Ensuring the efficient operation of a combined-cycle gas plant in the warm season

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Abstract. Summer technological restrictions on the electric power generation by the power stations have a significant impact on the economic indicators of generating companies. These restrictions are associated with the deterioration of performance of the generating and auxiliary equipment of stations at high air temperature and due to the following factors: the progressive decrease of electric power of gas turbines with increasing outside temperature above the calculated one (+15 °C); the rise of the water temperature in the cooling systems of main and auxiliary equipment and, as a result, the deterioration of the vacuum in the condensers of steam turbines and the operation of the cooled equipment in more intense thermal conditions.

1. Introduction
During the summer period, the wholesale market sets maximum prices for electricity and the annual increase in the summer loads is higher than the interseasonal and winter loads. The problem of these technological limitations can be solved by intensifying the operation of the cooling systems for power station equipment using the absorption refrigerating machines, in particular lithium bromide ones. The prerequisites for using these devices, which allow to transform heat into cold with the minimal energy consumption, are obvious. For example, during the summer period, stations have a large amount of heat released into the atmosphere with outgoing gases and through the station cooling towers. The power stations where are ensured the use of waste heat for the production and subsequent use of the coolant will have serious competitive advantages.

The problem of increase of the efficiency of the electricity production at the thermal power plants is one of the key issues in solving the problems of energy and resource-saving in the energy industry.
2. Materials and Methods

In order to decrease the influence of high outdoor temperature on the generation of electric energy from the combined-cycle gas plant, it is proposed to use pre-cooling of the air before the compressor in the heat exchanger of an integrated air filtering and conditioning system (AFCS). As a source of cold, it is suggested to use an absorption refrigerating machine (ARM) where an aqueous solution of lithium-bromine is as the working medium [1].

ARM is cooled in the evaporator by the coolant circulating through the heat exchanger. During the operation of the unit, the electrical energy is consumed exclusively by pumps and the main source for the cold production is exhaust steam.

In AFCS the process of purification and refrigeration of the air has occurred before sending it into the compressor of the gas turbine. Moisture that is formed by the condensation of water vapor contained in the cooled air is a desalted water, which is an essential resource at the power station and therefore it is collected and used for the auxiliary needs of the power station [2]. To remove the heat from the ARM, it is planned to install a natural draught cooling tower.

The experience of implementing ARM at various energy facilities is analysed.

Ten years ago, PJSC "LUKOIL" due to experts from "R-Engineering" LLC, studied the possibility of installing a refrigerator at the thermal power plant in the South of Russia. The improvement of the CCGT-110 with the use of ARM to reduce the temperature of the air in the warm season was considered.

At the beginning of the work, it was decided to use a condensate with a temperature of up to 95 °C as a heat generator. At the same time, it is heated in the boiler-utilizer using the waste heat of the exhaust gases.

Considering the options for reducing the air temperature in the CCGT-100 in Astrakhan, the analysis revealed that the best solution would be the combined action of the Sprint system and ARM with a cooling capacity of 3800 kW. This solution is cost-effective in relation to profit and capital expense.

Figure 1 shows a graph of the characteristics of the gas turbine unit (GTU) LM6000PF with the Sprint system (burgundy line) and without it (black line) and the humidity 60%. The green line shows the operation of the previously selected scheme with the capacity of 3.8 MW. The cooling capacity is presented by the blue line [3,4].

![Figure 1. Dependence of the power of GTU LM-6000PF and ARM on the outdoor temperature.](image)

This application leads to reduce the temperature of the cooling water for the turbo generator, stabilize its operation in the summer and solve the problem associated with the cooling of the lubrication system.
of the steam turbine plant (STP) since the oil temperature behind the lube oil coolers could reach a temperature of +50 °C with a maximum permissible +45 °C. The authors of the project used the ARM in the heat pump mode, which allows to be used all year round, providing both an optimal mode of cooling for equipment and the return of the heat to the technological cycle of the station of about 500 kW of the heat energy with minimal losses [5].

Due to the use of an absorption chiller, an additional 136 million kWh of electricity was produced in Astrakhan during the warm season of 2017 and the fuel costs were reduced by 2.51-3.62 g/kWh.

