | Equipment, including:         | 3000                        |
|   | gas turbines;                 |                             |
|   | boiler-utilizer;              |                             |
|   | steam turbines;               |                             |
|   | electrical equipment;         |                             |
|   | auxiliary equipment.          |                             |
| 2 | Construction and installation works | 900                   |
| 3 | Pre-commissioning activities  | 100                         |
| 4 | Design and survey works       | 200                         |
| 5 | Unexpected expenses           | 300                         |
| 6 | Dismantling of existing power unit | 500               |
|   | Total                          | 5000                        |

The cost of construction of a combined cycle plant CCP-110 MW, in accordance with the calculations made during the development of the preliminary project feasibility study of the construction of the power unit, is 4.5 billion rubles. Taking into account the cost of dismantling one power unit of the SDPS, which is 0.5 billion rubles, the total cost of implementation of this technical solution is 5.0 billion rubles. The realisation deadline of this option according to expert estimates is 3 years. The thermal diagram of CCP is shown in figure 2. Table 2 presents the specific performance indicators of CCP-110 MW.

| Name                                      | Unit of measure | CCP-110 |
|-------------------------------------------|-----------------|---------|
| Specific reference fuel consumer for heat energy | kg/Gcal        | 147.6   |
| Specific reference fuel consumption for electric energy | g/kW*h         | 252.4   |
Figure 2. Thermal scheme of CCP.

Figure 2 includes the following designations: 1 — gas turbine; 2 — combustion can; 3 — compressor; 4 — compressor motor; 5 — steam turbine; 6 — boiler-utilizer; 7 — condenser; 8 — condensate pump; 9 — generator.

3. Results
Calculation of annual fuel savings from generation of heat energy in the form of hot water on CCP-110 MW was performed according to the following algorithm [10,11].

The reference fuel consumption for the output of thermal energy in the form of hot water under the existing scheme is:

\[ G_{\text{te}} = \left( Q_{tg} \cdot b_{h/p-tg} \right) /1000 = (278262 \cdot 171.2)/1000 = 47638.45 \text{ ton of reference fuel} \] (1)

The reference fuel consumer for the production of thermal energy in the implementation of the CCP-110 MW is:

\[ G_{\text{cp}} = \left( Q_{tg} \cdot b_{h/p-ccp-110} \right) /1000 = (278262 \cdot 147.6)/1000 = 41071.47 \text{ ton of reference fuel} \] (2)

Annual savings of reference fuel for the output of thermal energy from SDPS is as follows

\[ S_{\text{yearhp}} = G_{\text{te}} - G_{\text{cp}} = 47638.45 - 41071.47 = 6566.98 \text{ ton of reference fuel} \] (3)

Calculation of the annual saving of fuel from the output of electric energy from the CCU-110 MW:
The calculation of savings is made under the following initial conditions:

- number of hours of use of CCP-110 MW is 8,300 hours/year;
- the combined cycle plant operates in the basic mode with the generation of electricity of 110 MW.

The actual electricity output of SDPS according to accounting data is 8662876 thou. kWh. The annual average specific reference fuel consumption for electricity generation is 349 g/kWh.

The reference fuel consumption for the released electricity in the whole station:

\[ G_{tfe} = \frac{(8662876000 \times 349)}{10^6} = 3023343.7 \text{ ton of reference fuel} \]  

Electricity generation of CCP-110 MW:

\[ E_{ccp} = \frac{(110000 \times 8300)}{10^3} = 913000 \text{ thou. kWh} \]  

Electricity output from CCP-110 MW:

\[ E_{ccp,vac} = \frac{(110000 \times 8300)}{10^3} \times 0.9404 = 858585.2 \text{ thou. kWh} \]  

According to the accounting data, the consumption of electric energy for the plant's own needs is 5.96%.

The reference fuel consumption for electricity output from the CCU-110 MW:

\[ G_{ccp} = \frac{(858585200 \times 252.4)}{10^6} = 216706.9 \text{ ton of reference fuel} \]  

Electricity output by the power units of station excluding the electricity output from the CCU-110 MW:

\[ E_{eb} = 8662876 - 858585.200 = 7804290.8 \text{ thou. kWh} \]  

The reference fuel consumption for electricity by power units of station excluding CCU-110 MW:

\[ G_{tfe-eb} = \frac{(780429080 \times 348.8)}{10^6} = 2722136.6 \text{ ton of reference fuel} \]  

Annual savings of reference fuel according to SDPS:

\[ S_{yeare/p} = G_{tfe} - G_{ccp} - G_{tfe-eb} \]  

\[ S_{yeare/p} = 3023343.7 - 216706.9 - 2722136.6 = 82767.62 \text{ ton of reference fuel} \]  

Total annual fuel savings at commissioning CCP-110 MW is:

\[ S_{year} = S_{year/p} + S_{yeare/p} = 6566.98 + 82767.62 = 89334.6 \text{ ton of reference fuel} \]  

The economic effect of the project is:

\[ S_{sav.} = S_{year} \times \text{Price}_{f} = 89334.6 \times 4700 = 419.87 \text{ million rubles} \]  

where \( \text{Price}_{f} = 4700 \text{ rub./ton of reference fuel} \) is the cost of reference fuel [3].

A payback period is calculated by the formula:

\[ PP = S_{sav.}/S_{sav.} \]  

Payback period is:

\[ PP = 5000/419.87 = 11.9 \text{ years.} \]  

At the same time, the specific capital investment per 1 Gcal are calculated by the formula:

\[ SCI = S_{exp.}/W_{power} \]
where \( W_{power} \) is the thermal power of newly introduced equipment, Gcal/h (100 Gcal/h).

Specific capital investments per 1 Gcal are:

\[
SCI = \frac{5000}{81} = 56.8 \text{ million rubles /Gcal. (17)}
\]

4. Conclusion

The main criterion of the implementation of the variant of construction of a combined cycle plant CCU-110 is replacement of the spent estimated service life of the generating equipment by new capacities [5-8].

At the same time, the option with the construction of a combined cycle plant CCU-110 with the production of thermal energy in the amount of 81 Gcal/h at the estimated thermal load of 168 Gcal/h does not fully solve the problem of modernization of the heat output scheme.

Taking into account the execution deadline of this project, which is about 4.5-5 years, losses from operation of power units in the mode of forced heating production can be quite serious. It is worth noting that combined cycle plants are a promising direction for the energy industry thinking of their high efficiency and have an acceptable payback period as a part of programs of capacity supply contracts designed to co-finance of investments in the construction of new generating capacities.

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