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Study on Load Optimal Distribution of Power Plant Considering the Quick Start and Stop of Coal Mills

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Abstract: In order to meet the requirements of rapid load change for coal-fired power plants under the situation of new energy power system, this paper studies the problem of rapid plant level load optimal distribution considering the start-up and shutdown section of coal mills. Firstly, a mathematical model of rapid plant level load optimal distribution considering the start-up and shutdown interval of the coal mill is constructed. Taking the start-up and shutdown interval of the coal mill as a constraint condition, the non operational region processing strategy is used for pretreatment, and the improved genetic tabu algorithm is used to find the optimal solution of the objective function. The simulation results show that the distribution results obtained by taking rapidity as the goal and economy as the goal are significantly different. The load adjustment time with rapidity as the goal is significantly shorter than that with economy as the goal. The effectiveness of the model and algorithm is illustrated, and it is verified that the plant level load optimal allocation with the goal of rapidity is an effective control strategy for the rapid load change of units, which can contribute to further improving the flexible operation capacity of coal-fired units under the situation of new energy power system.

1. Introduction

To improve the operating flexibility of coal-fired units is an effective and necessary way for our country and even the world to solve the problem of large-scale renewable energy integration in grid [1-3]. In 2009, China Electric Regulatory Commission promulgated the "two rules". At first, we use it to assess the load adjustment capability of the units in grid, intended to protect power quality and the safety and stability of power system operation. Unexpectedly, it also provide much convenience for large-scale renewable energy units integrate in grid these years. Such as wind power units, although much more wind power units integrated in grid, the proportion of abandoned wind power has declined year by year [3]. This situation is also to a certain extent, thanks to the rigorous assessment of the "two rules" on grid power plant. Therefore, with the continues expand of renewable energy power, it is imperative to improve the operating flexibility of coal-fired units much further.

Operating flexibility contains the rapid load adjustment and the deep load adjustment. There are many kinds of control strategy for operating flexibility of coal-fired power plants, such as condensate throttling, cold source throttling, extraction steam adjustment of heating units, optimal load dispatch in power plants, and wide-range load operation of circulating fluidized bed units [3]. Optimal load dispatch in power plants (Power Plant Load Dispatching, PPLD) is one of the effective means to realize the rapid load adjustment of units.

The earliest research of PPLD is based on economy, many scholars at home and abroad made a lot of research on mathematical model and distribution algorithm [4-9]. In 2006, WANG Zhi-guo proposed PPLD based on speediness, who put forward an effective mathematical model based on speediness and distribution method [10]. WANG provides a way for PPLD to participate in the rapid load adjustment of units. Since then, many scholars have devoted to the research of PPLD based on speediness, including model and algorithm, and applied intelligent optimization method such as dynamic programming algorithm and particle swarm optimization algorithm and so on to solve the problem [11,12]. In this paper, we propose an improved Genetic Algorithm-Tabu Search (GA-TS) algorithm to study the PPLD based on speediness.

During implementation procedure of PPLD, author found that there are some specific load areas of thermal power units, in which some coal mills need frequent starting and stopping which reduce economic performance and have bad influence on mills' life [13-16]. Those areas are considered as Prohibited Operating Zones (POZs) in this paper, and should be avoided in load distribution. In PPLD based on speediness, the start and stop time of the coal mills has little effect on the time of unit load adjustment. Since when the load command of the unit is determined, the operator will choose appropriate time to start or stop the coal mill needed beforehand. Therefore, the objective function does not consider the effect of the coal mill start and stop time, only POZs are considered as a constraint to limit the unit load.

In this paper, we study the optimal load dispatch in power plant prevents frequent mills operation based on speediness. The structure is organized as follows: Section 2 presents mathematical formulation of PPLD with POZs based on speediness. Section 3 introduces strategy of solving POZs and improved GA-TS algorithm to solve the problem. Section 4, illustrates case study and simulations. Section 5, provides conclusion and points out further work.

