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Research On Thermal Power Plant Economic Dispatch Based On Dynamic Programming

Yun LI [1], Kailin JI [2], Pengyu ZHANG [3], Yanbin LI [2]

[1] *School of Electrical & Electronic Engineering, North China Electric Power University, Beijing, 102206, China*
[2] *School of Economics and Management, North China Electric Power University, Beijing, 102206, China*
[3] *Department of Electronic Engineering, North China Electric Power University, Baoding, 071003, China*

Abstract

For large multi-unit power plant, reasonable unit dispatch is closely related to the operating economy of it. In this paper, the application of dynamic programming on thermal power economic dispatch has been studied. First, put forward a unit commitment optimization model which can avoid frequent starts and stops. Then, elaborated the method how to apply dynamic programming method on the economic dispatch problem. Finally, established the characteristic curves of power units through real-time consumption data in SIS database and conducted a simulation operation on 4 parallel units of X plant. Results show that the economic dispatch model is correct and effective. Its application can bring significant economic and social benefits and has common practical value.

*Keywords:*Thermal Power Plant；Economic Dispatch; Dynamic Programming

1. Introduction

With the introduction and implementation of "energy-saving scheduling approach"[1], thermal power plants are facing enormous competitive pressure. Large-scale thermal power units must adopt effective strategies to reduce energy consumption, reduce emissions and improve the utilization hours in order to create more benefits and survive and develop in the fierce competition. Carrying out economic dispatch which can help to optimize the units operation level, reduce coal consumption and reduce emissions is an effective way to reduce power generation cost and enhance competitiveness.

Economic dispatch problem consists of two parts, one is unit commitment and the other is optimal load distribution[2]. At present, extensive researches have been done by many scholars both at home and abroad on the economic dispatch problem, many research findings emerged[3-9]. In ref. 10, optimal load distribution problem was discussed and a set of programs for solving the problem were put forward. Based on the result further research was carried out, an unit commitment judging model was introduced and used to solve the unit commitment problem.

At last, a simulation operation was conducted on 4 parallel units of X plant. Results show that the economic dispatch model is correct and effective. Its application can bring significant economic and social benefits and has common practical value..

2. Model For Thermal Power Plant Economic Dispatch

2.1. Unit Commitment Judging Model

For the unit commitment problem, many researchers have proposed various mathematical models and solution methods, such as mixed integer programming, Lagrangian relaxation, etc.,[11-12] to obtain the optimal solution in theory. However, in actual operation, the operating of unit commitment is complicated and could

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cause loss of life. Therefore, in the case of small load fluctuations, plant often choose low-load operation rather than start and stop units frequently in accordance with the theoretical optimal solution. Only when the low load lasts a long period, the measures to close unit will be considered. No matter from a security point of view or from an economic point of view it is more excellent. According to this thinking, we use the following method to determine the unit commitment.

In the low load, unit commitment is closely related to the running time under peaking. In determining the unit's start-stop state, there are usually two operation modes to select, one is all units operating with low-load, the other is shutting down some of them[13]. Compare and choose the mode with lower energy consumption. Between the two programs, there is a critical time. Over this time, the low-load operation losses will be greater than start-stop mode. The selection process can be expressed as the following formula:

$$\Delta B = \Delta B_1 + \Delta B_2 + \frac{P_3\tau_3}{60}(b_0^3 - b_0^n)\times 10^{-6} \quad (1)$$

Where ΔB is consumption loss of shutting down units; ΔB_1 and ΔB_2 are the fuel loss during increasing load and decreasing load; b_0^3 is the coal consumption rate of low-load operation and b_0^n is the coal consumption rate of rated-load operation; P_3 is the average load during low-load period; τ_3 is the length of low-load period.

From the equation $\Delta B = \Delta B_l$ above we can calculate the critical time:

$$\tau_{cr} = \frac{(\Delta B - \Delta B_1 - \Delta B_2)\times 60}{P_3(b_0^3 - b_0^n)\times 10^{-6}} \quad (2)$$

When the low-load running time is less than the critical time τ_{cr}, low-load operation is more economical. When the time is longer than τ_{cr}, shutting down a few units is more economical. By calculating the critical time of units with the above equation and comparing the critical time and the time the low-load lasts, we can find the right operating mode should be adopted.

