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Reduction of the technological minimum by bypass method with environmental impact estimation on the example of energy blocks with T-100 and T-250/300-240 turbines

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Abstract: The article describes existing methods of reducing the technological minimum with a quantitative assessment of reducing emissions of pollutants at the CHP using the method of bypass. With the help of specialized program complex the efficiency of the method has been analysed on the example of the power units at Yuzhnaya CHP-22 and CHP-21 JSC "TGC-1" with turbines T-250/300-240 and T-100-130. The article provides guidelines for the range of application of this method as well.

Statement of the problem

Thermal power plants (TPP) have a prominent place in the electric power industry of Russia. 537 TPPs with total electrical capacity of 148.6 thousand MW and 640.5 million MWh per year electric power generation operate in Russia in 2018. The annual fuel consumption of thermal power plants of general use in 2018 is estimated 265.8 million tons of reference fuel. At present, most TPPs of RF operate in the wholesale electricity and capacity market (OREM). A significant share of thermal power plants in Russia is of combined heat and power plants (CHP).

Methods of dealing with night of-peaks at CHP plants used by power companies today are based on simplified methods of selecting the main equipment, which does not provide an opportunity to find beneficial solutions and considers expected dynamics of changes in thermal loads and the uncertainty of prices for WECM insufficiently. As a result, generating companies are forced to transfer CHP power units to a reduced generation of electricity (technological minimum) mode, while maintaining the generation of thermal energy at a certain level in accordance with the schedule.

Optimization of the technological minimum at the CHP allows to reduce the fuel costs without significant investments, as well as decrease pollutant emissions [1-6].

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Methods description

Method of bypassing or shutting down the high-pressure heater (HPP) can be applied to deal with night off-peak loads. Reduction of the electric power occurs due to the reduction of the steam flow to the head part of the turbine by the value of the displaced withdrawals, while the load and the parameters of the heat-extraction withdrawals remain unchanged. When the bypass channel is completely opened through the HPP, the feedwater consumption is 25-30% of its total flow. In this case, heaters work reliably with the normalized parameters of the heating steam and water. This method has the following limitations:

- regulation of a large number of valves;- difficulty in reducing steam pressure, the speed should not exceed 0.6 kgf / cm2 per minute (setting the condensate level);
- due to HPP bypass, the temperature of the feed water also decreases, while all the boiler units are designed for a certain temperature of the feed water, which means that a certain control range for the feed water must be provided.

Table 1 shows the test results of the technological minimum passage by applying the method of bypass LDPE on the T-100 block

Table 1. Test results

Characteristic	Initial	HPP bypass
Electric power, MW	77	70
Steam consumption per turbine, kg / s	91,5	79,7
Fuel consumption, kg / s	8,9	8,6
Heat supply, MW	154	154

Changing the pressure in the heating systems is done by adjusting the diaphragm or by applying completely closed position by changing the steam flow to the turbine. Maintaining the specified heat load is achieved by adjusting the proportion of the bypass of the network heaters. The scheme of the steam-turbine unit (STU) is shown in Fig. 3

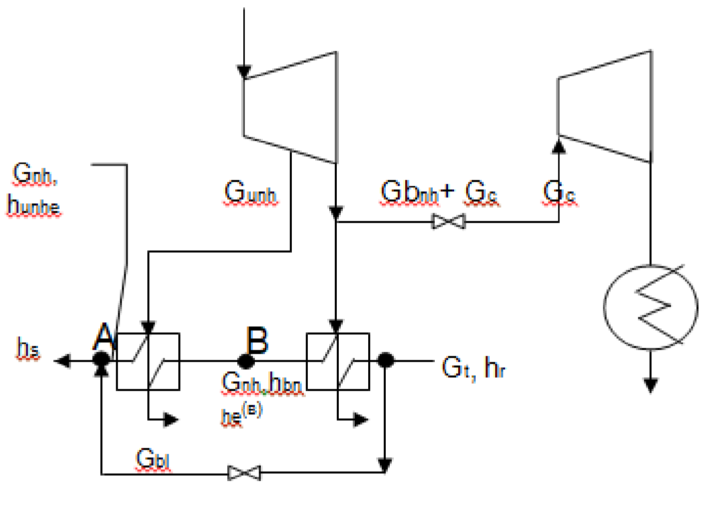

Fig. 1 The scheme of the bypass of the STU network heaters.
Gunh, Gbnh, Gc - steam consumption, respectively, in the upper (UNH) and bottom (BNH) network heaters, as well as in the condenser; Gt, Gnh, Gbl- network water flow, respectively, common, through the network heaters and through the bypass line; h_r, h_s, h_{unhe}, $h_{bnhe}^{(B)}$ – enthalpy of the network water, respectively, reverse, direct, at the exit from the UNH and at the exit from the BNH (at point B).

