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STUDY AND APPLICATION ON REAL TIME OPTIMUM OPERATION FOR PLANT UNITS

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ABSTRACT

The optimum unit commitment is to determine an optimal scheme which can minimize the system operating cost during a period while the load demand, operation constrains of the individual unit are simultaneously satisfied. Since it is characterized as a nonlinear, large scale, discrete, mixed-integer combinatorial optimization problem with constrains, it is always hard to find out the theoretical optimal solution. In this paper, a method combining the priority-order with dynamic comparison is brought out to obtain an engineering optimal solution, and is validated in a power plant composed of three 200MW and two 300MW units. Through simulating the on-line running datum from the DCS system in the power plant, the operating cost curves are obtained in different units, start-up/shut-down mode and load demand. According to these curves, an optimum unit commitment model is established based on equal-incremental rate principle principle. Make target function be minimum gross coal consumption, the results show that compared with the duty-chief-mode that allocates the load based on operators' experience, the units' mean gross coal consumption rate is reduced about 0.5g/(kW•h) when operating by this unit commitment model, and its economic profit is far more than the load economic allocation model that doesn't considered the units' start-up/shut-down.

INTRODUCTION

With Chinese electrical power technology development, electrical power system reformation has been carried out continuously, which induced the separation of network operation and generation, and made electric generation market competition necessary. Under the premise of ensuring safe operation, distributing load to every unit rationally in a whole power plant, so as to minimize the gross coal consumption, is the practical demand to power plant.

Currently, in most power plants in our country, load dispatch is depending on the traditional duty-chief-mode method based on operators' experience and commissioning tests, which usually make the economical and wealthy unit take heavier load, or make the same type units operate at the same load, even arrange the unit operate at random load according to the duty-chief's custom. Sometimes these methods may be feasible and in some range of loads units may be close to optimal operation. But since there exists quite difference in design, length of running time and maintenance status between different units, the economical performance is different between different types of units, even for the same type. On these conditions, the results from the traditional methods are much worse than optimal values. Based on the operating status in power plants, great efforts are devoted to study the economical dispatches in these years, so as to make power plant operate economically and achieve an optimal operating status.

At present, the economic dispatch in power plant is divided into two ways: load dispatch and unit commitment[1]. Unit commitment is the urgent problem in a short period generating plan. Because it is a nonlinear, large scale, discrete problem with constrains[2], it is difficult to find out the theoretical optimal solution when the system dimension is large. Development and research have been carried out from various algorithms, such as heuristic algorithm, dynamic programming, integer programming and hybrid integer programming, branch-and-bound approach, artificial neural network, genetic algorithm, ant colony optimization, social evolutionary programming[3-8], and so on. Based on diversity from each model characteristic, all algorithms can gain a good commitment result aimed to its own system. Of course, every algorithm has its own merits and faults. For example, dynamic programming is an ingenious mathematics method in multistage decision process, but for the complete state of dynamic programming, because the calculation quantity is too large, it is easy to come into being "curse of dimensionality". This paper researches the optimal unit commitment among three 200MW and two 300MW units for a power plant, using a method combining the Priority-order and dynamic comparing method, by which both the amount of calculation and optimization effect get a good result.

NOMENCLATURE

a	Coal consumption characteristic coefficient
b	Coal consumption characteristic coefficient
c	Coal consumption characteristic coefficient
B	Unit's coal consumption, g
b_s	Mean unit's coal consumption rate, g.Kwh^{-1}
f	Operating consumption function of unit
M	Unit's maximum permitted start-up/shut-down times
P_D	Given total load to be dispatched, MW
P_e	Unit output when it reach the minimum specific consumption, MW
P_H	Optimal progressing increasing load, MW
P_{min}	The low load boundary of Unit, MW
P_{max}	The upper load boundary of Unit, MW
S	Start-up/shut-down consumption function of Unit, g.Kwh^{-1}
S_n	Total load shared by n units
T_1	Unit's minimum permitted halted time, h
T_2	Unit's minimum permitted operating time, h
U	Operating status of Unit
μ	The specific consumption rate of unit

