Research on Wind Power Dissipation Capacity Model of Considering Inter-provincial Mutual Aid

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***Abstract*— Due to the intermittent and anti-peaking properties of wind power,wind power-enriched provinces face system peaking and energy consumption problems. The construction of inter-provincial mutual aid is one of the effective ways to solve the problems of wind power consumption.In response to the current large number of wind abandonment phenomena,this paper takes Hebei Province Southern Power Grid Network in China as an example to establish a model for predicting wind power absorption capacity from 2018 to 2020,and establishes an inter-provincial mutual aid model that considers wind power transmission,forms the equivalent load curve and the wind power output after adjusting the contact line.The results show that the inter-provincial mutual aid construction can reduce the system's abandonment.Finally,this paper puts forward some effective measures to improve the capacity of absorbing wind power.**

***Index Terms*— Contact line power,Wind power consumption forecast,Provincial power grid network dispatch,Wind power grid**

I. INTRODUCTION

The development and utilization of wind power and large-scale grid-connected networks have become an inevitable trend for the future development of the power grid.However,the current development of wind power in China is extremely unbalanced. Affected by wind energy resources, wind power is mainly concentrated in the “Three North” region,Grid-connected capacity accounts for 87% of the nation's wind power grid-connected capacity.Due to the short planning and construction period of wind power,resulting in the difficulty of grid-connected wind power operation in the “Three North” region.This article takes Hebei Province Southern Power Grid Network's wind power system as an example.Firstly, forecasting the wind power consumption capacity of Hebei Province Southern Power Grid Network from 2018 to 2020,and then establishing the provincial power grid optimization dispatching model of wind power grid-connected system.When there are surplus wind power storage spaces in neighboring provincial systems.When surplus wind power sinking space exists in neighboring provincial systems,it is possible to apply for transmission line power adjustment under the premise of safe power grid operation,and transport wind power beyond the accommodation space to the neighboring provinces for consumption.The use of flexible tie-line transmission methods for provincial dispatching can improve the ability of absorbing wind power of the provincial system, and effectively alleviate the limitation of wind power output caused by peak-constraint constraints.In addition, due to peak-constraint-constrained wind power is only exceeds some of the peak wind power that consumes space,and the amount of electricity to be compensated at that time is minimal relative to the power consumption of the grid.Under the conditions of the transmission capacity of the tie line can be guaranteed,the balance of electricity within days can be completely achieved.

At present,there have been a lot of studies on the peak shaving issues of wind power grid-connected systems.Liu and Fang in their paper used the weibull distribution to fit the equivalent load curve and quantify the effect of abandoning wind power on peak regulation and wind power generation capacity [1] .Chen and Wang improved the ability of the system to eliminate winds by controlling the heat storage and energy storage [3–5] .In the paper of Wang,they designed a simulation example with typical characteristics of the operation of wind and fire and proposed a recommendation for wind power consumption model suitable for China's wind and fire mutualism operation system [6] .In the paper of Ma and Han,they established an inter-regional peak-sharing model for wind power grid-connected systems and used information gap decision theory (IGDT) to process wind power uncertainties and improve the model [8] .Most of the above studies used reasonable wind abandonment as a means to relieve the pressure of peak load.In fact,We can make full use of the different regional peaking capabilities and inter-regional communication channels to achieve inter-regional peak adjustment and mutual assistance.it is an effective way to solve the difficulties of peak trough adjustment.At present,there are few related studies about it.

Based on the above considerations,in order to effectively guide the development of wind power and future dispatching and operation,this paper forecasts the future capacity of wind power consumption and establishes the inter-provincial mutual aid model of wind power grid-connected systems,and clearly defines the objective function in the model and constraints of each influencing factor.Finally, the effectiveness of the proposed model is proved by an example analysis,which verifies that the provincial-level power grid dispatch can cope with the difficulty of power grid peak shaving and wind power consumption problems effectively.Finally, based on the actual operation of the power system,it proposes measures and suggestions to improve the capacity of absorbing wind power.