2. Problem Formulation

2.1 The minimum time for a given load command of a power plant

WANG Zhi-guo proposed the concept of the minimum time for a given load command of a power plant. That is, when there is a given load command P_D, if we want to ensure that the power plant to complete the load adjustment at the fastest rate, should ensure that the time of each unit to complete its load adjustment is equal. The optimal time for this ideal state T_{ideal} is the minimum time for a plant to complete a given load adjustment, written as T_{ide}. It is called an ideal state because, in the case of T_{ide}, it must be assumed that the dispatched load of each unit meets all the constraints.

$$T_{ide} = \left|P_D\text{-}P_N\right| / \sum_{i=1}^{n} U_i V_i \qquad (1)$$

P_N represents the current load of the power plant, n represents the number of units participated in load adjustment, V_i represents the load rate of unit i ,and U_i represents the state of unit i, $U_i = 1$ means the unit i is running, $U_i = 0$ means the unit i is outage.

2.2 Formulation of POZs

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of thermal power units, in which some coal mills need frequent starting and stopping which reduce economic performance and have bad influence on mills' life [13-16]. Those areas are considered as Prohibited Operating Zones (POZs), and should be avoided in load distribution.
Mathematic formulation of POZs:

$$\begin{cases} p_{i\min} \le p_i < p_{i1}{}^d \\ p_{i1}{}^u < p_i < p_{i2}{}^d \\ \vdots \\ p_{im}{}^u < p_i < p_{i,m+1}{}^d, m = 1, 2, \cdots, M \\ \vdots \\ p_{iM}{}^u < p_i \le p_{i\max} \end{cases} \tag{2}$$

M represents the number of POZs, $p_{im}{}^d$ represents the minimum of the m_{th} POZ, and $p_{im}{}^u$ represents the maximum of the m_{th} POZ, $p_{i\min}$ represents the lower limit of unit i, $p_{i\max}$ represents the upper limit of unit i.

2.3 Formulation of PPLD with POZs based on speediness

The time of unit i to complete its load adjustment is

$$t_i = |p_i - p_{inow}| U_i / V_i \tag{3}$$

p_i represents the demand load of unit i, and p_{inow} represents the current load of unit i.

How to dispatch the load of each unit, so that t_i can approaches T_{ide} as much as possible is the key of solving the problem.

The objective function takes the form of quadratic polynomial:

$$\min T(p_i) = \sum_{i=1}^{n} t_i(p_i) = \sum_{i=1}^{n} (t_i - T_{ide})^2 = \sum_{i=1}^{n} (|p_i - p_{inow}| U_i / V_i - |P_D\text{-}P_N| / \sum_{i=1}^{n} U_i V_i)^2 \tag{4}$$

Constraints:

1) Load balance

$$P_D = \sum_{i=1}^{n} U_i p_i \tag{5}$$

2) Upper and lower limits and POZs constraint of unit i

$$\begin{cases} p_{i\min} \le p_i < p_{i1}{}^d \\ p_{i1}{}^u < p_i < p_{i2}{}^d \\ \vdots \\ p_{im}{}^u < p_i < p_{i,m+1}{}^d, \quad m = 1, 2, \cdots, M, \quad i = 1, 2, \cdots, n \\ \vdots \\ p_{iM}{}^u < p_i \le p_{i\max} \end{cases} \tag{6}$$

3) Upper and lower limits of the plant

$$P_D \le \sum_{i=1}^{n} U_i p_{i\max}, P_D \ge \sum_{i=1}^{n} U_i p_{i\min} \tag{7}$$

3. Strategy and Algorithm

In this section, introduces strategy of solving POZs and improved GA-TS algorithm to find the optimal solution of PPLD with POZs based on speediness. The author used this strategy and algorithm to solve the problem of PPLD with POZs based on economy before, so the principle and concrete steps are not introduced in detail here, only to introduce the flow chart of strategy and algorithm, which is shown in Figure 1.