Subscripts

i	The No of power unit
n	The number of power unit in operation
t	Time block

ON-LINE POWER PLANT'S CONSUMPTION CHARACTERISTIC

The coal consumption rate is an integrative target that reflects energy conversion rate and perfect degree of thermal process. The character curve of unit's consumption rate is usually given by the manufacture factory, or obtained by scheduled thermodynamic tests. But with the variations of environment, operational mode, device status, technique level of the operators and coal type, the unit's consumption performance is changing continually. To calculate the unit's real-time consumption exactly, a dynamic detecting system is established in our research, which can access to DCS per 10 second to obtain datum. Those data that cannot be obtained automatically from DCS such as the primary analysis of raw coal, fly ash, slag and flue gas are taken manually, and then inputted into the computer directly. Based on these two kinds of data collection, a calculating module of the consumption character is established to calculate the unit's real-time consumption character (as showed in Fig. 1).

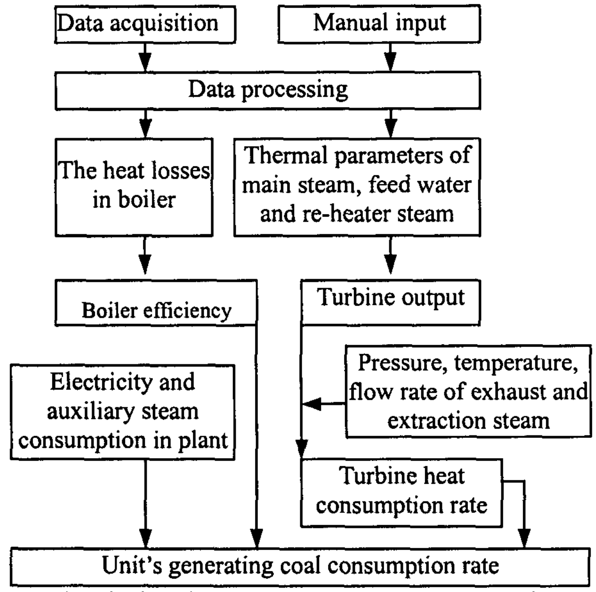

Fig.1.logical diagram of unit's consumption module

This module contains boiler thermal efficiency calculation and thermal principle system calculation, and the latter is divided into six sub-modules: turbine, re-heater, condenser, bleeder heater, deaerator and blow-down. Anti-balance method is used in boiler's thermal efficiency calculation; stable-power output method is used in unit's thermal principle system calculation.

OPTIMUM COMMITMENT MODEL

Based on the premise of load demand and constraint condition, unit commitment determines the schedule of starting up or shutting down unit in a period, minimizing the total consumption. In this model, one day considered as a period is divided into 24 time blocks; the system total consumption contains consumptions in operation and during starting up, as well as shutting down. The model is described as follow:

(1) Object function

Considering unit start-up/shut-down, each unit's coal consumption B_i is expressed as quadratic polynomial: $B_i = a_i P_{it}^2 + b_i P_{it} + c_i$, object function is expressed as following:

$$\min F = \sum_{t=1}^{T} \sum_{i=1}^{N} \left[U_{it} \cdot f_{it}(P_{it}) + U_{it} \cdot (1 - U_{it-1}) \cdot S_i(\Delta T_i) \right] \quad (1)$$

Where f_{it} is operating consumption of Unit i at t time block, S_i is start-up/shut-down consumption of Unit i, U_{it} shows operating status of Unit i at t time block.

$$U_{it} = \begin{cases} 1 & shows \quad operating \quad state \\ 0 & shows \quad halted \quad state \end{cases}$$

