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Analysis of Dispatch Methods in Northwest Area

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Abstract. The northwest area is full of renewable energy in China, and the development of renewable energy is rapid which brings great influence on the operation of power system. With the large-scale of renewable energy, it is difficult for energy consumption in the northwest provinces, and there still exists energy curtailment in all provinces. Renewable energy consumption in the northwest area is limited by insufficient demand, potential of sending out electricity, and peaking capacity. As the basis of system operation, the research of scheduling methods provides basic data and reference for all aspects of system operation scheduling. In order to further promote the consumption of renewable energy, we study the impact of different scheduling methods on the ability of renewable energy consumption. Combining with the actual data, we analyze and evaluate the scheduling methods, comparing the characteristics of each scheduling method, and studying its impact on renewable energy consumption. Combined with relevant calculations and analysis, the optimization suggestions for exploiting the potential of renewable energy and improving consumption space are provided.

1. Introduction

In 2017, the renewable energy consumption of a typical area in the northwest region was 22.5 billion kWh, accounting for 23% of the electricity consumption. The renewable energy consumption was 20.6 billion kWh, which is 21% of social electricity consumption. The percentage of renewable energy curtailment there is gradually decreased. The rate of wind curtailment and photovoltaic curtailment was 4.8% and 6.4%, respectively reducing 8.5% and 0.7% [1].

In order to further improve the energy efficiency, reduce environment pollution, promote the structure adjustment of energy, and ensure the safe and efficient operation of system, the departments issued documents indicating priority scheduling based on generator type, energy consumption level and emission index. The annual generation scheduling is optimized to maximize the consumption of renewable energy, and the units with low energy consumption and low pollution are prioritized. The dispatching agency ensures to accept renewable energy on the premise of safe operation, and permit trades with other areas through DC. There has been lots of relevant research about this topic. Literature [2], [3] and [4] detail several typical models considering prediction error of renewable energy and scene selections, and literature [5] reduces the conservation of the scheduling and increases the economic by eliminating the extreme scene.

Although researchers have achieved results and developed many types of models and methods. But the current research is limited to the use of specific methods to model and solve problems, ignoring the impact of different optimal scheduling models on operational results, affecting the development of renewable energy. Therefore, it is necessary to further study and obtain an optimal scheduling.



2. The overview of power, load and grid

At the end of 2017, the installed capacity of generation in the area was 41.876 million kw. The proportion of various types of units is shown in Figure 1.

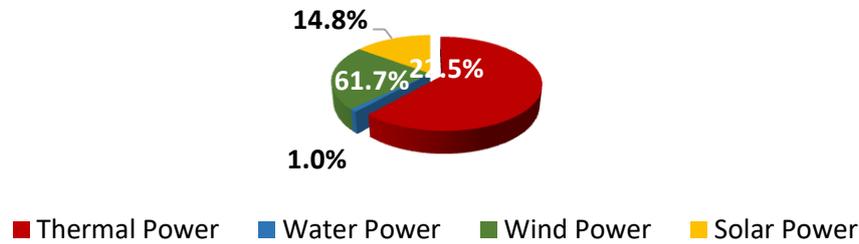


Figure 1. The proportion of installed capacity

In 2017, the electricity demand of the whole society was 97.83 billion kWh, and the total consumption in the area was 87.68 billion kWh. The net value of energy supply was 42.01 billion kWh.

The highest load for the year was 12.66 million kW, and the load rate was 79.1%. The maximum valley-to-peak was 1.72 million kW. The average utilization hours of thermal power was 5126 hours.