2.2. Model for Optimal Load Distribution

The base of economic dispatch model is coal consumption curve and the model’s optimal objective is to minimize the total coal consumption with the constraints to meet the system requirements. Therefore, economic dispatch model for thermal power plant consists of three parts. They are consumption characteristic curve, objective function, and constraints. In ref 10, an optimal load distribution model was built. In this model, the lowest coal consumption was selected as the objective function. Taking three aspects-system balance, unit technical terms and network security-into account, set 4 key constraints: system active power balance, system backup constraints, maximum and minimum output of generator constraints and transmission constraints. It is a good balance between completeness and ease of solution. It is as followed:

$$\min F = \min \sum_{i=1}^{n} f_i(P_i) = \min \sum_{i=1}^{n} (a_i P_i^2 + b_i P_i + c_i) \quad (3)$$

$$\text{S.T.} \quad \sum_{i=1}^{n} P_i = P_D \quad (4)$$

$$\sum_{i=1}^{n} K_i P_{\max,i} - P_D \geq R \quad (5)$$

$$P_{\min,i} \leq P_i \leq K_i P_{\max,i} \quad (6)$$

$$\underline{P}_m \leq P_D \leq \overline{P}_m \quad (7)$$

Where K is state parameter for the device within the range [0,1]. When the *ith* unit is operating in normal state, $K_i = 1$. When the unit is running under the rated conditions, $K_i \in [0,1)$, the specific value of K_i will be decided according to the situation by the operating personnel.

3. Implementation of Dynamic Programming Method in Economic Dispatch

3.1. Principle of Dynamic Programming

The research objects of dynamic programming are multi-stage decision problems. When the dynamic programming method is applied, the first step is to divided a practical issue into stages, describe the state of each stage and define decision variables and indicators[14].The optimization direction of dynamic programming is from the terminal point n to the starting point. At terminal point n, the best index function is $F_n(x_n)$:

$$F_n(x_n) = \min\left\{ f_n(x_n, u_n(x_n)) \right\} \tag{8}$$

Where x_n is the state of stage n and $\mu_n(x_n)$ is the decision variable of this stage. Add the values of best index functions in correct order, the best index function value from stage *n* to stage *k* should be calculated as followed:

$$F_k^*(x_k) = \min\left\{ f_k(x_k, u_k(x_k)) + F_{k-1}^*(x_{k-1}) \right\} \tag{9}$$

Formula (9) is also the basic function of dynamic programming. It identifies the recursion relations of index functions.

3.2. Dynamic Programming to Solve Economic Dispatch

The process of building the dynamic programming model to solve economic dispatch is as followed[15]:

In a system consisting of *n* units, there are *n* stages. The *n* units were numbered with 1,2,3, ..., n. Where s_i: load assigned to the *i-n*th units, Q_i: load assigned to the *i*th unit, si+1=si-Qi: load assigned to the i+1-nth to the nth units, *Ci (Qi)*: cost of the *i*th unit when its load is Q_i, *fi (si)*: minimum cost of the *i-n*th units when their load are s_i. The back stepping expressions are as followed:

$$\begin{cases} f_i(s_i) = \min\limits_{0 \le Q_i \le s_i} \left\{ C_i(Q_i) + f_{i+1}(s_i - Q_i) \right\} \\ f_n(s_n) = 0 \qquad\qquad i = n, n-1, ..., 2, 1 \end{cases} \tag{10}$$

First, obtain the minimum coal consumption by calculating backward from the end. Then calculate forward step by step to get the load distributed to each unit. In this way, the problem can be solved.

4. Empirical Analysis

The X plant has a total installed capacity of 3600MW which consists of two 800MW-unit and two 1000MW-unit. There are some differences between consumption characteristics of each unit. The average designed coal consumption rate of power supply of phase I project is 339g/kWh, while it’s only 299.5g/kWh in phase II project. Obviously, the phase II project has significant technical and economic advantages.

4.1. Consumption Characteristic Curve

To requiring the raw coal consumption data is the first step of fitting the unit consumption characteristic curve.

In conventional methods, the characteristic curve is generally provided by manufacturer or is got from the periodic thermal test. But with the changing of the operation environment, operation mode, device status and the fuel type, unit coal consumption characteristics are changing. To obtain exact unit consumption characteristics, the following measures were taken. 30-day operation data of the chosen units were collected from their SIS system and were processed, in which unreasonable data points were eliminated. Then a number of groups of load and the corresponding coal consumption data were identified, they were used to fitting energy consumption characteristic curves by least square fitting method. The results are shown in Fig. 1 to 4:

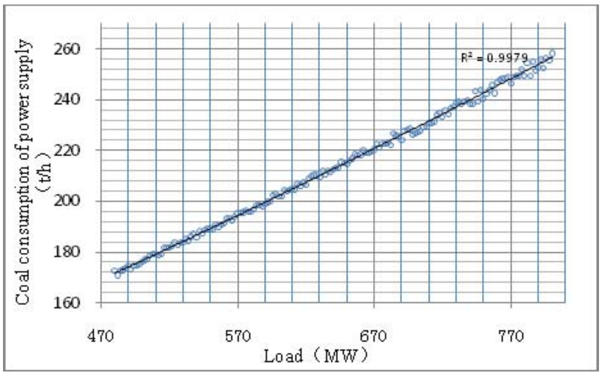

Fig.1 Consumption Characteristic Curve of Unit 1#

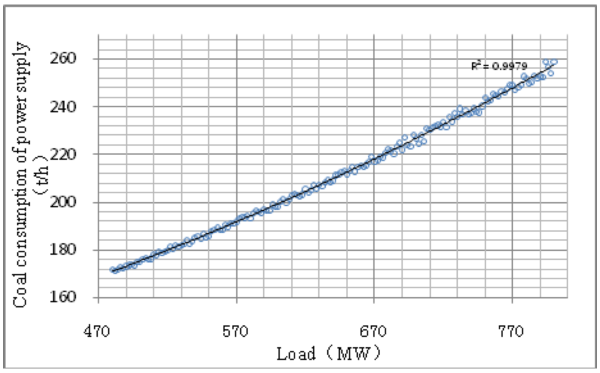

Fig.2 Consumption Characteristic Curve of Unit 2#

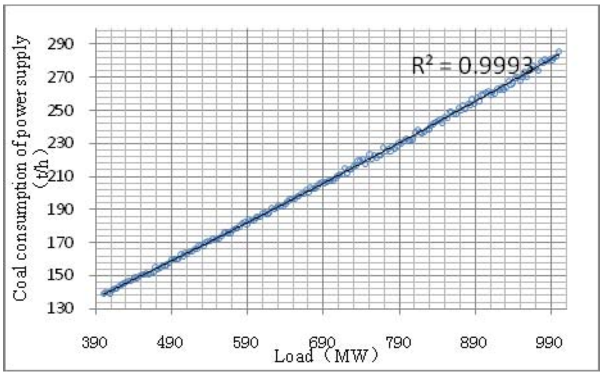

Fig.3 Consumption Characteristic Curve of Unit 3#

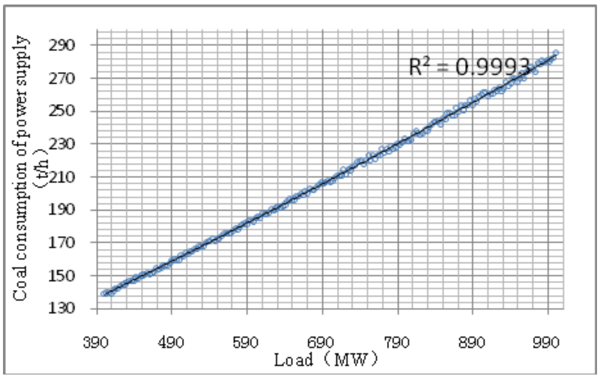

Fig.4 Consumption Characteristic Curve of Unit 4#

4.2. Related Parameters

In this paper, the issue of economic dispatch between 4 parallel units has been studied. The coal consumption functions of four units are as followed:

$$F_1=0.000048828P^2+0.20411P+62.2958$$
$$F_2=0.00017473P^2+0.047636P+107.8471$$
$$F_3=0.000026543P^2+0.20458P+52.2727$$
$$F_4=0.000026543P^2+0.20458P+52.2727$$

The characteristic data of each unit are shown in Tab. 1.

Table 1 Characteristic Data of Each Unit Commitment

Items	Units			
	#1	#2	#3	#4
Minimum Capacity(MW)	480	480	600	600
Maximum Capacity(MW）	800	800	1000	1000
Start Consumption(t)	71.4	71.4	192.8	192.8
Stop Consumption (t)	42.8	42.8	115.7	115.7
state parameter	1	1	1	1
Reserve Capacity(MW)	0MW			
Transmission Capacity(MW)	<=3600MW			

4.3. Simulation Computing

The average total load during 24 hours during January 20 to January 21 of X power plant was selected as object of study. With the help of MATLAB, programmed according to the model and algorithm above and conducted the simulation on each load point corresponding to 24 time points. The daily load curve of X plant is shown in Fig. 5.

