

Research on Multi-objective Optimization Linear Programming Problem of Power Generation under Carbon Emission Trading

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Abstract. Carbon emissions trading is an important means to achieve the target of low carbon and energy saving, the construction and promotion of which has been widely concerned in recent years. As carbon emitters, electricity industry is shouldering more pressure to reduce emissions and will definitely participate in carbon emissions trading. Energy saving dispatching is one of the most important ways to realize energy saving and emission reduction for electricity power companies. One kind of multi-objective optimization linear programming model for generating units under carbon emissions trading is constructed in this paper. The model is verified by a practical case analysis, which ensures the optimal allocation of power resources with multi-objective of Energy saving, emission reduction and economy, and sustainable development of electricity power companies.

1. Introduction

As a means of market regulation, the introduction of carbon emissions trading will effectively promote the development of energy-saving and emission reduction technologies in power industry. However, with the introduction of carbon emissions trading system in power industry, carbon emissions trading has brought the great impact on the traditional trading and dispatching mode of power industry, which makes the mode of traditional power resource allocation and the mechanism of operation scheduling dispatching need to be further improved. In addition to considering the emission of sulfuric dioxide, nitrogen oxides and solid particles, it is critical to for power industry to optimize the allocation of power resources with carbon constraints.

So far, there have been a lot of research results on the power generation scheduling under carbon emissions trading. For example, literature [1] has established three optimization models of inter-regional generation scheduling including clean energy generation, taking minimum regional generation cost and minimum comprehensive cost as objective functions respectively and the models considered the issues of economic efficiency, carbon emission and transmission constraints. Literature [2] has constructed a day-ahead dispatching scheduling model which takes minimum synthetically generation cost as optimization objective. Literature [3-4] has established the thermal power unit scheduling optimization models and multi-objective model according to the cost, energy consumption and emission quantity. And these models are compared with the traditional electricity distribution model. Literature [5-6] has set up low carbon power generation scheduling model for generation planning the day before. Then optimization model of carbon generation scheduling is transformed into



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a single-objective optimization model for power system energy consumption and carbon emissions as the goal of minimizing the total cost. Literature [7-8] has established optimization models based on equal utility efficiency, minimum coal consumption, minimum carbon emission, least generation cost and least total cost to analyse and evaluate the result of generation permit substitution with different allowance allocation.

The optimal allocation of generation resources is a problem of generator unit commitment planning substantially. This paper studies the problem of priority scheduling strategy for generator units and established the multi-objective optimization linear programming model of power generation under carbon emissions trading, which is applied to a real case. Finally, electricity purchasing optimization strategy for electricity power companies is obtained in the mode of carbon emissions the transaction.

2. Priority strategy of generator units dispatching under carbon emission trading

The equal incremental principle refers to every generator unit in power system operating according to the same incremental rate of consumption. Therefore, the total energy loss in power system will at the lowest level. Similarly, if each generator unit in power system operates with the same consumption level, which includes total input among various type of resources such as primary energy consumption, the use of emission rights and capital investment, the total resources loss in power system would be at the lowest level while the system operation mode will be in most economical level accordingly.

The process of constituting the priority strategy of generator units dispatching under carbon emission trading is mainly divided into four steps.

First of all, it is necessary to collect the data of power supply, coal consumption, emissions of all pollutants and electricity purchase capital consumption in recent years. Through regression analysis based on the data obtained, the function mapping relation between unit power supply and coal consumption, emissions of all pollutants and electricity purchase capital consumption is put forward correspondingly.

Secondly, according to the function mapping relation obtained, solve the derivative function of each function relation to power supply and get the relationship between the micro variations of power supply and the micro variations of coal consumption, emissions of all pollutants and electricity purchase capital consumption among each generator unit.

Then, the weight of each unit coal consumption, emissions of all pollutants and electricity purchase capital consumption is calculated and multiplied by the micro-increment relationship obtained in the previous step. So that an integrated consumption of the micro-increment relationship can be received by the sum of the above results.

Finally, making integrated consumption micro-increment rate of generator unit equal to each other, incremental value interval of each generator unit can be calculated combining with a series of constraint conditions under the equal incremental principle, and then the optimal generator unit dispatching program can be put forward according to the range of micro-increment rate.

3. Multi-objective optimization linear programming model of power generation under carbon emissions trading

3.1. Construction of linear programming model

Power trading center promotes energy saving and emission reduction in generator units through bilateral transactions. Therefore, the primary goal of the linear programming model is energy conservation, followed by emission reduction, the final consideration of electricity prices. Assuming that there are N generator units in the region, objective function can be obtained combining with energy-saving emission reduction targets.

