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Study on synergetic schedule of hydro-wind power for minimizing impact on power grid

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Abstract: For smoothing and weakening the random and fluctuant wind power, an approach of hydropower coordinate with wind power is proposed. Firstly, based on a certain capacity of wind farm and the hypothesis of indifference of wind power capacity in this paper, the capacity of hydropower station to absorb wind power has been analyzed quantitatively and the relationship characteristic curve between hydropower and wind power absorption has been depicted; secondly, the characteristic of the curve under the condition of different quantities of wind power electricity is analyzed and proved; finally, a model which maximizes the combination of hydro-wind power is built and an adjustable hydropower plant coordinated with wind power station is simulated. According to the results, the effect of wind power absorption was fairly good and the output of combo that hydropower cooperated with wind power was stable, and this research has provided a favorable strategy for absorbing wind power for power grid.

1 Introduction

Compared with conventional power supply, such as hydropower, thermal power, the most outstanding characteristics of wind power is that the output power is random, intermittent and uncontrollable [1, 2]. In the power system with large scale wind power, the volatile and intermittent wind power seriously challenges the quality of power supply [3, 4, 5]. Stochastic volatility of wind power is one of the main reasons for these effects [6, 7, 8]. Considering the randomness of wind power and the flexible characteristics of hydropower operation, the hydropower station with excellent regulation performance is the ideal power source for smoothing wind power output.

In power system that does not contain reverse conversion facilities such as pumped storage energy, the current researches about hydropower and wind power mainly focus on two respects: On one side, some researchers established the assessment of the capacity that can compensate wind power by the generation schedule. Such as Yi L. et al. [10] sketched the method that hydropower pitched peak for the changeful wind power and assessed the hydropower peaking capacity for wind power from the standpoint of the power grid. In addition, Chang J. et al. [11] detailed and figured up the required compensation power that hydropower match up with the wind power in the context of considering the relationship between different sizes of hydropower quantity and the installed capacity of wind power, the essence of that hydropower compensate for wind power elaborated by the above two literatures, was the evaluation process of confirming how much the wind power could be compensated by the hydropower. They mainly analyzed and evaluated the capability of accommodating wind power of hy-



dropower, but ignored the influence on the wind power from hydropower dispatching in the long period. On the other side, the study optimized the objectives by changing the operation mode of hydropower to compensate the wind power in a mid-and-long term. Such as considering the flood season and the non-flood season, Huang C. [12] established an optimization model considering in comprehensive of hydropower station generation and wind power, to maximize the amount of clean energy consumption so as to confirm the mode of operation of conventional hydropower that cooperates with large-scale wind power, but this study can only apply to the situation of that hydro-wind power have almost the same installed capacity.

In view of this, this paper takes into account that the hydropower operation strategy influence on wind power consumptive amount and every unit of wind power capacity having no difference in generation is assumed, quantitatively analyzes and evaluates the ability of hydropower smoothing wind power. Combining with the provisions of China Renewable Energy Law that the power grid enterprises should acquire full of renewable energy generation projects within the grid electricity [13], this paper builds a long-term scheduling plan of wind power and hydropower that named electric energy maximization model, so as to exert the capacity that hydropower smooths the wind power in maximization.

This rest of the paper is organized as follows. Section 2 briefly introduces the principle of hydropower smoothing wind power. Section 3 analyzes the capacity of hydropower smoothing wind power. Section 4 provides the combination model of hydropower and wind power and its solution method. Section 5 gives the numerical example. Section 6 outlines the conclusions. Finally, acknowledgements are given in Section 7.

2 Principle of Hydropower Smoothing Wind Power

By taking advantage of the controllable characteristic of hydropower with reservoir, the hydropower output is decreased when wind power output is increasing. On the contrary, the hydropower output is increased when the wind power output is decreasing. As a result that the combined output of wind power and hydropower can be kept in a certain range [10, 11], the original wind power of randomness combined with hydropower output then will be a relatively stable output. Hydropower coordinated with wind power should follow two principles, namely the principle of electric reliability and avoiding spilling. Electric reliability refers to that the principle of hydro-wind power combined operation should provide a stable and reliable electricity to the grid, and avoiding spilling refers to the principle of that hydropower station should not spill for smoothing wind power.