The cold water accumulator of the volume of 1500 m$^3$ facilitates the use of the ARM, as the unit is operating continuously. Water, accumulated at night, is used during the day to cool the GTU air. The achievement is an increase in the cold productivity and the formation of the cooling system of STP hull [6].

The paper [7] presents the methodology and results of the calculation and the selection of the absorption lithium-bromide refrigerating machine ARM taking into account the economic components (economic effect, payback period, etc.). The ARM is recommended as the most perspective technology in the air cooling systems for the gas turbine unit. The process parameters were analyzed for the 48 MW GTU-TPP Mezhdunarodnaya station. It is recommended to focus on the GTU with the cooling power about 2 MW (for these climatic conditions). This value is selected from the researched power range of 1.5-4.8 MW and air temperatures from -41 to 37 °C.

As a result, when the average monthly temperatures fluctuate from maximum to minimum, the total economic effect of the recommended system is in the range of 3.7-10.1 million rubles/year and the payback period is about 5 years. The article [7-10] presented the research of the energy indicators of STP based on the GT13E2 GTU of Alstom company during the operation of the air cooling system in the period April-October for the city of Krasnodar that showed that the increase in the STP power was from 10 to 40 MW. Thus, the results of the analysis of the energy parameters of the STP with the air cooling system, that uses water-water exchangers as the heat sources for the ARM, show the practicability of its use in the development of the STP thermal schemes for the southern regions of Russia.

In the research [11-12], the results which were obtained when the air temperature decreases before the gas turbine unit were worked out. Indicators for GTU GE 9351 FA and STP are as follows:

- The capacity increases from 215 to 260 MW.
- The efficiency coefficient increases to 3%.
- The temperature of the exhaust gases increases that leads to an increase of the amount of steam in the boiler-utilizer and the power of the GTU.

3. Results

The schematic solution for the use of ARM is proposed for the Kazan thermal power plant (TPP). This solution ensures the use of thermal energy which is generated at the TPP for cooling the refrigerant and its efficient use at the plant.

A defining feature of the developed scheme from the existing one [13-19] is the implementation of parallel connection of the condenser and the absorber of the refrigerating machine. This reduces the heating of the cooling water. Consequently, thermal emissions to the atmosphere in the natural draught cooling tower are reduced.

Cooling the ARM is carried out by connecting to an existing circulating water supply system, which reduces the capital investment for the purchase and construction of a separate cooling tower.

Also, the scheme differs in that the heat source for the ARM generator is the working steam of the ejector. As a result of this technological solution, steam is fully used for the technological cycle of the steam turbine.
Figure 2. The diagram of cooling of the air before the GTU compressor. HE – heat exchanger; DC – drop catcher; C – compressor; T – turbine; CT – cooling tower; BU - boiler-utilizer; ST – steam turbine; Con – condenser; CG – combustion gas; ARM - absorption refrigerating machine; 1 – the generator of the ARM; 2 – the absorber of the ARM; 3 – the evaporator of the ARM; 4 – the condenser of the ARM.

4. Conclusion
As a result of thermodynamic calculation, the following characteristics are determined: the thermal coefficient for the ARM is $\zeta = 0.93$. The mass of the refrigerating agent circulating in the system is $D = 1.15 \text{ kg/s}$. The full heat load is $Q_a = 2590 \text{ kW}$ for the absorber, $Q_c = 3078 \text{ kW}$ for the condenser, $Q_g = 2933 \text{ kW}$ for the generator and $Q_e = 2735 \text{ kW}$ for the evaporator.

When installing the ARM in the TPP system, the significant savings in money and fuel are observed. The stable electricity generation will additionally provide 12206.891 MW/year, which is equivalent $S_{\text{ele}} = 11840684$ rubles when it is implemented in the system. Savings in fuel (natural gas) is 7800.593 m$^3$ or 5.5 rubles/m$^3$ that is $S_{\text{gas}} = 42903$ rubles/year expressed in monetary terms. One of the positive factors is the elimination of punitive penalties for short-delivery of power in the warm season.

When connecting the ARM, the operating costs are $C = 7286705$ rubles/year and the capital costs are $C_{\text{cap}} = 68045703$ rubles. According to the values, the payback period for the implementation of the ARM in the STP technological scheme is $\tau = 4.4 \text{ year}$.

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