- Target of minimum coal consumption.

$$\text{Min}M = \sum_{i=1}^n u_i \times q_i \quad (1)$$

- Target of minimum emissions of all pollutants.

$$MinC = \sum_{i=1}^n Ec_i \times q_i, MinS = \sum_{i=1}^n Es_i \times q_i, MinN = \sum_{i=1}^n En_i \times q_i, MinG = \sum_{i=1}^n Eg_i \times q_i \quad (2)$$

- Target of minimum power purchasing cost.

$$MinU = \sum_{i=1}^n P_i \times q_i \quad (3)$$

Combining with the constraint conditions, a set of constrained inequalities for multi-objective linear programming problems can be proposed.

- Restriction of generator unit output power.

$$0 \leq q_i \leq Qr_i \quad (4)$$

- Restriction of power supply and demand.

$$\sum_{i=1}^n q_i \leq Q_d \quad (5)$$

- Restriction of emissions of all pollutants.

$$\sum_{i=1}^n Ec_i \times q_i \leq W_c, \sum_{i=1}^n Es_i \times q_i \leq W_s, \sum_{i=1}^n En_i \times q_i \leq W_n, \sum_{i=1}^n Eg_i \times q_i \leq W_g \quad (6)$$

If electricity power companies promote energy saving and emission reduction in power generation companies through energy saving dispatching, the smaller the objective function values of formula (1) – (3) are, the better emission reduction effect is. Therefore, the model is to obtain the generating capacity of each generator unit when the objective function value is smallest based on the inequality constraint conditions (4) - (6), which is regarded as optimal program under linear programming. However, it is quite difficult to solve the problem of multi-objective linear programming directly. In this way, it is much easier to transform multi-objective linear programming problem into single-objective linear programming problem.

3.2. Solution to linear programming model

First of all, under the constraints conditions of the inequalities, the optimal value of each objective function is obtained by solving the single-objective linear programming problem, which is written as M_0, C_0, S_0, N_0, G_0 and U_0 .

At the same time, because the objective function is the minimum, and the direction of optimization is the same, we can introduce a super-objective function.

$$Z = \alpha M + \beta (\beta_c C + \beta_s S + \beta_n N + \beta_g G) + \gamma U \quad (7)$$

$$\alpha + \beta + \gamma = 1 \quad (8)$$

$$\beta_c + \beta_s + \beta_n + \beta_g = 1 \quad (9)$$

Among them, $\alpha, \beta, \gamma, \beta_c, \beta_s, \beta_n$ and β_g are all weight coefficient equal to or more than 0.

In addition, compromise constraint condition is constructed.

$$\beta_c (C - C_0) = \beta_s (S - S_0) \quad (10)$$

$$\beta_s (S - S_0) = \beta_n (N - N_0) \quad (11)$$

$$\beta_n (N - N_0) = \beta_g (G - G_0) \quad (12)$$

$$\alpha(M - M_0) = \beta[\beta_c(C - C_0) + \beta_s(S - S_0) + \beta_n(N - N_0) + \beta_g(G - G_0)] \quad (13)$$

$$\alpha(M - M_0) = \gamma(U - U_0) \quad (14)$$

After constructing the super-objective function and the compromise constraints, a new linear programming problem can be presented.

$$\text{Min}Z = \alpha M + \beta(\beta_c C + \beta_s S + \beta_n N + \beta_g G) + \gamma U \quad (15)$$

Among them, the constraint conditions are inequalities (4) to (6) and compromise constraints are inequalities (10) to (14).

Finally, compromise solution set can be obtained by solving the linear programming problem above with the method of solving single-objective linear programming problem, which the non-inferior solution of the original multi-objective linear programming problem. At this point, the values of which is obtained are the optimal bilateral trading generator units and generating capacity under the multi-objective linear programming.

4. Model application

As a means of market regulation, carbon emissions trading will effectively promote the development of energy saving and emission reduction technologies in power industry and contribute to the realization of carbon emission reduction targets in China. However, with the introduction of carbon emissions trading system in power industry, carbon emissions trading has brought great impact on traditional trading and dispatching mode of power industry. So, the mode of power resource allocation and the mechanism of scheduling dispatching should be further improved. It is critical for power industry to optimize the allocation of power resources with carbon constraints.

4.1. Restriction of generator unit output power

Restrictions of 24 generator units' output are shown in Table 1.