II. WIND POWER AND LOAD POWER DISTRIBUTION

Wind power has intermittent and random characteristics.The large-scale wind power grid-connected operation will increase uncontrollable power generation output in the system,and will affect the power system's ability to maintain a balance between supply and demand.Adapting to the impact of wind power access on the system to maintain the balance between supply and demand

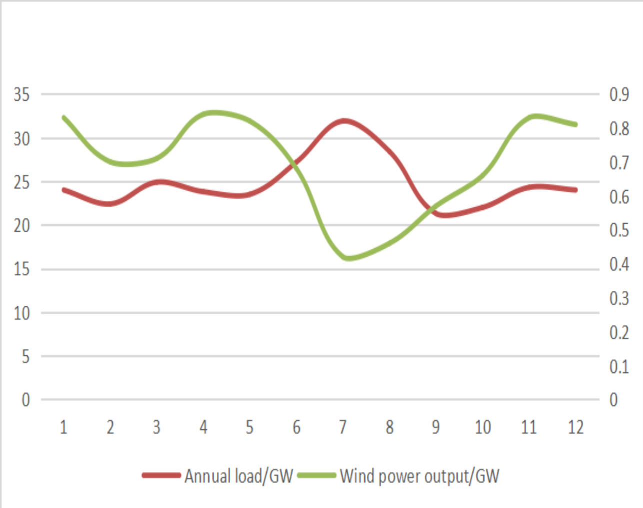

Figure 1 Comparison of load and wind power output in Hebei Province for the whole year of 2017

is the most important condition for the grid to accept wind power capacity.Under the premise without considering the connection lines to participate in peak shaving,the wind power that can be accepted in the regional power grid is greatly limited by the adjustment ability of other power supply output,that is the peaking capacity.When the system load is at a minimum value,the wind power output may reach the maximum level and other power sources will adjust the output to allow the load to be supplied by the wind power. However, due to the limitation of conventional thermal power micro-increasing characteristics, reducing output operation or shutting down the thermal power will increase the cost of power generation.If the wind can be properly discarded during the low load period of the grid,This can improve the safety and economy of the entire power system operation.

The peaking characteristics of the power grid are closely related to the grid load and the output characteristics of the wind turbine.The peak shaving capacity is the conventional installed capacity minus the load power,plus the wind power output power.Figure 1 shows the comparison of load and wind power output in Hebei Province for the whole year of 2017.

It can be seen that the maximum output of wind power output changes greatly within one year.From the analysis of annual output data,it shows certain seasonal characteristics:wind power has a large number of occurrences in the spring and winter, and it has a marked trough in summer. The annual output show a“high-low-high "characteristics.The maximum output in spring and winter can reach about 82% of the installed capacity.In summer,the maximum output only reaches about 42% of the installed capacity,which shows a reverse trend with the annual load.

III. THE METHOD OF WIND POWER CONSUMPTIVE CAPACITY CALCULATION

We should consider the anti-peak regulation of wind farms,the most severe anti-regulation condition is obviously the rated capacity of the wind farm.The peak-shaving capability of the grid is determined by the different types of power supply within the power grid and the different peak-shaving capabilities of the power supply and the peak-shaving capabilities of off-grid power.To study the problem of wind power consumption,we must,firstly,analyze the load characteristics of the power grid,the output characteristics of wind power, and the different types of installed capacity and peak shaving capacity in the network.

Considering the convergence effect of wind power,the installed capacity of wind power that the grid can accept will increase.If the wind power generation capacity is 0.75,the installed capacity of wind power can be calculated.

Defining the peak load on one day as $P_{L\max}$,the trough load as $P_{L\min}$,the peak-to-valley difference as P_{fg} ,the peak-to-valley ratio as α ,the tie line transmission power as P_{line} , the peaking coefficient of the tie line as θ , and the peaking capacity of the system as P_a .The peaking demand of the system is P_d ,the maximum starting capacity of the system operating unit is $P_{G\max}$,the minimum starting capacity of the system running unit is $P_{G\min}$,the rotation standby rate of the system is γ ,the installed capacity of wind power is P_{Gwind} ,and the collection coefficient of wind power is δ .

