The system of trigeneration with binary cycle for use as an energy source for gas fuel

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Abstract. The article describes the relevance of the problem of increasing the efficiency of fuel and energy complexes, based on the energy strategy of Russia for 2030. A review of various methods of air cooling for a more intense combustion process in a gas turbine plant is carried out and the most optimal one is chosen. The paper presents a model of the system of automatic control of the air cooling of the heat exchanger of a gas turbine unit to ensure the conditions of the nominal mode of operation when weather conditions change.

1. Introduction
According to Russian energy strategy for the period from 2030 it emerges the decrease of percentage fuel and energy complex in the gross domestic product and percentage fuel and energy resources in export not less than 1.7 times of primary energy carrier is actual [1,2]. Energy saving problems are very important now in connection of limit of natural resources, uneven distribution and because of increasing man-made pollution.

For efficiency of using primary energy carrier by generating of heating energy binary mode is provided, where the energy of exhaust is converting to the energy through steam turbine. such cycle implies collective using of gas-turbine and steam turbine installation. as a working environment low boiling liquids is used.

2. Binary electric power
The binary electric power generation cycle uses high-temperature exhaust gases from the gas turbine to generate steam from the low-boiling medium causing the secondary turbine. At the same time, depending on the indicators of energy consumption, the objects of oil and gas enterprises are graphs. It is possible to have generation of electrical energy.

As a low-boiling environment is used a refrigerant pentafluoropropane (the chemical formula of C3H3F5, the boiling point of 15.3 °C, the density in the liquid phase 1400 kg/m³, in the gaseous - 5.84 kg/m³). In this case, the conversion of frequencies and voltages during parallel operation of generators GTU and PTU might be carried out by connecting them through the appropriate converters to common AC or DC [3-5] Such a system could increase the electrical energy sales of the primary energy carrier to 55% [6-8].

Full efficiency of cogeneration plants is determined by the fuel utilization factor (UF) by the formula:

$$\eta_{UF} = \frac{\eta_{el} + \eta_{c,t}}{\eta_{min,\text{fuel}}}$$

(1)
Where $N_{el}$ and $Q_{t.e}$ – electrical and thermal power of the cogeneration plant, BOE; $Q_{min}^p$ – the specific lower calorific value of fuel, BOE/kg; $B_{fuel}$ – fuel consumption, kg/s [9].

The object of study is an electric complex on the basis of 2 GTU with a total capacity of 94 MW and an efficiency of 37.5%. This UF setting is used in traditional fashion on Formula 1:

$$\eta_{UF} = \frac{94000 + 0}{13 \cdot 19200} = 0,375$$  \hspace{1cm} (2)

Working in cogeneration mode, that is:

$$\eta_{UF} = \frac{135000 + 72000}{13 \cdot 19200} = 0,829$$  \hspace{1cm} (3)

3. Trigeneration system

Thus, UF cogeneration reaches about 83%, which is 2.2 times more than in the traditional mode. However, the highest rates of primary energy are achieved only when the system is operating in the nominal mode. According to technical data (Figure 1) for the nominal operating mode, the air temperature at the inlet of GTU 15°C is required, the temperature increase can reduce the power generated by up to 25%, while increasing the gas consumption is used as a primary energy carrier by up to 8.5%.

![Figure 1. Curve of the electricity (1) and heat capacity (2) in dependence on temperature of the gas turbine’s input air.](image)

To improve the efficiency of GTU and reduce fuel consumption, air cooling methods are used at the inlet of the gas turbine unit (Figure 2).
The UF of the cogeneration plant in the warm period could be reduced to

$$\eta_{UF} = \frac{102000 + 0}{1320736} = 0.378$$

(4)

To solve the problem of cooling the inlet air of the gas turbine has been considered on several refrigeration systems:

1. evaporating cooling system;
2. system, cooling of the spray of demineralized water;
3. absorption chillers.
4. system with using of compressor cooling.

Absorption chiller have a number of advantages over other cooling systems: no negative impact on GTU, high reliability, independence from ambient temperature, accurately controlling and the highest rate of efficiency, for example absorption refrigeration machine with capacity of 6.5 MW is capable of cooling the air at the inlet of two GTU to 15 °C even at a peak temperature of 40 °C for consumption of no more than 4.7 MW of thermal energy of exhaust gases with a conversion factor of 1.4 [10,11].

