Optimizing the Operating Modes of Cogeneration Stations
Taking Actual State of Main Equipment into Account

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Abstract—A software system is developed that allows the operating conditions of a cogeneration station to be
optimized taking into account the actual state of main equipment estimated from the values of parameters mea-
sured at different points of the technological circuits of steam boilers and turbines.

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Improvement of the power and economic efficiency of
cogeneration stations (CSs) is a very important prob-
lem. Optimizing the operating conditions of CSs is one
of the main ways for solving it. This problem was con-
sidered in many papers [1–3 and others]; however,
these studies were, as a rule, carried out using simpli-
fied models of equipment, which were not adjusted in
accordance with the actual state of this equipment.

A software system has been developed at the
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using which optimization calculations of CS
operating conditions can be quickly carried out. Meth-
ods and software for mathematical modeling and optim-
ization of thermal power installations are at the heart
of this software system [4, 5]. The complexity of tech-
nological circuits, the variety of types and characteris-
tics of power installations, and variable external con-
ditions under which they perform their functions are fac-
tors that make the problem of optimizing the operating
conditions of CSs quite complex and generate the need
of tuning the characteristics of main equipment in line
with its actual state. A technique for identifying (tun-
ing) the mathematical models of main power-generat-
ing equipment from the values of parameters (flow-
rates, temperatures, pressures, and others) measured at
different points of the technological circuits of steam
boilers and turbines was therefore developed and
implemented as part of the software system. This paper
presents detailed mathematical models of main equipment
that describe the processes in this equipment with
sufficient accuracy. On the basis of a check calculation,
the detailed models of steam turbines have been developed that take
into account the flow path (at the level of steam turbine
compartments) and the regeneration system; there is
possibility of carrying out calculations in configura-
tions with disconnected regeneration heaters. Power-
generating steam boilers are simulated using a two-
stage approach. At the first stage, detailed models of
steam boilers intended for carrying out check calcula-
tions are used. These models are used for carrying out
boiler calculations at different steam outputs, outdoor
air and feedwater temperatures, etc. The results of these
calculations are used to construct simple dependences
relating the consumption of fuel to these indicators.
These dependences are then used to construct simpli-
fied mathematical models of boilers that are used to
develop a mathematical model of the entire power sta-
tion. The mathematical models of steam turbines and
the detailed models of steam boilers include coeffi-
cients (the internal relative efficiencies of turbine com-
partments, the boiler surface contamination factors, and
others) by adjusting which these models can be tuned to
the actual state of equipment.

PROBLEMS SOLVED BY OPTIMIZING
THE OPERATING CONDITIONS
OF A COGENERATION STATION

Several optimization problems can be solved in
managing the operation of a CS [6]. The software sys-
tem being considered can be used for solving any of
them.

Problem I. Given the specified electric load of the
station and heat loads of external consumers, it is nec-
essary to minimize the consumption of fuel by CS boil-
ers (or its total cost when different kinds of fuel are
fired):

$$
\min_{x} B^{CS}(x, y, N^{CS}, Q_1, \ldots, Q_s),
$$

(1)
subject to the following conditions:

\[
\begin{align*}
H(x, y, N_{CS}, Q_1, \ldots, Q_s) &= 0; \\
G(x, y, N_{CS}, Q_1, \ldots, Q_s) &\geq 0; \\
\lambda_{\min} &\leq x \leq \lambda_{\max},
\end{align*}
\]

where \(B_{CS}\) is the total consumption of fuel at the CS, \(x \in E_\lambda\) is the vector of independent parameters being optimized (flowrates of steam to the turbine condensers and steam from controlled turbine extractions, pressure upstream of the turbine control diaphragms, steam pressure in the peaking delivery-water heaters, and others), \(y \in E_y\) is the vector of dependent parameters being optimized (flowrates of live steam to the turbines, steam flowrates from uncontrolled turbine extractions, electric power outputs of the turbines, pressures in uncontrolled turbine extractions, and the like), \(N_{CS}\) is the useful electric power output of the CS, \(Q_i\) is the specified heat load of the \(i\)th external heat consumer, \(s\) is the number of external heat consumers, \(H\) is an \(m\)-dimensional vector function of equality constraints (it includes equations describing technological connections between circuit components, energy and material balances of elements of the CS technological circuit, and others), \(G\) is an \(l\)-dimensional vector function of inequality constraints (it includes limitations on the minimal and maximal values of such parameters as flowrates of live steam to the turbines, electric power outputs of the turbines, and others), and \(\lambda_{\min}\) and \(\lambda_{\max}\) are the minimal and maximal values of the vector \(x\).

A need to determine the minimal and maximal possible total useful power output of the station with the specified heat loads of consumers arises quite frequently in optimizing CS operating conditions; i.e., it is necessary to find the interval in which the CS power output can be varied. This boils down to solution of the following two problems.

**Problem II.** Given the specified heat loads of external consumers, it is necessary to minimize the total useful CS power output

\[
\min_x N_{CS}^x, \quad \text{subject to conditions (2)–(4)}.
\]

**Problem III.** Given the specified heat loads of external consumers, it is necessary to maximize the total useful CS power output

\[
\max_x N_{CS}^x, \quad \text{subject to conditions (2)–(4)}.
\]

Once problems II and III have been solved, problem I on determining the minimal consumption of fuel is solved for the obtained CS power outputs.

The maximal useful electric power output that can be obtained at the minimal flowrates of steam to the turbine condensers is frequently required to be known for efficiently managing the CS operation. This generates the need to solve problems I and III at fixed minimal flowrates of steam to the turbine condensers. By solving the totality of the above problems it becomes possible not only to optimize individual modes of CS operation, but also to construct power performance characteristics correlating the flowrate of fuel consumed by the station with its total electric power output at fixed heat loads. To do so, the minimal and maximal CS electric power outputs \(N_{CS}^\min\) and \(N_{CS}^\max\) are determined in solving problems II and III. After that, problem I is solved for a few values of power output lying in the found range \([N_{CS}^\min, N_{CS}^\max]\). The CS power outputs and the fuel flowrates corresponding to them that have been found in this way are used to construct a dependence (the station power characteristic) that relates the flowrate of fuel to the station power output. This characteristic is necessary for distributing electric loads among power stations in power systems.

**THE SOFTWARE SYSTEM**

The structure of the software system for optimizing CS operation modes is shown in Fig. 1. The software system allows the user to enter initial data on the loads of external consumers, on the state of CS equipment, and so on in convenient form, to obtain calculation results in the form of hierarchically organized technological diagrams and tables, and to carry out calcula-