(2) Power balance constraint

$$\sum_{i=1}^{N} U_{it} P_{it} = P_{Dt} \quad (2)$$

(3) Power boundary constraint

$$P_{i\min} \le P_{it} \le P_{i\max} \quad (3)$$

(4) Start-up/shut-down times constraint

$$\sum_{t=1}^{T} \left| U_{it} - U_{it-1} \right| \le M \quad (4)$$

(5) Halted time constraint

$$U_{it}\left(U_{it} - U_{it-1}\right) \sum_{j=t-T_1}^{t-1} \left| 1 - U_{ij} \right| \ge T_1 \quad (5)$$

(6) Operating time constraint

$$U_{it}\left(U_{it-1} - U_{it}\right) \sum_{j=t-T_2}^{t-1} \left| 1 - U_{ij} \right| \ge T_2 \quad (6)$$

Where,

P_{Dt} is the power plant's total load at t time-block ordered by dispatch;

P_{imin}, P_{imax} is the upper and low load boundary of Unit i;

M is the unit's maximum permitted start-up/shut-down times;

T_1 is the unit's minimum permitted halted time;

T_2 is the unit's minimum permitted operating time.

OPTIMIZATION PRINCIPLE AND STEPS

Priority-order principle

In priority-order method, units are stacked according to the minimum specific consumption principle, that's means the unit whose specific consumption is least will be queued at first and start up firstly. While the unit, whose specific consumption is large, is queued at the end. Because the start-up/shut-down consumption is far less than the operating consumption, it is ignored in this paper, and units are queued directly according to the specific operating consumption.

$$\mu_i = a_i p_i + b_i + c_i / p_i \quad (7)$$

Where, μ_i is the specific consumption of unit i, p_i is its power output, a_i, b_i, c_i are coefficients from consumption characteristic calculation module. Suppose specific consumption μ_i reaches minimum when unit output is p_e, thus,

$$\frac{d\mu}{dp_i}\Big|_{p=p_e} = a_i - \frac{c_i}{p_e^2} = 0 ; \quad p_e = \sqrt{c_i} / a_i \quad (8)$$

$$\begin{cases} when \quad p_e \ge p_{i\max}, p_e = p_{i\max} \\ when \quad p_e \le p_{i\min}, p_e = p_{i\min} \\ when \quad p_{i\min} \le p_e \le p_{i\max}, p_e = \sqrt{c_i} / a_i \end{cases} \quad (9)$$

thus, $\mu_{\min} = a_i p_e + b_i + c_i / p_e$ (10)

Dynamic comparing principle

Suppose a load is P_H, which can be shared by n or $n+1$ units together, and is distributed according to the equal-incremental rate principle. When n units share the load, regarding n units as a whole one, its equivalent operating consumption is:

$$B_n = \sum_{i=1}^{n} (a_i P_i^2 + b_i P_i + c_i) = a_n P_H^2 + b_n P_H + c_n \quad (11)$$

Where,

$$P_H = \sum_{i=1}^{n} P_i$$

$$a_n = 1 / \sum_{i=1}^{n} \frac{1}{a_i}$$

$$b_n = \sum_{i=1}^{n} \frac{b_i}{a_i} / \sum_{i=1}^{n} \frac{1}{a_i}$$

$$c_n = \sum_{i=1}^{n} \left(\frac{b_n^2 - b_i^2}{4a_i} + c_i\right)$$

In order to make the operating consumption in $n+1$ units commitment scheme less than n units commitment scheme, the following equation must be satisfied:

$$a_n P_H^2 + b_n P_H + c_n > a_n P_{sn}^2 + b_n P_{sn} + c_n + a_{n+1} P_{n+1}^2 + b_{n+1} P_{n+1} + c_{n+1} \quad (12)$$

Where, P_{sn} is the total load shared by the former n units, P_{n+1} is the load shared by No. $n+1$ unit, and the following equality is satisfied:

$$P_H = P_{sn} + P_{n+1} \quad (13)$$

Since the load distribution among $n+1$ units is still following equal-incremental rate principle, thus equation (13) can be deduced as following [9]:

$$P_H > \frac{2\sqrt{c_{n+1}(a_n + a_{n+1})} + b_{n+1} - b_n}{2a_n} \quad (14)$$

That's means, when the dispatched load is satisfied with inequality (14), according to the priority-order principle, the unit No. n+1 can be added in the commitment to reduce the total operating consumption.