3. Dispatch models

3.1. Economic scheduling model

3.1.1. Objective function. The model aims to make the system operate at the most economical state. Consider minimizing the operation cost, including the cost of thermal units, taking into account the requirements of the actual scheduling for energy conservation and environmental protection and related policies. The mathematical forms[6] are as follows:

$$\min \sum_{t=1}^{N_T} \left(\sum_{i=1}^{N_G} (C_i^T F_i^T(t) + C_i^{T_onoff}) + \sum_{w=1}^{N_{Re}} C_{Re}^{curtail} (P_{Re}^{Predict}(t) - P_{Re}(t)) \right) \quad (1)$$

$$F_i^T(t) = a_i (P_i^T(t))^2 + b_i P_i^T(t) + c_i \quad (2)$$

where C_i^T represents the function of fuel cost; P_i^T represents the power of unit i at t hour; $C_i^{T_onoff}$ represents the start cost of unit i at t hour; $C_{Re}^{curtail}$ represents the cost of renewable energy curtailment; $P_{Re}^{Predict}(t)$ and $P_{Re}(t)$ represents the prediction and actual output of the renewable.

3.1.2. Constraints

1) System constraints

a) Power balance constraints of system[7]

$$\sum_{i=1}^{N_G} P_i^T(t) + \sum_{j=1}^{N_{Heat}} P_j^{heat}(t) + \sum_{i=1}^{N_H} P_i^H(t) + \sum_{w=1}^{N_W} P_w^W(t) + \sum_{s=1}^{N_S} P_s^S(t) = P_{load}(t) + P_{loss}(t) + P_{trans}^{DC}(t) + P_{tr}(t) \quad (3)$$

b) Reserve power constraints of system

$$\sum_{i=1}^{N_G} (P_i^{T_capa} - P_i^T(t)) + \sum_{j=1}^{N_{Heat}} (P_j^{heat_capa} - P_j^{heat}(t)) + \sum_{i=1}^{N_H} (P_i^{H_capa} - P_i^H(t)) \geq r_{reserve} P_{load}(t) \quad (4)$$

where $P_j^{heat}(t)$, $P_i^H(t)$, $P_w^W(t)$, $P_s^S(t)$, $P_{load}(t)$, $P_{loss}(t)$, $P_{trans}^{DC}(t)$ and $P_{tr}(t)$ represents the power of the heating unit, hydro unit, wind plant, PV generation, load, loss, DC transmission and AC transmission.

2) Thermal unit constraints

a) The range of units constraints

$$P_{min,i}^T U_i(t) \leq P_i^T(t) \leq P_{max,i}^T U_i(t) \quad (5)$$

b) The minimum start-stop time constraints

$$(U_i(t) - U_i(t-1))(T_i^{on}(t-1) - T_i^{on}) \geq 0 \quad (6)$$

$$(U_i(t-1) - U_i(t))(T_i^{off}(t-1) - T_i^{off}) \geq 0 \quad (7)$$

c) The ramping rate constraints

$$-R_i^{down} \Delta T \leq P_i^T(t) - P_i^T(t-1) \leq R_i^{up} \Delta T \quad (8)$$

where $P_{min,i}^T$ and $P_{max,i}^T$ respectively means the minimum and maximum power; $U_i(t)$ means the state of the thermal unit, T_i^{on} and T_i^{off} means the on-time and off-time of the unit, R_i^{down} and R_i^{up} means the down and up ramp rate.

3) Hydro units constraints

a) Reserve hydro units

For this type of units, the maximum power is limited by reservation and the minimum power is limited by the forced power and the constraint of generating capacity each day is described as follows:

$$P_{min,i}^H \leq P_i^H(t) \leq P_{max,i}^H \quad (9)$$

$$\Delta T \sum_{t=1}^{N_T} \sum_{i=1}^{N_H} P_i^H(t) \leq Q_i^{reservoir} \quad (10)$$

b) Runoff hydro units

The output of runoff hydro unit is greatly affected by the season and climate, which is fully absorbed in principle:

$$P_i^{ROH}(t) = P_i^{ROH-predict}(t) \quad (11)$$

4) The generation constraints of renewable energy

$$0 \leq P_{Re}(t) \leq P_{Re}^{predict}(t) \quad (12)$$

5) The constraints of transmission power

$$P_{tr}(t) = P_{tr,set}(t) \quad (13)$$

6) The constraints of DC power

$$P_{trans}^{DC}(t) = P_{trans,set}^{DC}(t) \quad (14)$$

where $P_{tr,set}(t)$ means the rated output of the transmission.