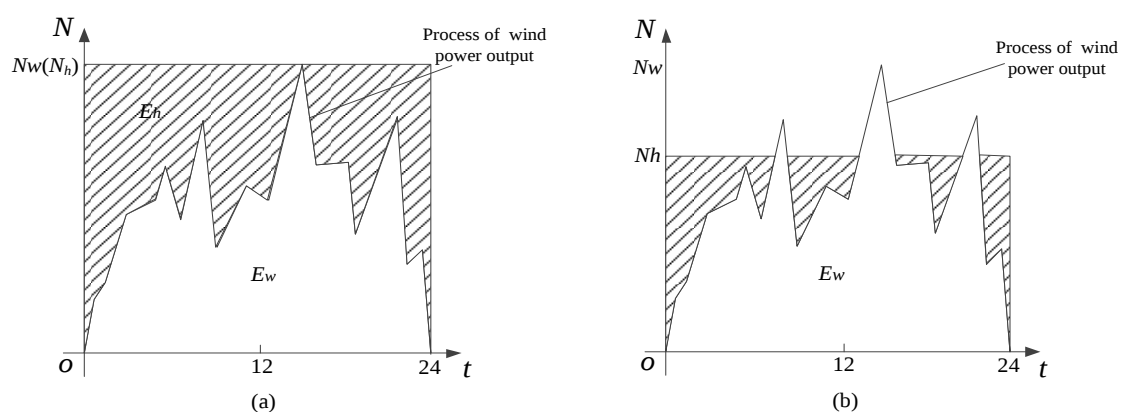


Fig. 1. The principle of combined operation of hydro-wind power (a. complete wind power smoothed; b. partial wind power smoothed)

It can be seen (a) in fig.1 that the capacity of hydropower should equal to the capacity of wind power for completely smoothing the wind power. At the same time, the demand to provide compensation power is equal to $(24N_w - E_w)$. That is, the conditions of complete compensation are as follows,

The compensation capacity condition,

$$N_h = N_w \quad (1)$$

The compensation power condition,

$$E_h = 24N_w - E_w \quad (2)$$

Where N_h and N_w are the capacity of hydropower and wind power, respectively. E_h and E_w are the quantity of electricity of hydropower and wind power, respectively.

During the actual operation, the compensation capacity and compensation power cannot always satisfy compensation conditions completely. As shown (b) in fig.1, when the compensation capacity provided by hydropower is less than N_w , the amounts of wind power compensated by hydropower depends on the wind power that generated by the capacity of wind power N_h , and it closely relates to the process of wind power output.

The process of wind power output always shows huge differences in different days, thus this paper chooses the typical process of wind power output as shown in fig.2 and regards compensated capacity as independent variable and exerts the principle of hydropower smoothing wind power to calculate the corresponding compensation of hydropower. The relationship between wind power capacity and compensation of hydropower is shown in fig.3, which is used for quantitative analysis of the capacity of hydropower smoothing wind power. The relationship is hardly expressed by a simple analytic expression, thus this paper makes the following assumptions for simplicity in this study, which called *Wind Power Capacity Indifference Assumption* that the power provided by each unit of installed capacity of wind farms is equal and the generated by unit capacity of wind power is equal to $E_w^u = E_w/N_w$, while wind power capacity is equal to N_w and the wind farm capacity generating power is equal to E_w in scheduling period. Under the assumption, the relationship between wind power capacity and compensation of hydropower reflects the straight line in the fig.3. In essence, the process of wind power output in the hypothesis is similar with the related literature [11].