Basic steps of optimization program

At first, the priority-order principle is used to determine the order of units, and then dynamic comparing method is used to obtain the optimal progressing increasing load. In the scheme, according to the equal-incremental principle, load dispatch is determined by each unit's consumption characteristics. The process can be listed as following:

1. Queue units from least to most according to μ_{min};
2. Determine the number n of un-halted units at current given load P_D;
3. Determine the optimal progressing increasing load P_{Hn+1} according to inequality (14);
4. According to unit's priority-order, add one unit as n+1, starting from n units;

When $P_D > P_{Hn+1}$, Unit $n+1$ start-up at the time of t;

When $P_D < P_{Hn+1}$, Unit $n+1$ don't start-up at the time of t;

5. According to the optimal progressing increasing load, seek the optimum distribution using equal incremental principle in this commitment;

6. Return to step 3, re-calculate the optimal progressing increasing load until $P_{Hn+1} > P_D$.

OPTIMIZATION RESULTS AND COMPARISON IN ECONOMIC EFFICIENCY

Using this optimization scheme, five units (three 200MW and two 300MW units) in the power plant are committed in various dispatch loads, whose generating coal consumption characteristic curves are shown in Figure 2.

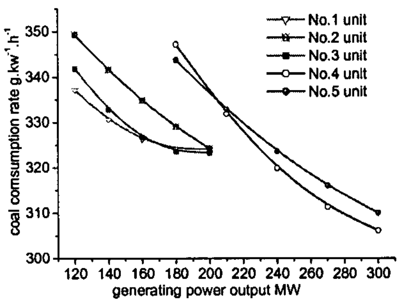

Figure 2. coal consumption characteristic curves

Compared the results from commitment with those from the duty-chief-mode and economic allocation that not considering start-up/shut-down, the advantage of the commitment model is shown in table 1, in which *bs* means the mean generating coal consumption rate.

Table 1. Comparing results from various distributions' schemes

Dispatched load MW	Method	No. 1 MW	No. 2 MW	No. 3 MW	No. 4 MW	No. 5 MW	*bs* g/kw.h
700	1	0	0	150	300	300	312.15
	2	120	120	120	210	180	339.82
	3	120	120	120	200	190	340.40
900	1	170	0	180	300	300	314.04
	2	120	120	120	290	300	321.68
	3	130	130	130	280	280	322.69
1100	1	140	200	160	300	300	316.42
	2	140	200	160	300	300	316.42
	3	170	170	160	300	300	317.06

Method: 1.Commitment; 2. Economic allocation; 3.Duty-chief-mode

It is shown in table 1 that because commitment dispatch considers every unit's start-up/shut-down process fully, its economic performance is far better than economic allocation schemes that don't consider start-up/shut-down process, especially when the total dispatched load is small which make units operate at conditions deviating far from designed condition. At the same time, in all situations, operating by commitment dispatch scheme, the mean generating coal consumption rate *bs* is less than the corresponding generating consumption operating by duty-chief-mode which dispatches according to experience,

CONCLUSIONS

The demanded load of electrical power system during one day is fluctuating continually; the load distribution adjustment is needed according to units' actual running condition simultaneously. In this paper, using a method combining the priority-order and dynamic comparing method, based on the equal-incremental rate principle, the unit commitment optimization model is established to minimum the generating coal consumption rate. Compared with the economic allocation scheme and duty-chief-mode scheme, the unit commitment scheme can receive better economic profits. The program of this optimization scheme can run fast, its applicability and mobility is great, and the system is dealt with modularization, suitable to the off-line or on-line optimization.

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