Study of feedwater regenerative heating operating modes at reduced loads of a turbogenerator by 300 MW power unit capacity

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Abstract. The article presents the results of numerical studies and analysis of the feedwater regenerative heating operating modes depending on power unit capacity. The main parameters of this system are the enthalpy of the turbine steam extraction for heaters, as well as the steam consumption in these extractions. The dependences of the turbine unit steam flow rate and the change in expansion process of the steam turbine during the load regulation were investigated. The mathematical model of calculation the thermal power plant for a 300 MW power unit capacity was developed. Following on the results of the calculation conclusions of feed water regenerative heating operating modes at reduced loads of a turbine-generator for a 300 MW unit.

1. Introduction
Thermal power plants (TPP) amount a large part of Russian energy system. The efficiency of thermal power plants does not exceed 40%, that is explained by the specific nature of energy conversion process, power equipment depreciation and operating modes that are different from the optimal and other factors [1]. In variable operation modes, the power equipment of the TPP operates at reduced initial steam parameters, which leads to a decrease in the rated capacity of power units, and as a result, the whole power plant efficiency [2].

On modern steam-powered power units, besides the basic facility: boiler, turbine and generator, an integral part is the feedwater system. Due to the feedwater system reduces fuel consumption and increases the efficiency of the power unit. The main elements of this system are high-pressure (HPH) and low pressure feed water heaters (LPH) and a deaerator. The condensed steam after the condenser passes through the group of low pressure heater, then enters the deaerator, where the removal of corrosive gases occurs and through high-pressure heaters enters the boiler with a temperature 270 °C for power-generating unit with 300 MW capacity [3].

2. Development of the regenerative feedwater heating system
To carry out the research on improving the efficiency of condensing power plant with a heat pump at variable modes the standard power unit of 300 MW with the turbine K-300-240-2 KhTGP working in
the electrical load range from 200 to 300 MW. The choice of this range was due to the processes that are accompanied by: significant worsening of steam operating parameters in the steam extraction, necessity of disconnection the high-pressure feed heater group, reduction of feed water parameters at the steam boiler inlet, that causes decrease the thermal power plant efficiency [4,5].

The research was carried out at the nominal operating parameters of a 300 MW power unit (Fig. 1):
- initial steam pressure 23,5 MPa;
- steam temperature 540 °C
- condenser steam pressure 3,43 kPa
- turbine unit power range 200…300 MW

To carry out the research of operating modes of thermal power plant the mathematical model was developed implemented in the Excel software environment added by WaterSteamPro 6.5 the program to determine the parameters of steam and water for different pressure and temperature in different parts of technological scheme [6,7]. This model is based on a standard calculation method for thermal power plants schemes. This model considering the laws of energy and mass conservation [8,9].

Operation of the power unit under reduced load conditions leads to a decrease in the temperature of the feed water at the inlet to the steam boiler, which leads to a decrease in efficiency and an increase in fuel consumption. The energy unit power capacity is controlled by reducing the flow of steam to the turbine, with constant parameters of superheated steam and pressure in the condenser [10]. The turbine steam consumption is calculated depending on the power and heat drop according to the following formula:

$D_0 = \frac{N_e \cdot 10^7}{(h_h - h_e + \Delta h_{RH})\eta_m \eta_s \eta_{ER}}$

Based on the mathematical model calculation results obtained (Fig. 2), it was found that with a decrease in the turbine electric power unit, the efficiency the compartments decreases:
Figure 2. Change the turbine efficiency compartments depending on the turbine unit load: 
1-change the intermediate-pressure cylinder efficiency, 2-change the high-pressure cylinder efficiency,
3-change the low-pressure cylinder efficiency, 4-change the feed-pump turbine efficiency.

The turbine compartments efficiency decrease leads to a shift steam expansion process in the h-s diagram, which rise the final enthalpy at constant pressure (Fig. 3).

Changes in the steam expansion process affects the parameters of the extraction system of regenerative heating feed water. Figure 3 shows the dependences in the enthalpy change of steam extraction on the power turbogenerator.

Figure 3. Displacement of the steam expansion process in a 300 MW turbine.
Changes in the steam expansion process affects the parameters of the extraction system of regenerative heating feed water. Figure 4 shows the dependences in the enthalpy change of steam extraction on the power turbogenerator.

![Diagram showing changes in steam extraction enthalpy](image)

**Figure 4.** Change in the steam extraction enthalpy with the electric load decrease of the turbine unit, 1, 2, 3 - steam extraction to LPH, de-aerator, 4, 5, 6, 7, 8, 9 - steam extraction for HPH.

As can be seen from the diagram, the enthalpies of stream do not change, except for steam extraction № 1 and 2, so far as steam to these bleeding is taken from a high-pressure cylinder, where the pressure of these extraction drops significantly with load reduces. The pressure drop in the steam extraction, for condensing turbines is approximately equal to the ratio of the power drop to the turbine unit rated power. Figure 5 shows the dependence of the change in steam consumption in the bleeding on the turbogenerator.

\[ D_1 = D_0 \alpha_1 \]
Figure 5. Flow variation in steam consumption in the turbine unit by changing the turbogenerator electric power.

Since with a turbine unit power change the enthalpies of the steam extraction do not actually change, then the deviation of the steam extraction fractions will be insignificant. One can conclude as follows, the amount of steam extraction depends on the stream flow to the turbine. The change in steam flow to the turbine is shown in Figure 6.
Figure 6. Changes in the superheated steam consumption of steam turbine with a 300 MW capacity by reduced load.

3. Conclusion
Taking into account the results obtained during the study of feedwater regenerative heating operating modes at reduced loads, one can conclude as follows:
- The mathematical model of calculation the thermal power plant for a 300 MW power unit capacity was developed.
- The analysis of the results obtained shows that the change in the turbine load significantly affects the enthalpies of the 1st and the 2nd steam extraction from the high-pressure turbine cylinder, which in turn indicates that the steam extraction proportion does not actually change;
- Reducing the turbogenerator load unto 200 MW leads to an increase in the enthalpy of 80 kJ.
- The first and the second steam extraction a load reduction by 100 MW leads to enthalpy decrease in extraction of 50 kJ.
- In the future the developed mathematical model will help to explore the feed water regenerative heating system more widely and create the economical mode charts.

Acknowledgements
The article was prepared with the financial support of the Foundation For Assistance To Small Innovative Enterprises – 143GUCES8-D3/56397 24.12.2019. The grant holder – Aleksandr Limar.

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