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CALCULATION OF INPUT-OUTPUT CHARACTERISTICS OF POWER UNITS UNDER INCOMPLETE INFORMATION

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Optimal operation of power plants, electrical networks and power systems is a most important issue in conditions of the electricity market. There are many unsolved problems in the field of optimal operation of power systems and power plants which are usually tackled as deterministic ones. Actually the initial information is never complete. The information may be in several forms: probabilistic, uncertain and fuzzy. This paper presents the principles of optimum dispatch of thermal and electrical power between boilers and power units in power plants under incomplete information.

Introduction

This paper presents the principles for calculation of input-output characteristics of power units under incomplete information. The problem of computation of optimum schedules for active power generation in a power plant for a certain time period (day, week) is one of relevant optimization assignments in power plant control. Input-output characteristics of power units are the most important initial data for solving this task. Usually this problem is tackled as a deterministic one at which the objective function, constraints and uncontrollable factors are single-valued [1]. Actually the initial information is never complete. Neglect of these circumstances decreases the efficiency of optimization. Therefore, it is necessary to elaborate optimization methods of power plant state, which consider the actual incompleteness of the initial information. This paper describes a method which takes into account probabilistic and uncertain information.

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The initial mathematical model of a power unit

The input-output characteristic of a condensing unit can be presented as a composite function

$$C = cB(Q_T(P)) = C(P)\,, \tag{1}$$

where

c – price of fuel;
C– fuel cost of the unit;
P– power output of the unit;
$B(Q_B)$ – input-output characteristic of a boiler, assuming that $Q_B = Q_T$;
Q_T – heat input of the turbine;
$Q_T(P)$ – input-output characteristic of the condensing turbine;
$C(P)$ – input-output characteristic of the condensing unit.

Cost functions of condensing power units are usually continuous, piece-wise smooth and strictly convex.

The most important characteristic for solving the problem of optimum dispatch in a power plant is the characteristic of incremental cost rate:

$$\beta = \frac{dC(P)}{dP}\,. \tag{2}$$

If a power unit consists of a turbine and two boilers (double unit), the optimisation of a power unit control means optimal dispatching of thermal power of two boilers at turbine input. In Estonia, all oil-shale power units are double units.

Input-output characteristics of boilers and power units depend on lots of parameters, which are characterized by random deviations from their nominal or planned values.

For solution of optimal load dispatch in a power plant under incomplete information, the method of planned characteristics may be used [2, 3].

Computation of optimal load dispatch in a power plant under the probabilistic or uncertain information consists of two stages:

1. Computation of planned characteristics of power units and construction of deterministic equivalents.
2. Solution of deterministic equivalents.

Some results of statistical analysis of state parameters of power units and boilers

During many years the probabilistic characteristics of boiler's state parameters, boiler's load and power units' loads have been analysed in Estonian power plants. The fuel used in Estonian condensing power plants is oil shale. The effectiveness and reliability of oil shale-fired power plants depends on oil shale quality, especially on its heating value. The average heating value of oil shale consumed by power plants depends on the quality and quantity of the fuel supplied by mines and opencasts and has been changing over the years. Some results of statistical analyses of deviations of oil shale parameters in Estonian power plants are shown in Table 1 [5].

The results of statistical analysis of deviations in state parameters of power units and boilers are shown in Table 2.

Table 1. **The results of statistical analysis of oil shale parameters in Estonian power plants**

Parameter	Minimal value	Maximal value	Coefficient of asymmetry	Root-mean-square, %
Heating value, MJ/kg	9.8	13.2	0.02–0.14	0.25–0.45
Moisture content, %	11.3	13.3	0.11–0.64	0.29–0.39
Ash content, %	47.7	51.6	–0.2–0.03	0.22–0.37

Table 2. **The results of statistical analysis of deviations in turbine and boiler parameters**

Parameter	Mathematical expectation, %	Root-mean-square, %	Coefficient of asymmetry
Steam pressure	–5.8…–5.6	4.71–4.93	–2.4–1.51
Steam temperature	–5–3	1.11–2.36	–1.27…–0.25
Flue gas temperature	3.4–7.0	3.6–5.0	–2–2
Excess-air coefficient	5–6	0.14–0.19	0.23–1.03
Feed-water temperature	–1–15	4–6	–2…–1

Computation of planned characteristics under probabilistic information

Let us assume that all initial functions (characteristics of power units, of boilers and of auxiliary power) and uncontrollable parameters are random functions and variables, the initial information on which is available in probabilistic form. Input-output characteristics of boilers depend on flue gas temperature after the boiler, fuel parameters, etc. Turbine characteristics depend on vacuum in the condenser, steam pressure and temperature at the inlet of the turbine, etc. All these parameters are random. On the basis of probabilistic information, it is possible to calculate new characteristics of boiler and turbine by the following formulas [6]:

Boiler:

$$C_B(Q_B) = C_B(Q_B, m_{X1}, ..., m_{Xn}) + \frac{1}{2}\sum \frac{\partial^2 C_{Bj}(X)}{\partial X_j^2}\sigma_{Xj} + \frac{1}{2}\sum_{k=1}^{n}\sum_{j=1}^{n}\frac{\partial^2 C_B(X)}{\partial X_k \partial X_j}\cdot k_{Xk}k_{Xj} \tag{3}$$

Turbine:

$$Q_T(P) = Q_T(P, m_{X1}, ..., m_{Xn}) + \frac{1}{2}\sum \frac{\partial^2 Q_T(X)}{\partial X_j^2}\sigma_{Xj} , \tag{4}$$

where

m – mathematical expectations of parameters;

σ – root-mean-square of parameters.