The main criterion of the chosen refrigeration machine is the cooling capacity N:

$$N = Q_{air} \cdot (h_c - h_o)$$

(5)

where $Q_{air}$ is the mass flow rate of air, which must be cooled.

$h_c$ - the enthalpy of the cooled air,

$h_o$ - enthalpy of outside air.

The mass air flow, which must be cooled, we should accept equal twice the consumption of air at the entrance to the GTU, as it is necessary to cool the air at the inlet of two gas turbines units to have the nominal value of the generated electricity during the combustion of primary energy. we accept the volumetric air flow rate at the inlet of GTU at nominal conditions equal to 350000 m³/h and lead to a doubled mass value for further calculations.

In the presence of a combined system output of 2 GTU and 1 PTU with a thermal capacity of about 122 MW, at an external temperature of 40 °C, a two-stage absorption Refrigeration machine for trigeneration based on 2D 8 K with an exhaust Thermax is selected, the cooling capacity of which can reach the level of 6585 kW the resulting system of trigeneration is able to provide potential consumers with electricity of the required voltage, hot water of about 80 °C. With and cooling the air up to 15 °C (Figure 3) [7].
At a peak temperature, the system is able to increase the energy efficiency of the primary energy carrier to 80% (Figure 4) [12]. Ambient air temperature changes by more than 20% during one day. To maintain the efficient operation of the trigeneration system it is necessary to regulate the heat exchange processes. To maintain a constant air temperature at the entrance to the GTU is adopted by regulating the flow of cooling water in the heat exchanger of the air cleaning compressor unit.

4. Automatic control system

Heat and mass transfer processes occurring in the heat exchanger is described by a system of nonlinear equations [13]:

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\begin{align*}
G_{\text{air}} \rho_a C_a (T_a - T_a^n) + m_a C_a \frac{dT_a}{dt} + \alpha_a F_{\text{out}} (T_a - T_{\text{pipe}}) &= 0 \\
 m_{\text{pipe}} C_{\text{pipe}} \frac{dT_{\text{pipe}}}{dt} - \alpha_{\text{water}} F_{\text{input}} (T_{\text{w}} - T_{\text{pipe}}) + \alpha_a F_{\text{out}} (T_{\text{pipe}} - T_a) &= 0 \\
 G_w \rho_w C_w (T_w - T_w^n) &= \alpha_w F_{\text{in}} (T_{\text{pipe}} - T_w)
\end{align*}
\]  

(6)

To implement the process of regulating air temperature at the inlet of the gas turbine it has been selected proportional-integral controller. This regulator combines advantages of P-and I-laws of regulation, namely: the proportional component, which provides sufficient speed of the regulator, and the integral component eliminates the static error of regulation [14,15].

At the beginning of the process of regulation the main role plays a proportional component, as the integral depends not only on the absolute value, but also on time. With the increase of time the role of the integral component ensuring elimination of a static error [16,17] increases.

According to the equations in Simulink MatLab the mathematical model of the chosen TA is constructed (Figure 4), calculated and represented by a PI controller ACS air flow when the ambient temperature changes, for a constant temperature of the air at the outlet of TA.
Figure 4. Model of ACS.

The principle of operation of the scheme is to set the variable ambient temperature in the range from 13°C to 37°C with a change in relative humidity in the range from 0 till 100%. When passing through the Converter elements corresponding to the physical processes of the real heat exchanger, the value of the air temperature at the entrance to the GTU is obtained at the output of the system [18,19].

This signal is regulated by a PI controller, which was installed in the negative feedback and regulating the coolant flow rate [20].

Figures 5, 6 show graphs of changes in the ambient air temperature and the air temperature at the inlet to the GTU.

Through this control system, when the input data changes, we have a constant output value not exceeding the mark 15 °C and decreasing below only at the corresponding OS temperature value.

Figure 5. Graph of changes in the ambient air temperature.
5. Conclusion
The results of researches which are given in the article confirm the efficiency of the trigeneration system. Reduction of gas fuel consumption more than 8% and increase of the generated power more than 18% is contribute to the reduction of natural resources consumption while increasing the consumption of electric energy in the current conditions and projected in the near future. ACS will achieve the output of the system in the nominal mode, which will allow to obtain the highest system efficiency and minimum wear and tear. Using of the exhaust gas temperature of GTU can reduce the emission of heat into the atmosphere, which contributes to the reduction of thermal pollution. Economic indicators prove the profitability of the system, especially in hot areas of the planet, and payback in less than a year justifies economic risks.

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