The turbine unit operates in the TP mode with a closed rotary diaphragm. The flow rate of steam in the condenser is a ventilation pass of steam through the diaphragm. The water flow through the network heaters is changed by bypassing a part of the flow through the bypass line. Directing part of the network water to the bypass of the network heater can be used to reduce the electric power of the turbine.

For this type of turbine units it is effective to work with counter pressure in the upper heating chamber by bypassing the network heaters. Greater flexibility in the distribution of thermal loads among network heaters can be achieved either by simultaneous flow of both heaters along the bypass line, by an individual circuit of each of the heaters, or by a combination of a common bypass with a bypass of one of the heaters. In some cases it can be limited to one heater bypass.

The thermal capacity of the heating selections and the electric power of the turbine are determined by the following formula:

$$Q_{\text{от}} = G_{unh}(h_u - h'_{\text{в}u}) + G_{bnh}\,(h_b - h'_b)$$
$$N = (G_{unh} + G_{bnh})(h_0 - h_u) + G_{lnh}\,(h_u - h_b) + \sum G_i\ H_i\ ,$$

where h_0, h_u, h_b is steam enthalpy , respectively, before the turbine, in the upper and lower selections.

The first term in the power expression determines the power produced by the steam in the turbine compartment before the lower selection, the second term is the capacity of the intermediate compartment, and the third term is the power of the steam chosen for regeneration.

To reduce the electrical power at a constant heat output power, it is necessary to increase the steam pressure in the upper selection (sliding counter pressure). The steam pressure in the lower selection will also increase.

In a wide pressure range pu and pb, the differences $(h_u - h'_u)$ and $(h_b - h'_b)$ remain practically unchanged. In this case, it follows from the first equation that with increasing counter pressure p_u occurs with a constant heat load Q_{OT}, the redistribution of loads between the upper and bottom network heaters, but at the same time the amount of steam consumption remains practically unchanged [7-9].

Residual $(h_0 - h_u)$ decreases due to growth h_u. The change in the power of the intermediate compartment (the second term) is a subject to additional research. The steam consumption for regeneration is somewhat reduced due to the increase in vapor pressures in the selections, so to save the sum (G_{unh}+G_{bnh}) it is necessary to reduce the steam flow rate to the turbine and thereby further reduce the power of the turbine.

The increase in steam pressure in the process of selection for the heat production allows reducing the electric power of the turbine while maintaining the thermal power capacity. The range of power reduction is limited by the maximum pressures in the upper selection determined by the manufacturer. The range of power reduction depends on the initial steam pressure in the upper selection: the lower the pressure is the greater the depth of turbine's discharge. Consequently, the depth of turbine’s discharge increases with the temperature of the outside air.

The temperature of the network water behind the UNH increases due to the increase in steam pressure in the upper selection, but after mixing the network water flow after UNH with the flow of water supplied through the bypass line, the temperature of the direct supply water will be equal to its initial value. Since the total flow of the network water has not changed, the heat absorbed by the water will remain unchanged.

Thus, it can be concluded that if a part of the regeneration selections (selections for HPH) is cut off, it is possible to reduce the steam flow to the turbine by the same amount.

In heat-recovery turbines approximately 15-20% of electricity is produced by a steam of regenerative sampling, that is, the regulation by the variable regeneration coefficient changes the power within these limits [10-12]. The calculations performed for STU T-100-130 are shown in Fig. 2

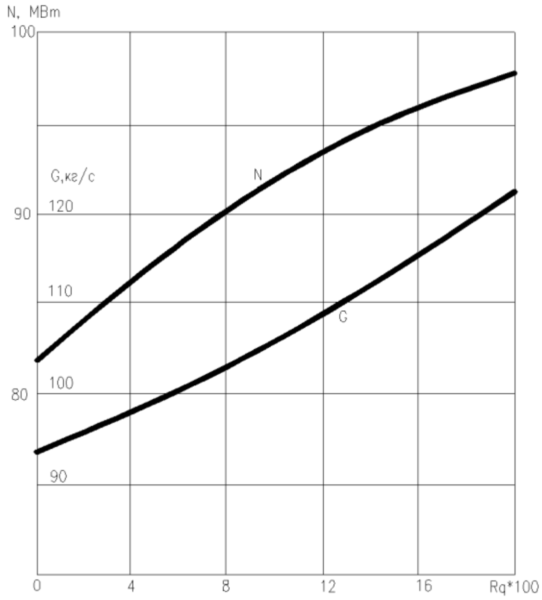

Fig. 2. Dependence of turbine T-100-130 characteristics on the coefficient of heat regeneration.

If the heat regeneration factor is changed from 0.2 to 0, the electric power is reduced from 98 to 81 MW with a decrease in steam consumption from 122 kg / s to 93 kg / s, hence this method of reducing the technological minimum is very effective for thermal stations [6,7].

