

Study on Generation Planning and Dispatching Model of Units under Power Market Reforming

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Abstract—Under the background of the deepening reformation of the power market, the introduction of power spot market can increase the activity of the reform. The systematic "orderly liberalization" of the market-trading power is also the key guarantee for the power electricity market reforming. On this basis, a power management model of generating units considering spot market trading is constructed. By means of marketization, the allocation of generating capacity is more reasonable and fairer, and the enthusiasm of coal-fired power plants is improved, and a reasonable and transparent spot trading mechanism on generation side is established.

Keywords—electric power reform; spot market; power generation plan

I. INTRODUCTION

With the "Several Opinions on Further Deepening the Reform of Electricity System" issued by the State Council on March 15, 2015, a new round of electricity market reform was officially launched. The reform has clearly defined the key points and paths for deepening the reform of the electric power system. On March 29, 2017, the National Development and Reform Commission and the National Energy Administration issued the Notice on the Orderly Release and Development of Electricity Plans, which stipulated the relevant matters.

The electricity spot market is an important part of price discovery and resource optimization. Spot transactions are closer to the real-time power consumption than that of the medium and long-term transactions, which is conducive to discovering electricity price through market mechanism. It can reflect the real market demand, supply capacity and the changes and trends, which also allows electricity to return to commodity attributes, so that electricity price can better reflect the relationship between cost and supply and demand. In 2017, the National Development and Reform Commission and the National Energy Administration issued the Notice on the Pilot Work of Electricity Spot Market Construction. Eight regions, including Guangdong, Zhejiang and Shanxi, etc. were selected as the first batch of pilot projects to accelerate the organization and promotion of the construction of electricity spot market, which are required to start the trial operation of the electricity spot market from the end of 2018.

At present, domestic and foreign scholars have conducted a lot of research on the electricity spot market and power generation plan. Literature [1-3] comprehensively compares and analyses the latest practice of power market construction in different countries and regions of the world, analyses the composition framework and operation mode of the spot market, and analyses the determinants of the trading space of the spot

market. Literature [4] considers the spot market trading mechanism and establishes a spot market clearing model with flexible block trading. Literature [5] studies the strategy of the current construction mode of electricity spot market to give full play to the key role of spot electricity market in balancing market demand. In view of the limitation of resource optimization and the contradiction between medium-term and long-term electricity trading and dispatching, Literature [6] propose that the spot market in the southern region should construct the mode strategy with balanced regional allocation. Combining with the characteristics of spot market, aiming at the contradiction between supply and demand of new energy in Gansu region, Literature [7] constructs a unit optimization model for priority consumption of new energy to improve the utilization efficiency of hydropower, wind power and photovoltaic in Gansu Province.

Literature [8] combines the relevant factors of the spot market trading space, concluding that when the power generation capacity is insufficient, it is mandatory to require the power spot market trading space to be "full power". Literature [9] constructed a two-stage annual rolling generation plan optimization model combined with "three public" dispatch. The first stage establishes a rolling unit combination optimization model that considers direct transaction and "three public" dispatch, and the second stage establishes a power generation plan optimization model that considers the daily load rate balance of the power plants. The literature [10] details the key technical contents of the power generation plan under marketization: the system structure with the basic characteristics of the comprehensive interaction between source and network load, and the optimization idea with the goal of operating economy. Literature [11] constructs a medium-term operational planning model, which considers both expected profit maximization and risk minimization, to help power generation companies formulate medium-term planning and improve the power sales strategy in spot market and contract market.

Based on the above research, this paper combines the current development trend of power reform and the construction and operation status of spot market in our country, and compiles the generation plan. Considering the spot transaction and the ancillary services, the unit-generation allocating model is constructed to determine the basic generation hours of each power unit according to the remaining electricity.

II. GENERATOR POWER ALLOCATING MODEL WITH SPOT MARKET PARTICIPATING

The design idea of the generator power allocating model is as follows:

1) Opening up part of the electricity power is preferentially traded in market transactions. Then set the spot market proportion according to the historical rules and determine the reserve capacity of conventional units to stabilize renewable energy output, which is the generation of the ancillary service market and is ensured according to the historical electricity consumption data.

2) The capacity of conventional units is partly cut off according to its corresponding market trading electricity power.

3) The capacity of conventional units which participate the ancillary market is deducted according to its corresponding auxiliary services power.

4) Determine the amount of electricity that is not involved in the transactions, i.e. the planned amount of electricity that needs to be allocated among the conventional units.

5) The remaining electricity is allocated among units in accordance with the principle of generating plan preparation. Then adjust the generating hours of each unit according to reward and punishment mechanism, unit maintenance arrangement, etc.