Table 1. Restriction of generator unit output power.

Generator unit	Installed capacity (MW)	Maximum utilization hours (h)	Upper limit of output power (MWh)	Subhead integrated plant power consumption rate (%)	Limit of generator unit output power (MWh)
1	1000	7889	7888720	4.50%	7533728
2	1000	7780	7779750	4.66%	7417214
3	600	8129	4877298	4.06%	4679280
...
22	300	7230	2169135	6.05%	2037902
23	315	7510	2365518	5.65%	2231866
24	315	8176	2575431	5.65%	2429919

4.2. Restriction of power supply and demand and emissions of all pollutants

Based on installed capacity and maximum utilization hours of each generator unit, upper limit of output power can be calculated. The remaining part of the output power is the maximum annual power supply, which is deducted from plant power consumption and power loss during power transmission.

Restrictions of each generator unit's power supply and pollutants emissions are shown as Table 2.

Based on multi-objective linear programming model above, power supply, pollutants emissions and purchasing cost of generator unit can be calculated. The results obtained by MATLAB program are shown in Table 3.

Compared to generator units dispatching with single objective including minimum coal consumption or minimum emissions of various pollutants, the difference among the operation modes of generator units with different targets is shown in Figure 1.

Table 2. Restriction of power supply and pollutants emissions.

Generator unit	Power supply (MWh)	CO ₂ emission factor (t/MWh)	SO ₂ emission factor (t/MWh)	NO _x emission factor (t/MWh)	Solid particulate emission factor (t/MWh)
1	q ₁	0.542463	0.000169	0.000462	0.000091
2	q ₂	0.543552	0.000152	0.000531	0.000073
3	q ₃	0.521601	0.000262	0.00203	0.000087
...
22	q ₂₂	0.644812	0.00018	0.003175	0.000058
23	q ₂₃	0.683169	0.000264	0.00071	0.000116
24	q ₂₄	0.68486	0.000256	0.000963	0.000099
Constraint	74916344	42548000	20420	96300	7700

Table 3. Result of solution to multi-objective optimization linear programming.

Generator unit	Power supply (MWh)	Coal consumption (t)	CO ₂ emission (t)	SO ₂ emission (t)	NO _x emission (t)	Solid particulate emission (t)	Power purchasing cost (RMB)
1	7533728	2392915	4086769	1273	3481	686	263731
2	7259256	2268050	3945783	1103	3855	530	272450
3	4679280	1463408	2440717	1226	9499	407	171661
...
22	2037902	648732	1314064	367	6470	118	77389
23	2231866	708060	1524742	589	1585	258	86257
24	2429919	768483	1664154	622	2340	241	86662

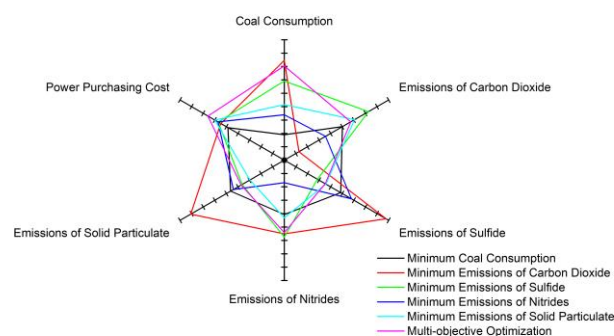


Figure 1. The difference among operation modes of generator units with different targets.

As the figure illustrated, power purchasing cost has not been greatly improved between dispatching model with multi-objective and single-objective. However, all kinds of pollutants emissions and coal consumption have decreased significantly. Therefore, multi-objective optimization linear

programming model proposed in this paper can reduce coal consumption and pollutant emissions as much as possible on the premise of economic consideration, which will conducive to energy saving and emission reduction in power industry.

5. Conclusion

In this paper, and one kind of multi-objective optimization linear programming model for generating units under carbon emissions trading is constructed. Meanwhile, the model is solved by a practical case. The result obtained is considered as a compromise solution for all targets, which provides a solution for electricity power companies to the optimal allocation of power resources with multi-objective of energy saving, emission reduction and economy, and ensure scheduling operation of power system with multi objectives and sustainable development of electricity power companies.

In order to solve the problems of energy shortage and environmental pollution, there will be a large-scale renewable energy power. At this time, the constraints of power system dispatching are no longer limited to coal consumption and pollutant emissions, as well as more technical and environmental constraints. How to realize economic operation management of power system with a variety of constraints, will be the research direction of the new energy power system in the future.

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