STU bypass research showed that:

1. Bypassing of some part of feedwater around the STU can be an effective method of unloading.
2. Decrease in feedwater temperature in the regime of free distribution of feed water is not much higher than in the initial state, which does not affect the reliability of the pipelines and the heating surfaces of the boiler.
3. The use of this method leads to a decrease in steam consumption for the turbine and a decrease in electric power by 15-20%. The heat release from the turbine selections remaines unchanged.
4. In heat-recovery turbines approximately 15% of the electricity is produced by the steam of the regenerative sampling, that is, the regulation by the variable regeneration factor changes the power within these limits [13-15].

Based on test data, the average duration of the heating period and the duration of the night off-peak, we calculated possible fuel economy, which is 6400 tons of reference fuel. (0.68% of the average annual consumption).

To assess the possible environmental aspects of reducing the technological minimum by bypass method pollutants emission were calculated (applying LDPE bypass method and not using it), the results are given in Table 2.

Table 2.Pollutants emission

	NO		NO2		SO2	
	Emission (tons per year)	MAE (tons per year)	Emission (tons per year)	MAE (tons per year)	Emission (tons per year)	MAE (tons per year)
1working mode	511,008	510,6	2501,369	3142,1	21,097	5855,5
2 pworking mode	507,786	510,6	2484,321	3142,1	20,937	5855,5

As can be seen from Table 2, the decrease in the technological minimum did not significantly affect the amount of pollutants emission, but allowed to meet the maximum allowable emission (MAE) in NO. Table 3, 4 shows the results of calculations of fees for pollutants emission. Since the excess of MAE was small, the savings on the payment for emissions also turned out to be insignificant and amounted to 4017.37 rubles.

Table 3. Fee for pollutants emission (1 working mode)

Name of pollutants	MAE	Emission	Also within the limits of		Standard fee	Amount of payment for		
			MAE	>ПМАЕ		MAE	>MAE	Total
Nitrogen dioxide	3142,1	2501,369	2501,369	-	52	419089,37	0,00	419089,37
Nitric oxide	510,6	511,008	510,600	0,408	35	57580,36	1150,25	58730,62
sulphur dioxide	5855,5	21,097	21,097	-	21	1427,47	0,00	1427,47
					Total:	478097,20	1150,25	479247,45

Table 4. Fee for pollutants emission (2 working mode)

Name of pollutants	MAE	Emission	Also within the limits of		Standard fee	Amount of payment for		
			MAE	>MAE		MAE	>MAE	Total
Nitrogen dioxide	3142,1	2484,321	2484,321	-	52	416233,08	0,00	416233,08
Nitric oxide	510,6	507,786	510,600	-	35	57580,36	0,00	57580,36
sulphur dioxide	5855,5	20,937	20,937	-	21	1416,64	0,00	1416,64
					Total:	475230,08	0,00	475230,08

Emissions of the main pollutants (nitrogen dioxide and sulfur dioxide) from two power units of CHP were calculated the following way:

$$\text{Nitrogen dioxide emission (NO2)} = m\cdot Ql\cdot KNO2\cdot(1-\beta)\cdot 10\text{-}3,$$

where: Ql- net calorific value of fuel, m – amount of fuel spent, KNO2 - a parameter characterizing the amount of nitrogen oxides generated per GJ of heat, kg/GJ, β - coefficient, depending on the degree of reduction of nitrogen oxides emission. Calculation of Nitric Oxide (NO) emission is similar to the calculation of Nitrogen Dioxide (NO2) emission. Determining the quantity of sulfur dioxide emission:

$$\text{Sulfur dioxide emission (SO2)} = 0{,}02\cdot m\cdot S\cdot(1-\eta')\cdot(1-\eta''),$$

where: S - sulfur content in fuel; η′ - fraction of sulfur oxides bound by fly ash of fuel, η″ - fraction of sulfur oxides trapped in the ash collector.

As can be seen from Tables 2 and 3, the decrease in the technological minimum had no significant effect on the amount of pollutant emissions, but it allowed to meet the regulatory requirements for maximum permissible emissions, which is not always possible when the power unit is operating in nominal mode. [16-18].

Conclusion

Performed calculations make it possible to evaluate the efficiency of the LDPE bypass method for reducing the technological minimum. Given the high cost and the amount of energy consumption, this method will save a significant amount of money due to fuel economy. The reduction of pollutant emissions at CHP was not so noticeable; however, at the country level application of this method can have a significant positive effect on the ecological situation.

The problem of using this and other methods to reduce the technological minimum lies in the field of operational dispatch management. A competent distribution of loads of generating equipment will allow the most efficient use of energy resources, which in its turn will have a positive environmental impact [19, 20].

Acknowledgments

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