Optimization of operating modes of the equipment on the example of a co-generation thermal power plant

A V Neklyudov, A V Andryushin, E K Arakelyan and K A Andryushin

1 National Bureau of Informatization, Russia, 107023 Moscow, Bolshaya Semynovskaya 11
2 National Research University "Moscow Power Engineering Institute" Russia, 111250 Moscow, Krasnokazarmennaya, 14

Abstract. The approach described in the article allows to solve the problem of the unit commitment and the equipment mode planning for power plants with cross-connections and several group points of supply for a period of several days with an hour resolution taking into consideration integral limitations for the quantity of the fuel used in the period under consideration.

Optimal control of modes of the equipment of power plants with complex mix means solving two problems that are very important for the modern power engineering. The problems are unit commitment and optimal distribution of the heat and electric load between generating equipment. These problems are necessary to solve in order to enter the power joint market and thus obtain maximum profit from selling heat and electrical energy.

However, the problems mentioned are interconnected, according to the Power joint market regulations they should be solved separately in time. The first problem is solved in the period from 6-7 hours to operational day, the second – two days ahead when the price bids for participation in the market are prepared and when the dispatch schedule is fulfilled i.e. in the mode that is very close to the real-time one. At the same time, it is obvious that the unit commitment without the equipment modes optimization may lead to a non-optimal unit mix and corresponding economic results [1].

This paper offers an approach based on the preliminary simplified load distribution optimization at the stage of the unit commitment.

Let us consider a co-generation thermal power plant with cross-connections as an example of a complex technological object. The optimization criterion is the power plant marginal profit on sales of energy that is equal to the power plant income from the participation in the power joint market and the heat supply with the deduction of the consumed fuel cost.

The optimization problem is considered with the following assumptions:

1. It is assumed that the heat load for each group point of supply (GPS) is known (as a result of a forecast) and the heat is supplied to consumers with a known tariff;
2. The paper considers only the power plant marginal profit on sales of electric energy (the power plant income from the power sales can be considered to be constant at this stage);
3. It is assumed that power of auxiliary mechanisms depends on the quantity of the electrical energy generated and is bought at the electrical energy market with the market price of the electrical energy for this GPS.

The objective function of the maximization of the marginal profit is:
minimize \[ \sum_{t \in time, i \in GTP} (GPS_{i,t} \cdot Price_{GPS,i,t}) - \sum_{t \in time, f \in Fuel} (Price_{Fuel} \cdot Volume_{Fuel}) \] (1)

The balance constraint for heat supply to the consumers is given by relation (2)
\[ \sum_{j=1,n} Q_{j,t} = Q_t \] (2)

The integral fuel limit in the time for each kind of fuel is given by relation (3)
\[ \sum_{t} Fuel_{f,t} = Fuel_f \] (3)

Where:
- \(GPS_{i,t}\) is the electric energy being sold at the moment \(t\) from the \(i\)-th GPS. (A GPS consists of one or several generating units);
- \(Price_{GPS,i,t}\) is the price of electrical energy for each GPS at the moment \(t\);
- \(Price_{Fuel}, Volume_{Fuel}\) are the price and the volume of the fuel consumed for moment \(t\);
- \(j\) is the index of the generating unit; \(f\) is the index of the fuel kind.

One can define several stages during the co-generation plant model development:

Stage 1: the mathematical model of the technological process is developed. At this stage, the model is developed as a set of equations solved on by one. Standards and technical documentation are used as a basis for the calculations.

Stage 2: verification of the technological process mathematical model is carried out; expert correction of some parts of the model based on real data is carried out.

Stage 3: The optimization model is formed that can differ from the mathematical model. While developing the model it is necessary to satisfy the constraints that the optimization method used imposes. In the example under consideration, the problem is the one of the mixed linear integer programming (MLIP).

When the optimization model is developed the decomposing of the power plant equipment into several groups is made. Each group is described as an element of the optimization model. The simplified diagram of a power plant is given in Figure 1.

**Figure 1.** The simplified diagram of a power plant
The main elements of the optimization model are boilers, turbines, heaters, high, average and low pressure steam chests, main and peaking water heaters, line heaters. Auxiliary equipment is taken into account by means of corrections on the main equipment characteristics.

A co-generation turbine can work in several modes. In order to describe each of them a dependency of the optimizable parameters is developed. The dependency is given as a set of points defining a surface, for example, a dependency of the main steam rate $D_0$ from the heat extraction $Q_t$ and electric generation $N$: $D_0(Q_t, N)$. The set of points forms a characteristic surface of the equipment work mode (Figure 2).

![Figure 2. A characteristic surface](image)

### Figure 2. A characteristic surface

Let us consider an example of parametrization for a piecewise linear function of one variable $F(X)$:[2]:

$$X = I_1 X_1 + \alpha_1 (X_2 - X_1) + I_2 X_2 + \alpha_2 (X_3 - X_2) + I_3 X_3 + \alpha_3 (X_4 - X_3)$$  \hspace{1cm} (4)

$$F = I_1 F_1 + \alpha_1 (F_2 - F_1) + I_2 F_2 + \alpha_2 (F_3 - F_2) + I_3 F_3 + \alpha_3 (F_4 - F_3)$$  \hspace{1cm} (5)

$$I = \sum_{i=1}^{3} I_i$$  \hspace{1cm} (6)

$$0 \leq \alpha_i \leq I_i \forall i \in \{1..3\}$$

Nine variables are necessary to describe a piecewise linear function consisting of four points mode (Figure 3).

The quantity of the variables is determined by the quantity of points defining the surface, the minimization of the quantity of the points describing the surface is important.

The time which is necessary to find the solution of the MLIP problem depends on the quantity of the variables and because of it the quantity of the points should be minimized. It is carried out when the optimization model is developed.

![Figure 3. Parametrization of a piecewise linear function](image)
Figure 4.1. Original surface

Figure 4.2. Smoothed surface

Figure 4.1 gives the original surface and Figure 4.2 gives the smoothed. This is an example of reducing the number of points.

When all the model components and connections between them are described the scenario calculations are prepared:

- Scenario 1: The calculation of the real modes of the equipment.
  This scenario is for calibration of the optimization model on the basis of the real data.
- Scenario 2: The working units commitment and the load distribution.
  This scenario is for solution of the unit commitment problem.

The cost benefit achieved from the co-generation power plant optimization system use can be from 1.5 to 6% of the cost of the fuel consumed. The cost-benefit is calculated as a difference between the marginal profits when the plant works on a real mode (scenario 1) and when the unit commitment problem is solved (scenario 2).

Reference

[1] Andryushchenko A I and Aminov R Z Optimization of the power plants operation modes and parameters (The Higher School 1983)

[2] Ahmadi H, Martí J R and Moshref A Piecewise linear approximation of generators cost functions using max-affine functions (In Power and Energy Society General Meeting July 2013) pp. 1-5.