3.2. Impartiality scheduling model

Considering the principle of fairness of the system, taking the fairness of generation among power plants as an indicator, try to enable each power plant to complete the contracted power at the same schedule. To simulate the operation, add a three-gong penalty coefficient to the objective function, to exceed the power plant that lags behind the average schedule. The specific mathematical form is:

$$\min \sum_{n=1}^{N_{G,fair}} Pen_thermal |R_{n,complete} - R_{complete}^{avg}| + \sum_{t=1}^{N_T} \sum_{n=1}^{N_{Re}} C_{Re}^{curtail} (P_{Re}^{predict}(t) - P_{Re}(t)) \quad (15)$$

$$R_{n,complete} = \frac{Q_n^{T-plant}}{Q_{n,set}}, R_{complete}^{avg} = \frac{\sum R_{complete}}{N_{G,fair}} \quad (16)$$

where $Pen_thermal$ means the deviation penalty coefficient, $R_{n,complete}$ means the contract generation completion rate of a thermal power plant, which is equal to the ratio of daily generation $Q_n^{T-plant}$ to contracted electricity $Q_{n,set}$, $R_{complete}^{avg}$ measures the daily average contracted generation completion rate of each plant, $N_{G,fair}$ means the number of power plants which participate in the contracted generation.

3.3. Energy-saving scheduling model

We care about the coal consumption of the system during operation in Energy-saving scheduling. To minimize the energy cost of the system, the specific mathematical form of the objective function is:

$$\min \sum_{t=1}^{N_T} \sum_{i=1}^{N_G} (Consum_i^T F_i^T(t) + C_i^{T-off}) \quad (17)$$

where $Consum_i^T$ means the coal consumption coefficient.

The constraints are similar to the economic scheduling

3.4. Low-carbon scheduling model

3.4.1 Objective function. Considering the impact of dispatch on the environment, we expect the system to minimize the carbon emissions during the operation and avoid the curtailment of renewable energy. The specific mathematical form is:

$$\min \sum_{t=1}^{N_T} \left(\sum_{i=1}^{N_G} (Carbon_i^T P_i^T(t) + C_i^{T-off}) + \sum_{w=1}^{N_{Re}} C_{Re}^{curtail} (P_{Re}^{Predict}(t) - P_{Re}(t)) \right) \quad (18)$$

where $Carbon_i^T$ is the coefficient of carbon price.

3.4.2 Constraints. Based on the constraints of the economic dispatch, the low-carbon scheduling model increase the constraint of carbon emission limit. The specific mathematical form is:

$$\sum_{t=1}^{N_T} \sum_{i=1}^{N_G} E_{i,t} \leq E^{capa} \quad (19)$$

$$E_{i,t} = f F_i^T \quad (20)$$

where $E_{i,t}$ and E^{capa} are carbon emissions and indicators, f is the factor of carbon emission.

4. Simulations and analysis of dispatch

We will focus on the tests of the models above based on the actual system parameters in 2017. According to the idea of post-evaluation, we calculate the fairness deviation, operation cost, renewable energy consumption capacity and low carbon emission of the four models, and verify the rationality and feasibility of the model by comparison.

4.1. Comparisons of operation indexes in various scheduling models

In view of different policy systems, we give four scheduling models, and will evaluate the indexes of them from the aspects of fairness, economy, energy saving and low carbon.

4.1.1. Fairness result. In order to avoid influencing economic benefits of plants, we consider the quantity completion rate of each plant as the fairness index, further determine the output of each plant and the total output in a day:

$$Q_n^{T-plant} = \Delta t \sum_{t=1}^{N_T} \sum_{i \in P_n} P_i^T(t) \quad (21)$$

The completion rate of each plant is:

$$\eta_n = Q_n^{T-plant} / Q_{n,set} \quad (22)$$

where, $Q_{n,set}$ is the contract electricity formulated.

The standard deviation of the contract electricity completion rate of each power plant is calculated to obtain the fairness index reflecting the dispersion degree of output in each plant.