The system's peak-to-valley difference is $P_{fg} = P_{L\max} - P_{L\min} = P_{L\max}\alpha$, and the peak-shaving requirement of the system is $P_d = P_{L\max}\alpha + P_{L\max}\gamma$ .Before the wind power access system was not considered,the peak-shaving capability of the system is $Pa = P_{G\max} - P_{G\min} + P_{line}\theta$,After considering the wind power, the peak-shaving capability of the system is $P*_a = P_{G\max} - P_{G\min} - P_{Gwind}\delta$ ·

After considering the installation of wind power,in order to cope with the situation in which the output of the wind turbine increases from zero output to full-time at the moment of low load,the minimum output of the system startup unit should be controlled to $P*_a = P_{G\max} - P_{G\min} - P_{Gwind}\delta$.

After the wind power is connected to the grid, the following two constraints must be met:

(1) Considering that the minimum technical output of wind turbine operation units should not exceed the system load,as:

(2)

$$P*_{G\min} \le P_{L\min} \quad (1)$$

(3) The peak shaving capacity of the system should not be less than the peak shaving requirement of the system,as:

$$P*_a \ge P_d \quad (2)$$

Substituting the relevant formula, we can get:

$$P_{G\min} + P_{line}(1-\theta) + P_{Gwind}\delta \le P_{L\min} \quad (3)$$

$$P_{G\max} - P_{G\min} + P_{line}\theta - P_{Gwind}\delta \ge P_{L\max}\alpha + P_{L\max}\gamma \quad (4)$$

By formula (3)

$$P_{Gwind} \le [P_{L\min} - P_{G\min} - P_{line}(1-\theta)]/\delta \quad (5)$$

By formula (4)

$$P_{Gwind} \leq [P_{G\max} - P_{G\min} + P_{line}\theta - (P_{L\max}\alpha + P_{L\max}\gamma)]/\delta$$

(6)

In summary,the maximum wind power installed capacity that the system can accept is:

$$P_{Gwind\ \max} = \min\{[P_{G\max} - P_{G\min} + P_{line}\theta - (P_{L\max}\alpha + P_{L\max}\gamma)]/\delta, [P_{L\min} - P_{G\min} - P_{line}(1-\theta)]/\delta\} \quad (7)$$

IV. THE WIND POWER ABSORPTION CAPACITY OF HEBEI PROVINCE SOUTHERN POWER GRID NETWORK

Winter wind power consumption when not taken into account contact line peaking:

In winter,the load is small,the capacity of the heating unit for peak regulation is limited,and the wind power capacity that the grid can accept is small.When the peak-shaving capacity of power lines outside Hebei Province Southern Power Grid Network not taken into account,and only the peak-shaving capability of the thermal power unit within the network is considered,the winter wind power generation during the period from 2017 to 2020 can be calculated based on the above method,shown in Table 1.

The capacity of wind power consumption is negative,indicating that the maximum load day in winter cannot absorb wind power.The influence of the peak of connection line on the capacity of wind power absorption:

If the peaking capacity of the tie line varies from 0 to 100%,the capacity of the wind power absorption is shown in Table 2.As the peak capacity of the tie-line increases,so does the wind power consumption capacity of the power grid.

Wind power consumption capacity in different seasons:

The load during the low period of Hebei Province Southern Power Grid Network is the base load, with little difference.In winter, the thermal power unit can only be “heated by electricity”,and the capacity of peak regulation is limited,which affects the consumption of wind power.In the spring,autumn and summer,the peak shaving capacity of the thermal power unit is not limited,and the peak shaving capacity becomes larger,which is beneficial to the absorption of wind power.The peak rate of the tie line is 0.Since spring and autumn load characteristics are the same,only spring is calculated.The overhaul of the thermal power unit was arranged in spring and autumn.When calculating the capacity of wind power consumption in autumn,the overhaul of the unit was considered to be 3000 MW.The consumptive capacity of wind power in different seasons is shown in Table 3.