First the objective function is transformed into a quadratic polynomial about p_i. From Equation (1) we can see that, if P_D and P_N are determined, T_{ide} will be a constant. So Equation (4) can be rewritten as the following form:

$$\begin{aligned}\min T(p_i) &= \sum_{i=1}^{n} t_i(p_i) = \sum_{i=1}^{n}(t_i - T_{ide})^2 = \sum_{i=1}^{n}(|p_i - p_{inow}| U_i / V_i - T_{ide})^2 \\ &= \sum_{i=1}^{n}\left[(U_i / V_i)^2 \cdot (p_i^2 - 2p_i p_{inow} + p_{inow}^2) - 2U_i / V_i \cdot |p_i - p_{inow}| + T_{ide}^2\right] \\ &= \sum_{i=1}^{n}\left[(U_i / V_i)^2 \cdot p_i^2 - 2p_{inow}(U_i / V_i)^2 \cdot p_i - 2U_i / V_i \cdot |p_i - p_{inow}| + (U_i / V_i)^2 p_{inow}^2 + T_{ide}^2\right]\end{aligned} \tag{8}$$

Define the fitness function as follows:

$$v_t = \frac{1}{T} \tag{9}$$

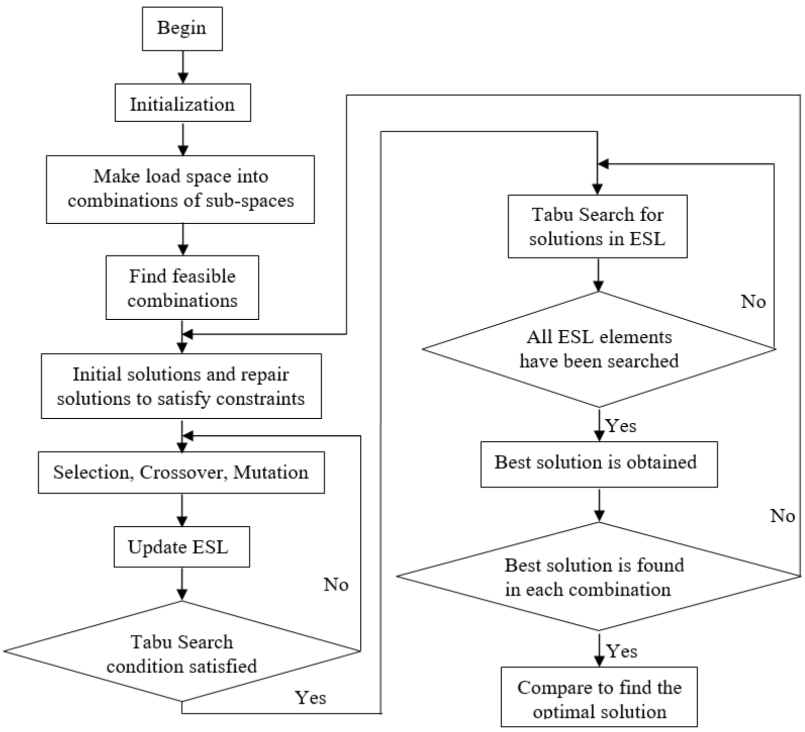

Figure 1 Flow chart of strategy and algorithm

4. Case Study and Simulation

In order to test the effectiveness of the proposed algorithm for the proposed model in section 2.3, the simulation is carried out. In this paper, the algorithms based on speediness and economy are compiled respectively, and the simulation is carried out under the same experimental conditions, and the data are obtained and compared.

Take a power plant with 8 units for example. Parameters of each unit are shown in Table.1, which referenced from the paper of Li[16]. Assume that all units are involved in load adjustment, that is $U_i = 1, \ i = 1, 2, ..., 8$. The current load of the power plant is 800MW, and the load of each unit is shown in Table.1 Column p_{inow}, which is dispatched based on economy. The maximum of plant load is 2000MW and the minimum is 695MW.

