Calculation methods of power efficiency of combined heat and power plant at change of equipment operating modes and thermal schemes

M M Zamaleev¹, I V Gubin¹, V I Sharapov¹ and E N Bushuev²
¹Ulyanovsk State Technical University, 32, Severny Venetz str., 432027 Ulyanovsk, Russian Federation
²Ivanovo State Power Engineering University named after V.I. Lenin, Rabfakovskaya Street, 34, 153003, Ivanovo, Russian Federation

E-mail: mansur_zamaleev@mail.ru

Abstract. Existing methods for determining the energy efficiency of thermal power plants are considered. Described are mathematical models and software products developed by the authors that combine the method of specific electric power generation by thermal consumption and the methodology for estimating the energy efficiency of the TPP operation in accordance with RD 34.08.552-93 and RD 34.08.552-95, to determine the thermal efficiency of the TPP.

1. Main part
In modern conditions of regulated economic relations in the sphere of formation of tariffs directly depends on the heat and electric power industry indicators of thermal efficiency of TPP.

Until 1996, the TPP of RAO "UES of Russia" used a balance sheet ("Physical") method of calculating fuel consumption for each type of energy [1], based on the calculation of the balance equations of energy flows without taking into account the second law of thermodynamics. The basis of this method is the principle of qualitative equality of electric and thermal energy from heating is. With this calculation, it is assumed that the amount of heat given off by the steam in the condenser, and the same amount of heat obtained in the power boiler, are equivalent. Calculations are based on the law of conservation and transformation energy, i.e. the first law of thermodynamics. In accordance with this method, all the economy of fuel related to electrical energy, and the cost of production of heat corresponded to the release of it directly from power boilers. High tariffs for heat (depending on its cost price) determined in 1992 – 1994 mass construction of individual boiler houses at industrial enterprises.

The application of the "physical" method to the conditions of the collapse of the system state planning and unsystematic decision-making about construction of boiler houses caused the outflow of heat consumers from TPP and industrial consumers to own sources of heat supply. From 1985 to 1995, heat output from TPP decreased by 164 million Gcal, or by 23%, which necessitated the transition of the industry to a presently the method of separate energy production [2]. On power plants, this method is often called "proportional".

Since 1996, the method [2] has been used as officially recognized in the electric power industry. Unlike the physical method distribution of fuel costs, the method of separate generation of energy the value of steam from the selection of turbines that provide heat energy by combined cycle. As a result, the introduction of the separate production has led to the fact that the value of specific consumption of
conventional fuel (URRT), attributable to the heat supply from TPPs, decreased in the industry as a whole by 29kg/Gcal (from 175 to 146kg/Gcal), and the value of GRPT for electricity supply increased by 34g/(kWh) – from 312 to 346g/(kWh) [3].

The disadvantages of the methods for estimating thermal efficiency TPP described above in accordance with RD 34.08.552 is the need for a significant amount of input data and labor-intensive calculations.

To assess the energy efficiency of structural changes in thermal schemes of thermal power plants in the research laboratory "Heat power systems and installations" (NIL TESU) of Ulyanovsk State Technical University was developed a methodology [4], based on the use of such an index of thermal efficiency as specific power generation by heat consumption (UVETP). When calculation of indicators of energy efficiency by UVETP method takes into account the value of specific power generation due to steam sampling turbine and regenerative heating of steam condensate used for heating the coolant:

\[
\nu = \frac{\sum_{i=1}^{n}(N_{hp,i} + N_{reg,i}) - N_{on}}{G}, \tag{1}
\]

where \(\nu\) is the specific generation of electricity by thermal consumption, (kWh)/t; \(G\) – coolant flow, t/h; \(N_{hp,i}\) – power, developed by the turbine unit on heat consumption due to steam sampling for heating of coolants on the \(i\)-th section of the installation scheme (additional heating power), kW; \(N_{reg,i}\) – the power generated by the steam of regenerative fumes during heating condensate of steam used to heat the coolant at the \(i\)-th section schemes, kW; \(N_{on}\) – power consumed by pumps, kW.

Capacity \(N_{hp,i}\) is calculated as:

\[
N_{hp,i} = D_{i}(h_{o} - h_{i})\eta_{em}, \tag{2}
\]

where \(D_{i}\) – consumption of steam released from the selection for heating the heating medium, kg/s; \(h_{o}, h_{i}\) – enthalpy of hot steam and steam from the \(i\)-th selection, kJ/kg; \(\eta_{em}\) – electromechanical efficiency of turbine generator.

The power \(N_{reg,i}\) is determined by the formula:

\[
N_{reg,i} = D_{reg}(h_{o} - h_{reg}^{e})\eta_{em}, \tag{3}
\]

\(D_{reg}\) – is the conditional equivalent steam consumption for regenerative heating of the \(i\)-th condensate condensate after heating of the coolant at the \(i\)-th section of the circuit, kg/s; \(h_{reg}^{e}\) – enthalpy of conditional equivalent regenerative selection, kJ/kg.

The power consumed by pumps \(N_{on}\) can be represented as:

\[
N_{on} = \frac{G_{j}\Delta p}{\eta_{p}}, \tag{4}
\]

\(\Delta p\) – the pressure created by the pump, MPa; \(G_{j}\) – the flow rate of the accounted flow, t/h; \(\eta_{p}\) – efficiency of the pump.