Table 1 Winter Wind Power Consumption Capacity of Hebei Province Southern Power Grid Network(Unit: MW)

Years	2018	2019	2020
Consumption Capacity	1198	-38	-1742

Table 2 Capacity of wind power consumption when different peak shaving capacity of tie line (unit:MW)

Years / Peak Connection rate	2018	2019	2020
0	1198	-38	-1742
50%	3231	1995	291
100%	5264	4028	2324

Table 3 Wind power consumption capacity in different seasons (Unit: MW)

Years / Season	2018	2019	2020
Spring	1090	3239	5388
Summer	7555	5984	4331
Autumn	1198	-38	-1742
Winter	1158	3036	4914

V. AN INTER-PROVINCIAL MODEL FOR PROMOTING WIND POWER CONSUMPTION

In order to promote the use of wind energy resources,this paper proposes a model of inter-provincial mutual aid.In the model,the transmission power of inter-provincial tie line is set as a controllable variable.The set value of the tie power is calculated by the inter-provincial transaction power calculation.When the transmission power of the tie line deviates from the planned value,the deviation is converted into a penalty fee and added to the objective function. The objective function is:

$$\min \sum_{t=1}^{T}\{\sum_{t=1}^{N_T} C[P_i^T(t)] + \sum_{j=1}^{N_L} C_{penalty} \,|\, P_{tie,j}(t) - P_{tie,j}^{set}(t) \,|\} \quad (8)$$

In the formula: $C[P_i^T(t)]$ is the power generation cost of thermal power unit i in t period, $P_i^T(t)$ is the output of thermal power unit i in t period, $P_{tie,j}(t)$ is the actual power value of j tie line in t period, $P_{tie,j}^{set}(t)$ is the set power value of j tie line in t period, $C_{penalty}$ is the deviation penalty coefficient of the delivery power and the set value of the tie line, is the total N_T number of equivalent thermal power units in the system, N_L is the tie line number, T is the number of scheduling periods.Use the DC power flow method and bring it into the objective function.In the power system,the expression of DC power flow calculation is as follows:

$$P = B\theta \quad (9)$$

$$P_1 = Y_B A\theta \quad (10)$$

In the formula: P is the column vector that each node injects power, B is the node admittance matrix, θ is the voltage phase angle vector of the node, P_1 is the vector formed by the active power of the branch; Y_B is the diagonal matrix formed by the branch admittance, A is a network affinity matrix.

Using equation (9)(10), the relationship between the injected node power and the branch current can be derived.

$$P_1 = Y_B A B^{-1} P \qquad (11)$$

From equation (11), the current $P_{tie,j}(t)$ corresponding to each tie line can be obtained.

The main object of study in the inter-provincial optimization scheduling is the provincial tie line power,and the precise scheduling of the crew is considered in the provincial dispatch.Therefore,in the model,the power supply is “bundled” into the equivalent unit according to the province,which can greatly reduce the amount of simulation calculation. The following constraints are mainly considered in this model:

(1) Power balance constraints:

$$\sum_{i=1}^{N_T} P_i^T(t) + \sum_{i=1}^{N_H} P_i^H(t) + \sum_{i=1}^{N_w} P_i^W(t) = P^L(t) \qquad (12)$$

In the formula: N_T , N_H , N_W are the total number of equivalent,thermal power, hydropower,and wind power turbine units in the system, $P^L(t)$ is the sum of the load of the provincial system and the power sent to the outside of the province during the t period, $P_i^T(t)$ is the provincial equivalent thermal power i plan output during the t period, $P_i^H(t)$ is the output of equivalent hydropower i in each province during the t period, $P_i^W(t)$ is the output of equivalent wind turbine i in each province during the t period.

（2）Power generation output constraints:

$$P_{i,\min}^T \le P_i^T(t) \le P_{i,\max}^T \qquad (13)$$

In the formula: $P_{i,\min}^T$ is the minimum technical output of the equivalent thermal power unit i, $P_{i,\max}^T$ is the maximum technical output of the equivalent thermal power unit i. Equivalent hydropower and wind turbines have similar constraints and are no longer listed.

（3）Tie line transmission power constraint:

$$\underline{P_{tie,j}} \le P_{tie,j}(t) \le \overline{P_{tie,j}} \qquad (14)$$

In the formula: $P_{tie,j}(t)$ is the transmission power of transmission branch j in period t, $\underline{P_{tie,j}}$ and $\overline{P_{tie,j}}$ are the upper and lower limit values of transmission capacity of branch j respectively.