Table.1 Parameters of units

ID	a_i	b_i	c_i	Upper and lower limits	V_i	POZs	p_{inow}
1	0.00510	2.2034	15	20,80	7		20
2	0.00396	1.9101	25	25,100	8		25
3	0.00393	1.8518	40	30,100	10		46.98
4	0.00212	1.8015	29	50,150	8		50.27
5	0.00261	1.5354	72	75,280	6	[120,130],[190,200]	75
6	0.00289	1.2643	49	120,320	11	[180,190],[255,265]	191.67
7	0.00148	1.2130	82	125,450	10	[260,270],[355,368]	141.08
8	0.00127	1.1954	105	250,520	12	[305,315],[410,420]	250

4.1 Simulation of load distribution with speediness as target

Solving PPLD with POZs based on speediness under load command P_D 1200, 1500, and 1800 MW, and 50 times simulations are done for each command. 20 solutions are initialized in each combination because sub-space of each unit is relatively small[16]. If the best fitness value have not been changing in 5 percents in 5 times, GA process stopped, and the size of STM is 7. Stop criterion of TS is a better solution cannot be obtained within 5 steps.

Due to the dynamic stop condition of the genetic operation process and the simple search of tabu search process, in some cases the optimal solution can not be found. But at least 45 times in 50 times can find the optimal solution, the probability is up to 90%, which is shown in Table.2.

Table.2 Best fitness value and global optimum found times

Load Command	Best Fitness Value	Simulation Steps	Global Optimum Found Times
1200	12.87	200	47
1500	0.0359	500	47
1800	0.00364	1000	45

With the increase of P_D, the more serious the restriction imposed by the constraints, the more difficult to find the optimal solution. Performance in the optimization process is that the increase of simulation steps, which is also shown in Table.2.

Results of optimal dispatching are shown in Table.3, Column 1200-K, 1500-K and 1800-K.

Table.3 Best result of dispatching and the actual time of load adjustment

	1200-K	1200-J	1500-K	1500-J	1800-K	1800-J
Unit 1	59.14	20.95	80	58.67	80	79.92
Unit 2	69.74	25.15	100	52.41	100	99.91
Unit 3	100	33.56	100	73.89	100	99.86
Unit 4	95.05	63.85	137.41	101.86	150	149.59
Unit 5	108.58	150.42	140.36	242	200.13	279.24
Unit 6	253.25	265.1	311.49	283.76	320	318.98
Unit 7	197.06	390.97	250.02	437.41	349.62	448.75
Unit 8	317.18	250	380.72	250	500.25	323.75
t	5.598	24.989	10.894	29.633	20.855	34.040

4.2 The simulation comparison of load distribution with economy and speediness as target separately

Solving PPLD with POZs based on economy under load command P_D 1200, 1500, and 1800 MW. Results of optimal dispatching are shown in Table.3, Column 1200-J, 1500-J and 1800-J.

Calculate the actual time of load adjustment, that is $t=\max(|p_i - p_{inow}|U_i / V_i)$, $i=1,2,...,8$, which is shown in the last line of Table.3.

When the load is distributed with the economy and speediness as target separately, the distribution results are significantly different, and the load adjustment time with the aim of speediness is obviously shorter than that of economy. The simulation shows the effectiveness of the mathematical formulation of PPLD with POZs based on speediness.

The significant difference of distribution results also illustrates the contradiction between the economy and speediness of power plants. If the power plant wants to get better economic benefit, it must sacrifice part of the speediness. On the contrary, it has to sacrifice some economy in order to get rapid load adjustment. How to combine speediness and economy according to the requirements of the grid will be the next research focus.

5. Conclusion

This paper presents mathematical formulation of PPLD with POZs based on speediness, and then introduces strategy and improved GA-TS algorithm to solve the problem. Through simulation the effectiveness of the mathematical formulation of PPLD with POZs based on speediness is tested. When the load is distributed with the economy and speediness as target separately, the distribution results are significantly different, and the load adjustment time with the aim of speediness is obviously shorter than that of economy. It shows that the optimal load dispatch in power plants based on speediness is an effective control strategy for the rapid load adjustment of units, which can contribute to the further improvement of the operating flexibility of coal-fired units in the new energy power system situation.

The significant difference of distribution results also illustrates the contradiction between the economy and speediness of power plants. If the power plant wants to get better economic benefit, it must sacrifice part of the speediness. On the contrary, it has to sacrifice some economy in order to get rapid load adjustment. How to combine speediness and economy according to the requirements of the grid is the keypoint, that is multi-objective optimization of PPLD with POZs will be the next research focus.

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