A. Market Trading Electricity Allocation Model

Priority will be given to the electricity market transactions, and the result depends on the long-term trading agreements and the bidding transactions between the power plants and users. According to the average utilization hours of the generating unit in the previous year, the deduction capacity is calculated as follows:

$$\Delta R = Q_l \div T_{last} \times T \quad (1)$$

where, ΔR represents the capacity that needs to be cut off due to the market transactions. Q_l is the amount of electricity of all kinds of market transactions. T_{last} is the generating hours of the units in last year. T is the capacity rejection coefficient, and ranges from 0 to 1.

Renewable energy has uncertainties and volatility of output, so it is necessary to rely on reserve capacity to suppress its fluctuation when intervening in electricity trading. In order to facilitate calculation, assume that the renewable energy in the current market is only wind power, which is known as follows:

$$D = Q_{Market} \times \gamma_d = P_T + W_d \quad (2)$$

where, D is the total transaction volume of the spot market. γ_d is the proportion of the spot market. P_T represents the reserve power that conventional units provide for renewable power. W_d is the amount of wind power participating in spot market.

$$P_T = D - W_d \quad (3)$$

Due to the uncertainty of the coming wind and the fluctuation of wind power output, the conventional units are facing various scheduling states. Assume that $(D - W_d)_u$, $u = 1, 2, 3, \dots$, the deviation from the actual load change in the market can be expressed as:

$$\Delta G_u = (D - W_d)_u - (D - W_d) \quad (4)$$

If conventional units are not involved in reserve market, the maximum generation amount reaches P_{GT}^{MAX} . Then, there is,

$$\begin{cases} P_{GT}^{MAX} - P_T \geq \text{Max}(\Delta G_u) \\ P_T \geq |\text{Min}(\Delta G_u)| \end{cases} \quad (5)$$

Interval $[P_T^L, P_T^U]$ divide by the units operation hours is the capacity interval of the reserve market, which is $[R_{Min}, R_{Max}]$.

B. Renewable Energy and Heating Power Calculation

Considering China's policy of renewable energy security acquisition, it should be considered that renewable electricity which isn't involved in market transactions should be purchased for policy consideration. Meanwhile, heating electricity power belongs to basic public services, and should not be included in the allocated planned electricity, either.

Forecasting annual renewable energy generation uses probability and statistics methods. The smaller value between the forecasting value and the minimum guaranteed power generation hours is selected as its planned power generation. Heating demand can be extrapolated and predicted according to historical data or estimated according to heating area and heating standard. The total number of thermal power units is $M = C + G$. In order to meet the thermal supply during the heating period, the power generation of thermal power units should meet the following requirements:

$$H = \sum_{m=1}^M \eta_m \times (Q_m \times 3600) \quad (6)$$

where, H is the total need of heat. η_m is the thermoelectric ratio. Q_m is the power generation of m thermal units that is used to satisfy the heating demand.

According to the average operating hours of thermoelectric units in last year, the hours that need to be re-allocated this year should be calculated as follows:

$$\Delta R_m = \frac{Q_m}{T_0} \quad (7)$$

$$R'_m = R_m - \Delta R_m - R_u \quad (8)$$

where, R_u is the capacity of units participating in reserve services.

After deducting the unit capacity, the units participating in heating need to deduct the unit capacity for heating and power generation, and then allocate the corresponding basic generating hours. It is necessary to restrict the participation of power suppliers in direct purchasing or bidding transactions, so that power plants can only use electricity beyond planned generation to conduct market transactions. Assuming that the planned basic generating hours of thermal power plant i are T_i , and by plusing the changing hours caused by rewards, penalties and maintenance, the planned generating capacity of thermal power plant i is:

$$Q_m = (T_m + \Delta T_m) \times R_m \quad (9)$$

where, ΔT_m is the changing hours caused by rewards, penalties and maintenance. And the capacity of the units is calculated though the electricity amount that participate in market transactions.

$$R'_m = R_m - \frac{Q_m}{\bar{T}} - R_u \quad (10)$$

where, \bar{T} is the average generating hours of the total thermal units last year.

C. Calculation Model of Basic Generation Hours of Units

$$R' = R - R_{heat} - \Delta R \quad (11)$$

where, R' is the capacity of units getting involved in planed power allocating. R represents the installed capacity. R_{heat} is the capacity of the units that provides heat. ΔR is the deducted capacity.

So the basic generating hours for conventional thermal units is calculated as follows.

$$Q_D \times (1 - \gamma) = Q_C + Q_G + Q_H + Q_W + Q_P + Q_S + Q_{IN} - Q_{OUT} - W_d \quad (12)$$

where, Q_C is the thermal power generation. Q_G is the gas generation. Q_H is the hydro generation. Q_W is the wind power generation. Q_P is the PV generation. Q_S is the deducted power affected by rewards, penalties and maintenance. Q_{IN} is the purchasing power from other regions. Q_{OUT} is the selling power with other regions. γ represents the proportion of electricity that takes part in market trading.