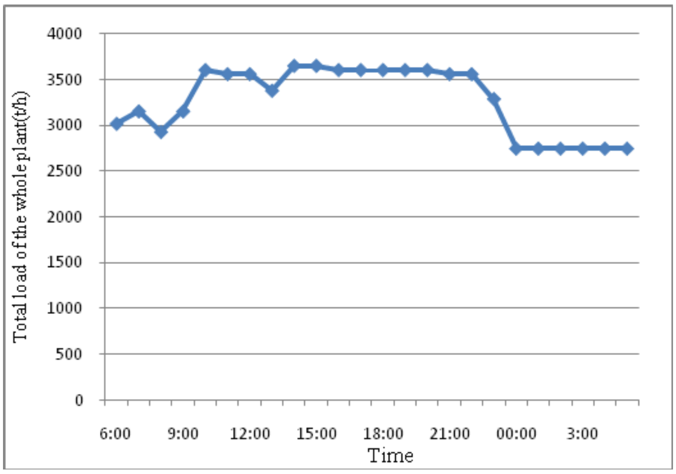

Fig.5 Daily Load Curve of Plant X in during January 20 to January 21

In Fig.5 we can see that from 6 am to 11 pm in January 20, except 7 am the average load rate is always higher than 83% and four generating units operated in parallel. At 7 am, the load decreased to 2790MW, low load lasted for 1 hour, the duration T1 = 1. Then, there are two operation modes are selectable. The one is four units operating in parallel and the other is shutting down the unit 2# with higher coal consumption rate and distributing load optimally to the rest of the unit. Started from 24 o'clock, the load dropped significantly and the average load rate was 76%, the average load was 2749MW, until 5 am, the duration T2 = 6. Ibid, we can choose to shut down unit 2# to improve overall operating efficiency. According to formula (2), we can calculate the critical time in both cases. $\tau_{cr1} = 2.98$, $\tau_{cr2} = 3.74$. Because $T_1 < \tau_{cr1}$, in this one hour at 7:00, the scheme four units maintain to operate in parallel is the most economical. And because $T_2 > \tau_{cr2}$, in the 6 hours from 0:00 to 6:00, it is better to shut down the 2# unit and let unit 1# 3 # and 4 # operate in parallel.

To prove that the economic dispatch model can provide optimal operating scheme in order to improve the economy of plant operation effectively, at every point of a given load, 3 schemes were compared. Among them, scheme I is the actual running scheme, which is calculated with the load distribution data under transfer order. Scheme II is the optimal load distribution scheme without change of unit commitment. Scheme III is the economic dispatch scheme solved by the model proposed in this paper. Through the simulation operation, we obtained the unit commitment and coal consumption data of 3 schemes. 10 sets of selected data corresponding to 10 time points out of the 24 hours which can display the load fluctuations are listed in Tab. 2.

Table 2 Load of Each Unit Commitment and Coal Consumption

Average Load /MW		Scheme I	Scheme II	Scheme III					
		F_1(t/h)	F_2(t/h)	P_1/MW	P_2/MW	P_3/MW	P_4/MW	F_3(t/h)	Unit Commitment
6	3015	921.5	919.2	560	592	909	954	919.2	1111
7	2790	864.4	862.2	501	579	855	854	862.2	1111
10	3600	1078.9	1072.4	723	639	1000	1237	1072.4	1111
13	3375	1017.2	1012.3	646	620	1000	1109	1012.3	1111
15	3645	1091.5	1084.6	721	646	1002	1276	1084.6	1111
16	3600	1078.9	1072.4	718	637	1000	1245	1072.4	1111
21	3555	1066.5	1060.3	687	636	1000	1232	1060.3	1111
23	3285	992.9	988.9	569	632	993	1091	988.9	1111
24	2758	855.7	854.5	480	571	849	858	828.5	1011
5	2745	852.4	851.2	480	582	845	839	824.9	1011

According to the data from simulation operation, we analysis the economics of three schemes for further:

(1)In the period studied, economic dispatch reduce the coal consumption effectively.

In the 24 hours, the consumption of coal of the plant operated under 3 different schemes were 23,780 tons, 23,749 tons and 23,591 tons. To the actual operation scheme (Scheme I), the application of optimal load distribution scheme (Scheme II) could save about 31 tons of coal. Compared with previous two schemes, the application of economic dispatch scheme (Scheme III) could reduce total coal amount for further. Scheme saved 158 tons of coal more than Scheme II and saved 189 tons of coal more than Scheme I.

(2) Dispatch the units with economic dispatch instruments can reduce the coal consumption rate of the whole plant with 2.81g/kWh.