These characteristics are the first-degree planned characteristics of units.

Figure 3 shows the planned incremental cost rate characteristics of a power unit.

If necessary, the planned cost rate and planned input-output characteristics of units can be calculated.

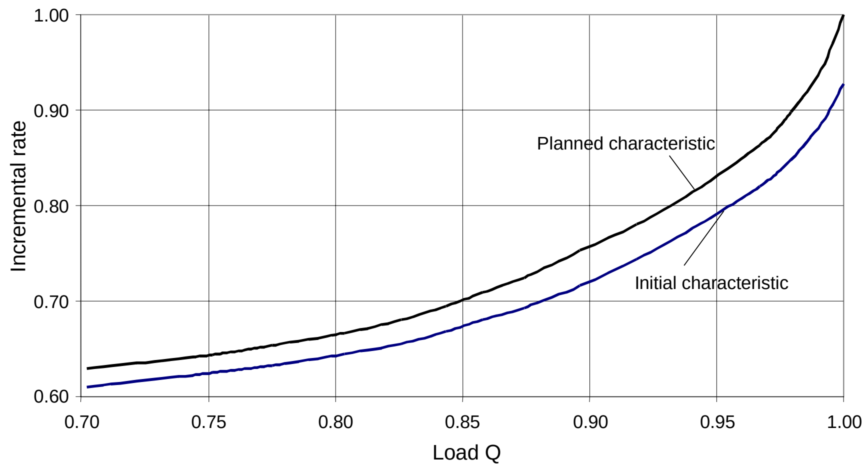

Fig. 1. Initial and planned characteristics of the boiler.

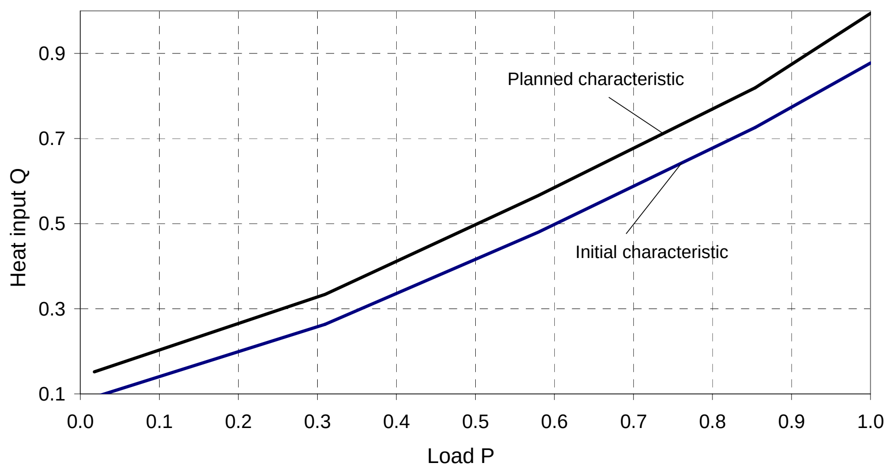

Fig. 2. Initial and planned characteristics of the turbine.

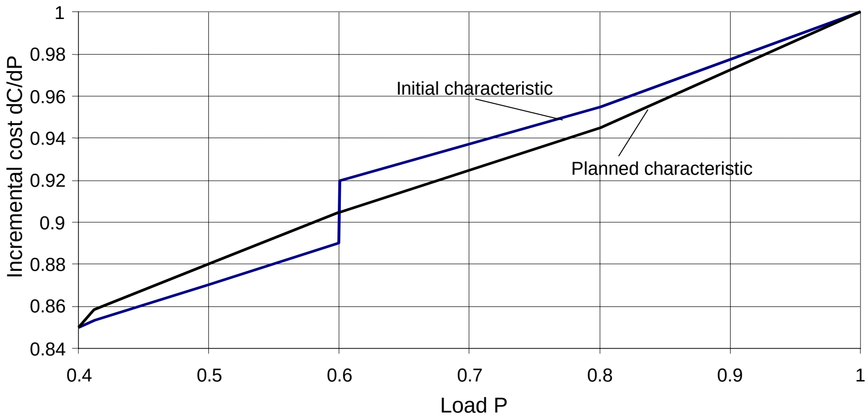

Fig. 3. Initial and planned incremental cost rate characteristics (in relative units) of the power unit.