Wind power generation, PV power generation, reserved power, purchasing and selling power, and hydropower power generation can be regarded as fixed values. Then formula (12) can be expressed as:

$$Q_D \times (1 - \gamma) - (Q_H + Q_W + Q_P + Q_S + Q_{IN} - Q_{OUT} - W_d) = Q_C + Q_G \quad (13)$$

If

$$Q'_D = Q_D \times (1 - \gamma) - (Q_H + Q_W + Q_P + Q_S + Q_{IN} - Q_{OUT} - W_d) \quad (14)$$

there is

$$Q'_D = Q_C + Q_G \quad (15)$$

The allocating of generating hours is related to unit types and capacity levels. Assuming that the basic generating hours of the minimum capacity of coal-fired units is T_{C0} , and the capacity increment of the units in next level is ΔT_c . The basic generating hours for units in level c can be expressed as follows:

$$T_c = T_{C0} + (c - 1) \times \Delta T_c \quad (16)$$

Assuming that the basic generating hours of the minimum capacity of gas units is T_{G0} , and the capacity increment of the units in next level is ΔT_g . The basic generating hours for units in level g can be expressed as follows:

$$T_g = T_{G0} + (g - 1) \times \Delta T_g \quad (17)$$

Then formula (15) can be expressed as follows,

$$\begin{aligned} Q'_D &= \left(\sum_{c=1}^C R_c \times T_c \right) + \left(\sum_{g=1}^G R_g \times T_g \right) \\ &= \left(\sum_{c=1}^C (R_c^0 - \Delta R_c) \times T_c \right) + \left(\sum_{g=1}^G (R_g^0 - \Delta R_g) \times T_g \right) \\ &= \left(\sum_{c=1}^C (R_c^0 - \Delta R_c) \times (T_{C0} + (c - 1) \times \Delta T_c) \right) \\ &\quad + \left(\sum_{g=1}^G (R_g^0 - \Delta R_g) \times (T_{G0} + (g - 1) \times \Delta T_g) \right) \end{aligned} \quad (18)$$

According to the support degree for coal-fired units and gas units, the relationship between variables T_{C0} and T_{G0} can be set up. Such as,

$$T_{G0} = T_{C0} \times \alpha \quad (19)$$

$$T_{G0} = T_{C0} + \beta \quad (20)$$

III. CASE STUDY

Taking the electricity market of a certain place in China as an example, the concept of power spot market is introduced based on the existing power generation plan management. The proportion of open spot market and the related ancillary service market are eliminated when calculating, so that the planned electricity is redistributed.

A. Basic Data

Presently, the spot market is mainly open for renewable energy power, so the auxiliary service market is needed to solve the fluctuation of its output. coal-fired thermal power units are required to join the auxiliary service market to provide reserve services for renewable energy. In order to suppress the fluctuation of renewable energy generation, units providing reserve services should give priority to increasing or reducing output. According to related rules, qualified conventional coal-fired power units with a single capacity of 300,000 kW or less should be reduced to at least 50% of the rated capacity when providing reserve services. units with a capacity of 300,000 kW or more should be reduced to at least 60% of the rated capacity. In this case study, 20 units in this region are chosen to be further analyzed.

TABLE I. ACCESS ANALYSIS OF UNITS

No.	Capacity	Amount of Planned- power Last Year	Provide Heating	Type of units	Accessible or Not
1#	200	75.90	No	Coal-fired	Yes
2#	200	82.41	No	Coal-fired	Yes
3#	60	48.8	---	---	No
4#	252	96.14	Yes	Coal-fired	Yes
5#	100	39.34	No	Coal-fired	Yes
6#	240	87.22	No	Coal-fired	Yes
7#	240	90.63	No	Coal-fired	Yes
8#	360	131.69	No	Coal-fired	Yes
9#	132	51.59	No	Coal-fired	Yes
10#	60	22.23	Yes	Coal-fired	Yes
11#	120	42.5	No	Coal-fired	Yes
12#	120	82.59	No	Coal-fired	Yes
13#	120	43.31	No	Coal-fired	Yes
14#	120	49.61	No	Coal-fired	Yes
15#	120	45.63	No	Coal-fired	Yes
16#	60	22.36	Yes	Coal-fired	Yes
17#	60	22.64	Yes	Coal-fired	Yes
18#	60	25.81	Yes	Coal-fired	Yes
19#	120	45.41	Yes	Coal-fired	Yes
20#	60	22.67	Yes	Coal-fired	yes

B. Scenarios Setting and Result Analysis

During the period of 2015-2017, the generating hours used for policy requirement of wind power in this region are about

1900 hours. Therefore, in scenarios setting, the acquisition criteria are maintained unchanged, and the wind power output in 2018 is forecasted. The number of renewable energy generating hours involved in spot market transactions is about 425 hours. According to the historical reserve requirement in this area, the corresponding reserve electricity power is about 1.53 billion kWh. Capacity changes of conventional units under different open ratios and rejection coefficients of market power are analyzed.