In units of hours, we calculated the consumption rate of 3 schemes in each hour and then calculated the average consumption rate of 24 hours of each scheme. Compared to the previous two schemes, Scheme III reduced the consumption rate by 2.39g/kWh and 2.81g/kWh separately.

(3) Economic dispatch can save the cost of power supply effectively.

Taking economic dispatch measures to control the load distribution and unit commitment can reduce coal consumption rate by 2.81g/kWh. Estimated according to this, X plant generate every 100 million kWh electricity, 281 tons coal can be saved. If the coal price is 650 Yuan/ton, generating every 100 million kWh electricity can save coal cost by 182,000 Yuan.

This shows that the application of economic dispatch in power plants can improve plant operation efficiency and reduce power supply costs and then bring significant economic and social benefits. The correctness and effectiveness of model and algorithm are also verified.

5. Conclusion

Through the discussion above and empirical analysis, we can draw the following conclusions:

(1) From the perspectives of operational safety and economy, put forward a unit commitment optimization model. In this model, the premise to change the unit commitment is the low load will last for an extended period of time. In this way, the objectives of economic operation and avoiding frequent starts and stops can be both met at the same time.

(2) Analyze the data from the real-time database of plant's SIS system and fit the consumption curve. In this way, it can get closer to the actual coal consumption characteristics and provide more accurate prerequisite for economic dispatch.

(3) The simulation results shows that, this economic dispatch model constructed in this paper can provide rational unit commitment and economic dispatch scheme and then reduce the cost of power supply. The study provide scientific method and means for the realization of economic dispatch in thermal power plants.

References

[1] YE Jian-bo.The Affect and Countermeasures of Power Generation Companies under Energy-saving Scheduling Approach[J]. China Power Enterprise Management, 2008, (1):58-59.

[2] WU Yong-gang, The plant's optimal load dispatch and unit commitment of thermal power plant [D]. Beijing: North China Electric Power University: 2009.

[3] WANG Zhi-guo, LIU Ji-zhen, TAN Wen, YANG Guang-jun. Multi-objective Optimal Load Distribution Based on Speediness and Economy in Power Plants [J]. Proceedings of the CSEE, 2006, 26(19): 86-92.

[4] WU Jie-kang, HAN Jun-feng, LIU We, WU Zhi-hua. Economic Dispatching of Power System Based on Anti-Predatory Particle Swarm Algorithm [J]. Power System Technology, 2010, 34(6): 59-63.

[5] YANG Jun-jie, ZHOU Jian-zhong, WU Wei, LIU Fang. Application of Improved Particle Swarm Optimization in Economic Dispatching [J]. Power System Technology, 2005, 29(2): 1-4.

[6] HUANG Wen-cheng, XIE Gang. Research on Unit Commitment Based on Immune Mind Evolutionary Algorithm [J]. Mechanical Engineering & Automation. 2008,150(5): 38-40.

[7] Abido, M, A. Multiobjective particle swarm optimization for environmental/economic dispatch problem[J]. Electric Power Systems Research, 2007, 79(7): 1105-1113.

[8] Prasanna T.S., Somasundaram P. Fuzzy mutated evolutionary programming based algorithm for combined economic and emission dispatch[A]. TENCON 2008. IEEE Region 10 Conference, 2008: 1-5.

[9] Basturk B, KarabogaD. An artificialbee colony (ABC) algorithm for numeric function optimization[A]. In:Proceedings of the IEEE Swarm Intelligence Symposium[C]. 2006.

[10] LI Yun, Ji Kai-lin,Zhang Peng-yu. Application Research of Dynamic Programming on Thermal Power Plant Optimal Lload Distribution, Journal of Computational Information Systems, 2011,7(1): 239-246.

[11] LI Xue-bin. Study of Multi-objective Optimization and Multi-attribute Decision Making of Economic Load Dispatch Problem[J]. Proceedings of the CSEE, 2008, 28(35): 102-107.

[12] YANG Peng-peng, Han Xue-shan. A Security Economic Dispatch Method Considering Time Correlation Constraints [J]. Automation of Electric Power Systems, 2008, 32(17): 32-34.

[13] LIU Xia, XU Hao. Application of LINGO to Power System Unit Commitment Optimization[J]. Electrical Engineering Materia, 2010,1: 48-52.

[14] HU Yun-quan. Operations Research[M]. Beijing: Tsinghua University Press, 2007.

[15] FU Xiao-jun. Research on Load Economical Dispatching and Bidding Strategy of Thermal Power Plant [D]. Nanjing: Southeast University, 2005.