Computation of planned characteristics under uncertain information

In this paper the uncertainty of information means that only intervals of values of functions (input-output characteristics) are given, not their concrete values. The values of functions at given intervals are uncertainties.

The first step in calculating the planned characteristics is the calculation of initial lower and upper incremental cost rate characteristics of power units.

The lower characteristic must be determined as a characteristic in the case of which all the operation parameters of the power unit are on the best level, and the upper characteristic – the one in the case of which all the operation parameters are on the worst level. For example: the worst fuel, the worst vacuum in the condenser, the worst state of furnaces of boilers and so on.

The lower characteristic of the power unit may be calculated by the formula

$$\beta^{-}(P) = \beta(P) - \sum k_i \cdot \Delta X_i^{-} \,, \tag{5}$$

where

$\beta(P)$ – initial characteristic of the incremental cost rate of the power unit;

k_i – correction coefficient of operation parameter deviation;

ΔX_i^{-} – deviation of operation parameter towards the direction which reduces the incremental cost rate of the power unit.

The upper characteristic of the power unit may be calculated by the formula

$$\beta^{+}(P) = \beta(P) + \sum k_i \cdot \Delta X_i^{+} \,, \tag{6}$$

where

ΔX_i^+ – deviation of operation parameter towards the direction which increases the incremental cost rate of the power unit.

The deviations of operation parameters in the oil shale power units are considerable.

The calculations show that the zone of uncertainty of incremental cost rate characteristics is about 10% in boilers, about 7% in turbines, and up to 20% in power units.

The min-max planned characteristics can be calculated by various approximate methods [3, 4].

The simplest method for calculation of min-max planned characteristics is as follows.

1. Choose different values of incremental cost rate of a power plant.
2. Calculate the min-max load distribution by chosen values of incremental cost rates.

Min-max incremental fuel cost characteristic of a boiler is shown in Fig. 4. The point of the planned incremental cost characteristic $\beta(\overline{P})$ is found on condition that $S_1 = S_2$.

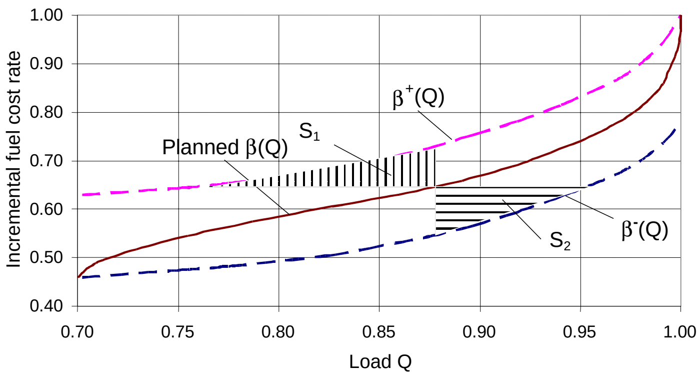

Fig. 4. Initial (lower and upper) and planned characteristics of a boiler.

Figure 5 shows the planned incremental fuel cost rate characteristic of a power unit.

After determining the planned characteristics for min-max task, the common deterministic task of optimization with planned characteristics subject to constraints will be solved.

The deterministic equivalent may be solved by ordinary computer programs and methods, which have been elaborated for solution of deterministic optimal scheduling problems in thermal power plants.

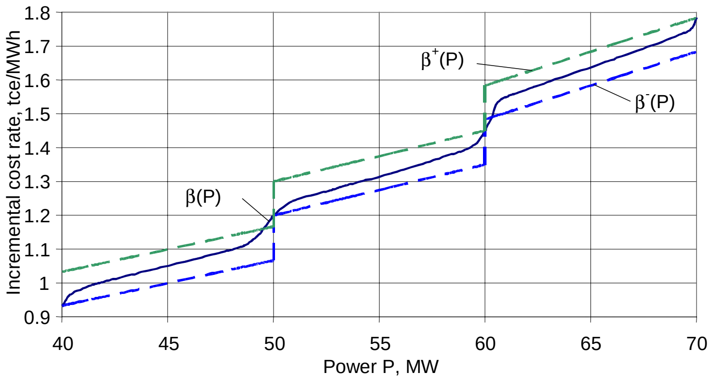

Fig. 5. Initial and planned incremental fuel cost rate characteristics (in relative power units) of a power unit.

Computer programs

The methodology described above was realized in a complex program at Tallinn University of Technology. The modules for state optimization enable to compute planned input-output characteristics of power units under probabilistic and uncertain information and solve the optimization problem in power plants. The program may be used as a supplement for the existing software.

Conclusions

The methodology described here enables a rather simple use of probabilistic and uncertain information in optimal dispatching of power plants. The method of planned characteristics is also used in the software for optimal scheduling of power generation at the power system level.

The optimal load dispatch on the basis of fuzzy information will be our subsequent object of interest.

The method of optimal dispatch in power plants which takes into account the probabilistic information about random factors enables economy of fuel by up to 1.5%.

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