After introducing the spot market, the renewable energy electricity is slightly reduced, and the electricity of ancillary service market is increased accordingly. The spot market is introduced and the open proportion of spot market is adjusted under the existing planning principle, and the planned Electricity Allocation of each unit is analyzed. The following pictures shows the changes of units under the opening proportion γ of 38% and 46% and with the capacity deducted coefficient T valued for 0, 0.5 and 1.

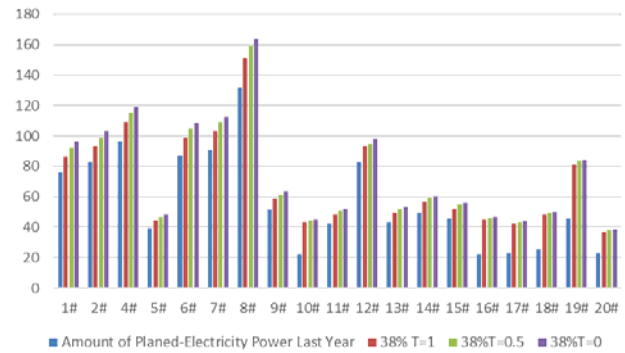


FIGURE I. CHANGES OF UNITS UNDER OPENING PROPORTION OF 38%

From the figure above, the generating capacity of the units participating in market transactions is less affected by auxiliary services, and with the decline of the capacity rejection ratio, the generating capacity of the units increases further. If the units that do not participate in market transactions and ancillary service market, their power space will be further compressed.

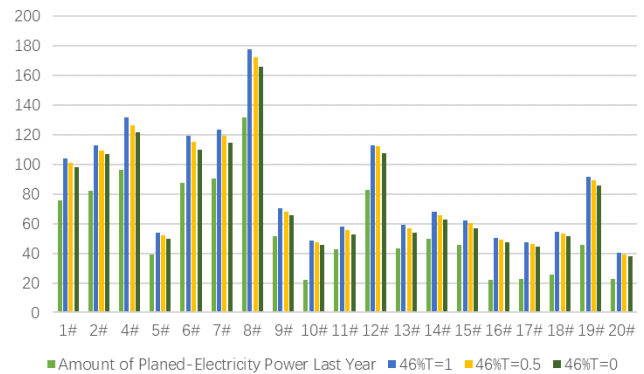


FIGURE II. CHANGES OF UNITS UNDER OPENING PROPORTION OF 46%

At 46% of the opening ratio, the trend of the auxiliary service unit and the capacity rejection coefficient is opposite,

that is, with the decline of the capacity rejection ratio, the power consumption of the unit decreases.

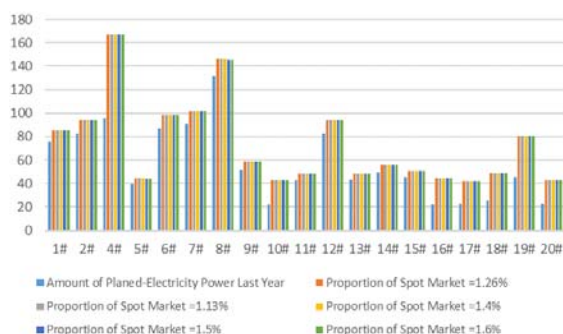


FIGURE III. POWER ALLOCATION OF UNITS IN DIFFERENT SPOT MARKET OPENING RATIO

As can be seen from the figure, with the expansion of the spot market liberalization ratio, the planned power allocation of each unit barely changes under each scenario. Due to the small proportion of the spot market, only accounting for 1%~2% of the total electricity on the generation side, and the numerous units managed by the power generation plan, the fluctuation of the spot market proportion affects a little.

IV. CONCLUSION

Based on the existing management mode of the power market, a capacity calculation model and a power allocating model of conventional units considering spot market's participation are constructed in this paper. Through the analysis of the example, it can be seen that the relationship between the capacity rejection factor and the units participating in peak shaving auxiliary service is different with opening ratios changing. As the spot market is currently only open to renewable energy power and the proportion is extreme small of total electricity consumption, the amount of power of the ancillary services market is correspondingly less. Actually, the open proportion of spot market has little change in the planned power allocation of each unit. However, with the trading rules improving and the renewable energy developing, the prospect of the spot market trading is cheerful. With the continuous liberalization of the electricity market and the continuous improvement of the rules, the planned electricity consumption will gradually decrease in the total electricity consumption, achieve the goal of reform, and realize the liberalization of market transactions.

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