Saving of the conventional fuel \(\Delta B\), t, is determined by the difference \(\Delta \nu_{hp}\), (kWh)/m:

\[
\Delta B = \Delta \nu_{hp}(b_{sc} - b_{sh})G_{tot} \cdot 10^{-3}, \tag{5}
\]

\(b_{sc}\) – specific consumption of conventional fuel for condensing electricity generation, kg/(kWh); \(b_{sh}\) – specific fuel consumption for heat production of electricity, kg/(kWh); \(G_{tot}\) - total coolant flow in the mode under consideration, t.
The application of the UVET technique allows rapid and sufficient technical calculations accurately assess the change in thermal efficiency TPP in tons of equivalent fuel using the minimum quantity source data. However, the main drawback of the method is the absence of the possibility of estimating the values of unit costs of the conditional fuel for the release of thermal and electric energy, as well as the main technical-economic indicators (TEP) of TPPs.

This drawback was excluded in the mathematical models developed by the authors, which combine the method of specific power generation by thermal consumption [4] and the methodology for assessing the energy efficiency of the TPP operation in accordance with RD 34.08.552-93 "Methodological guidelines for compiling a report of power plants and the joint-stock company of energy and electrification of the thermal economy of equipment" and RD 34.08.552-95 "Methodological guidelines for compiling the report of the power plant and the joint stock company of energy and electrification on the thermal efficiency of equipment".

The developed mathematical models allow calculating technical and economic indicators of the TPP in accordance with the methods officially recognized in the electric power industry. The main advantage is the ability to quickly estimate the amount of electricity generated by heat consumption when changing the scheme or operating mode of the TPP with subsequent consideration of this value when calculating the TEI in accordance with RD 34.08.552-93 or RD 34.08.552-95.

For the automation of calculations, the developed mathematical models are realized in the form of software complexes for a computer:

1. Calculation of the thermal efficiency of TPP in accordance with RD 34.08.552-93 "Methodological guidelines for the compilation of the report of the power plant and the joint stock company of energy and electrification on the thermal economy of equipment".
2. Calculation of the thermal efficiency of TPP in accordance with RD 34.08.552-95 "Methodological guidelines for compiling the report of the power plant and the joint stock company of energy and electrification on the thermal efficiency of equipment".

A distinctive feature of the design model for RD 34.08.552-95 in comparison with the "physical" method (RD 34.08.552-93) is the need to calculate additional indicators, such as:

- coefficient of the value of heat released from the selection of turbines;
- increase in heat consumption for electricity production with a conditional absence of heat supply to external consumers from the selection and from condensers of turbines;
- coefficient of fuel consumption increase by boilers in case of conditional absence of heat supply to external consumers from the selections and from the condenser of turbines;
- coefficient of increase in heat consumption for electricity production with a conditional absence of heat supply to external consumers from the sampling and from the condenser of turbines;
- coefficient of attributing fuel costs to power generation by power boilers.

At present, the calculation of the indicators of thermal efficiency at the TPP, as a rule, is carried out by both methods as in accordance with RD 34.08.552-93, and RD 34.08.552-95.

Conducted in accordance with RD 34.08.552-93, RD 34.08.552-95 and IUECP showed comparability of the results of calculating the heat efficiency of TPP. The deviation of the results of calculating the savings of conventional fuel by the methods considered is 0.7%. Convergence of the results of calculation of fuel economy is also confirmed for other options for optimizing the thermal schemes and operation modes of the TPP. Thus, the obtained results allow us to conclude that calculations of the absolute values of fuel savings, carried out according to the procedure of RD 34.08.552-93, RD 34.08.552-93 and SGETC, give a comparable result.

The use of the developed software packages allows to evaluate the thermal efficiency of the TPP by two methods with minimal time spent on performing calculations. The peculiarity of the developed programs is the ability to perform verification of the calculated mathematical models for the existing operating mode of the TPP (before making changes to the heat circuit or operating mode). Subsequent calculations for new heat circuits or operating modes are performed using a verified mathematical model, which allows obtaining reliable values of changes of indicators of economy of TPP.
It should be noted that at present software packages developed by the authors are used in Ulyanovsk PC "T Plus" with monthly and daily calculations of the thermal efficiency of equipment in preparation of price bids for the wholesale electricity and capacity market, as well as for assessing the impact of structural and regime changes in TPP schemes on TEI.

Conclusions
1. Mathematical models have been developed to estimate the thermal efficiency of TPP, combining the method of specific generation of electric power at thermal consumption and officially recognized in the electric power industry methods for assessing the energy efficiency of the TPP operation in accordance with RD 34.08.552-93 and RD 34.08.552-95.
2. For the automation of calculations, the developed mathematical models are realized in the form of software complexes for a computer:
   – Calculation of the thermal efficiency of TPP in accordance with RD 34.08.552-93 "Methodological guidelines for the compilation of the report of the power plant and the joint stock company of energy and electrification on the thermal economy of equipment."
   – Calculation of the thermal efficiency of TPP in accordance with RD 34.08.552-95 "Methodological guidelines for the compilation of the report of the power plant and the joint stock company of energy and electrification on the thermal economy of equipment."
3. The proposed mathematical models and software complexes developed on their basis allow the calculation of technical and economic indicators of the TPP operation, including specific fuel consumption, for existing and prospective regimes, as well as to make a rapid assessment of the influence of the amount of electricity generation on heat consumption when changing scheme or mode of operation of the TPP for thermal efficiency in the calculation of TEI in accordance with RD 34.08.552-93 and RD 34.08.552-95.

References
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