VI. Analysis of Examples

This paper uses the typical day in a year of Hebei Province Southern Power Grid Network in Hebei Province of China as an actual calculation.The estimated annual installed capacity of thermal power is 45,400 MW,the installed capacity of hydropower is 6,480 MW and the installed capacity of wind power is 24,600 MW.It is expected that a provincial-level optimized dispatch will be established between the wind power output of Hebei Province Southern Power Grid Network and a wind-power-enriched province A in northern China.Among them,the annual installed capacity of wind power in Hebei Province Southern Power Grid Network and Province A accounted for 32% and 15% of the maximum load in each province.The load and forecast output of wind power in the beginning of the years of the two provinces was obtained through load data and wind power output data linearly.The power supply structure,grid structure,connection line plan and wind power installation data are horizontal year planning data.

In order to illustrate the adjustment role of the tie line,this paper compares the total daily operating cost of different tie line power and the wind power consumption forecast results of the two provinces. The results are shown in Table 4.

It can be seen that with the shortening of the tie line adjustment period,the total cost of the system operation is decreasing, and at the same time,the two provinces have reduced their power consumption.Therefore,by flexibly adjusting the transmission power of the tie line,it is possible to effectively use the excess wind power consumptive space in the two provinces,as shown in Figure 2.

However, the increase in the allowable deviation of the tie line also means that the tie line power is far from the control target,which will affect the safety of the system.Therefore,a reasonable allowable deviation can make the tie line power control fluctuate within the range that does not affect the system security.On the one hand,It can use more lower-cost electricity, reduce system operating costs,on the other hand,It can increase the consumption of new energy throughout the region.

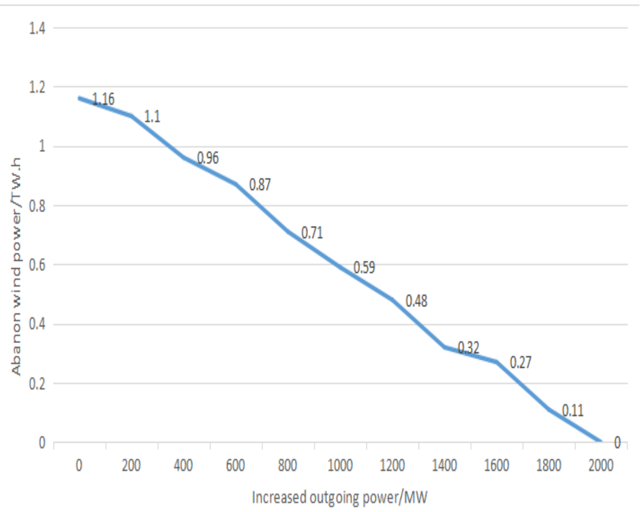

Figure 2 Changes in the amount of wind rejection as the outgoing power changes

Table 4 Wind power consumption forecast results and total operating expenses in the two provinces

Tie Line	Hebei Province			Province A			Total system operating costs
	Power generation/(TW.h)	Limited power /(TW.h)	Limited power ratio/%	Power generation/(TW.h)	Limited power /(TW.h)	Limited power ratio/%	
Constant power	2.33	0.39	16.91	3.09	0.10	3.23	48240
Power fluctuations in $\pm 50MW$	2.35	0.37	15.74	3.10	0.09	2.90	48239
Power fluctuations in $\pm 100MW$	2.38	0.35	14.71	3.14	0.07	2.23	48127

VII. CONCLUSION

According to the actual situation in China,the resolution of the wind abandonment phenomenon is urgently needed. In order to expand the space of wind power consumption,measures such as optimizing the power supply structure, developing the peak-regulating depth of conventional thermal power generation units, improving wind power accommodation capacity prediction accuracy can be implemented.This paper focuses on the need to establish inter-provincial wind power dispatching,relax the tie line plan, compare wind power consumption forecasting results with different tie line power and the total cost of the system operation.It can be seen that within a certain tie line power fluctuation range the proportion of power cuts in both provinces has been significantly reduced and system operating costs have decreased.Inter-provincial wind power can promote wind power consumption in a wider range and reduce the rate of wind curtailment.

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