4.1.2. Economy result. For the convenience of comparison, we use the operating cost as the economic evaluation index which is combined with fuel cost of thermal power and startup, shutdown cost of thermal power and the punishment of renewable energy curtailment.

4.1.3. Energy saving result. The evaluation of the energy saving of a scheduling model mainly depends on the fuel consumption of thermal units by the optimization of the model.

4.1.4. Low carbon result. When evaluating whether a scheduling can effectively reduce carbon emissions, we examine the carbon cost of units and their capacity to absorb renewable energy. So, the low carbon index includes the carbon emission and thermal units cost and the penalty for the renewable energy curtailment.

Table 1. The comparisons of operation index in various dispatches

	Impartiality dispatch	Economy dispatch	Energy saving dispatch	Low carbon dispatch
Fairness	0.2919	0.7285	0.7357	0.7122
Economic/RMB	45124000	43034000	43037000	43044000
Energy saving/t	73723.8	70617.6	70464.0	70642.5
Low carbon/RMB	1383.8	1290.5	1292.7	1285.5

As seen in the table1, the output of plants in impartiality dispatch compared with the total deviation of the contracted energy and the discrete situation is relatively the best. This dispatch considers the fairness among the plants, ensuring that the plant can complete the contract power with similar progress. It can be seen that the cost of economic dispatch is the least. The operation scheduling of the impartiality dispatching makes the system not run in an economical state, which means the economy is less than the other models. For the comparison of energy efficiency, it can be seen that among the models, the index of energy saving is the least compared to other models. For the comparison of low carbon, it can be seen that among the models, the indicators of low carbon model are the best.

4.2. Comparisons of renewable energy consumption capacity in various scheduling models

In order to face the access of large amount of renewable energy, we need to adopt a more reasonable scheduling strategy. The peaking margin indicator of the system can describe the contribution of the system to the renewable energy transfer. Therefore, we select the average peaking margin and depreciation rate of each scheduling model on a typical day for comparison.

Table 2. The comparisons of operation index in various dispatches

	Impartiality dispatch	Economy dispatch	Energy saving dispatch	Low carbon dispatch
Up peaking margin/kW	3672000	3346000	3326000	3347000
Down peaking margin/kW	1202000	1366000	1282000	1363000
Energy curtailment/kWh	4447000	3320000	3795000	3292000

It can be seen from the table 2 that index of impartiality dispatch is higher than the other dispatching methods, and the renewable energy depreciation rate is large. The average peak margin is relatively high. This is because the impartiality dispatching makes the system relatively fair among the plants, so that the excess unit staying online increases the minimum technical output of the system.

At the same time, each scheduling method still has a large peaking margin, which can absorb more renewable energy. The method with a smaller average negative peak margin is more likely to be abandoned when the wind exceeds expectations; while the average positive peak margin is more likely to be tight when the wind is lower. As shown in the table, the three public dispatches have fewer spares, and the renewable energy can be absorbed discount. They all have higher consumption.

5. Conclusion

This paper focuses on the different scheduling methods considering renewable energy consumption, and introduces the power and load in typical areas of Northwest in China. We give four typical scheduling methods analysed and compared with the actual data. There are certain shortcomings in the

current scheduling method. The economics of the methods cannot be guaranteed, and the ability to complete social tasks is relatively weak. So it is necessary to solve the problem of renewable energy curtailment by optimizing dispatching methods and relevant market mechanisms.

Therefore, firstly we recommend to use mechanisms such as compensation price to encourage self-supply power plants to participate in peaking, providing more flexibility for dispatching. Secondly, different dispatching agencies can choose their own scheduling methods according to energy and load conditions and related market constructions. For areas with abundant hydro energy, hydro units are expected to be peaking power sources. The requirements for renewable energy consumption can be relaxed in the areas with relatively insufficient power supply to ensure the reserve requirements. Thirdly, the deep peaking auxiliary service market can be combined to explore the scheduling potential of thermal power. In other words, the thermal power unit with high peaking capability is allowed to provide peaking services as a seller. Finally, the thermal power plant should decouple the “heat-set” operation mode to improve scheduling flexibility.

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