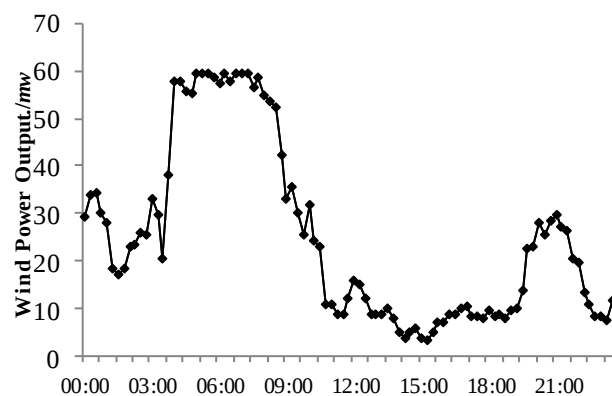


Fig. 2. Typical process of wind power output

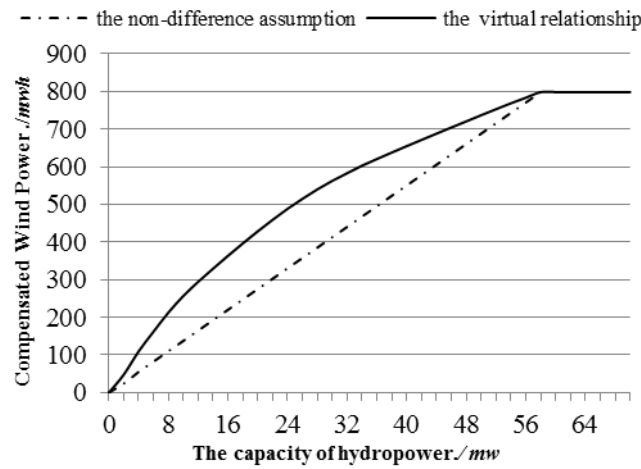


Fig. 3. The relationship between compensated wind power and hydropower

3 Evaluation Method

According to the conditions of hydropower completely compensated wind power, it needs that the compensation generation is $E_h^u = 24 - E_w^u$ and a unit of capacity of hydro power, while the generation by per unit of capacity of wind power is E_w^u .

The way that coordinating with wind power by hydropower is analyzed as follows,

- If $N_h = N_w$, there is the relationship :

$$\begin{cases} N_{\text{absorb}} = \frac{E_h}{E_h^u} = \frac{E_h}{24 - E_w^u} & \text{if } E_h \leq 24N_w - E_w \\ (24 - E_w^u) \cdot N_{\text{absorb}} + 24(N_h - N_{\text{absorb}}) = E_h, & \text{if } E_h > 24N_w - E_w \end{cases} \quad (3)$$

As $E_h/E_h^u < N_h$, the capacity of wind power compensated by hydropower can be only equal to E_h/E_h^u , in addition that the quantity of wind power compensated by hydropower is linear growth as hydropower is increased, until the quantity of wind power compensated comes to the maximum, as shown the line OA in fig.4.

As $E_h/E_h^u > N_h$, it means that there is surplus hydropower after compensating the wind power. The surplus hydropower should be occupied by partial capacity of hydropower. Based the principle of avoiding spilling, while the adjustable hydropower power continues to increase, the compensated wind power will decrease because of lacking surplus capacity of hydropower. Until the hydropower generates the maximum of capacity, the compensated wind power is decreased to zero, as shown the line AD in fig.4.

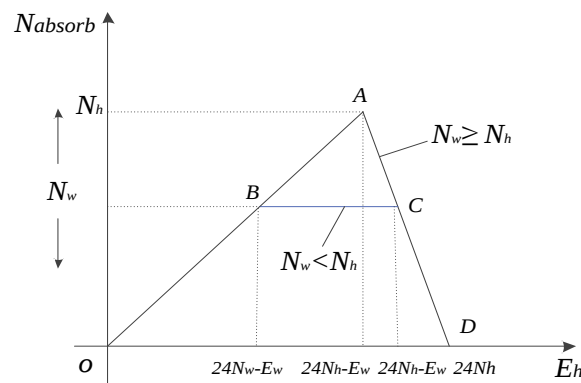


Fig. 4. The relationship between compensated wind power and hydropower in different situations

● If $N_h > N_w$, the relationship characterized by curve $OBCD$

As $E_h / E_h^u < N_w$, the capacity of wind power compensated by hydropower is E_h / E_h^u , in addition that the quantity of wind power compensated by hydropower is linear growth as hydropower E_h is increased, until the compensated capacity of wind power comes to the maximum, as shown the line OB in fig.4.

As $N_w < E_h / E_h^u$ and $E_h / E_h^u < (24N_h - E_w) / E_h^u$, it means that the hydropower can compensate all the wind power. With the increase of hydropower, the surplus hydropower was undertaken by the remaining capacity. During the process, the compensated wind power always remains the same, as shown the line BC in fig.4.

As $E_h / E_h^u > (24N_h - E_w) / E_h^u$, with the increase of hydropower, if hydropower still remains to compensate wind power completely, the remaining capacity of hydropower would not bear the rest of hydropower after calming wind power, it means to spill because of compensating wind power. Therefore, in order to meet the rule of avoiding spillage, while the adjustable hydropower power continually increasing to the maximum of capacity, the compensated wind power is decreased to zero, as shown the line CD in fig.4.

● If $N_h < N_w$, the relationship characterized by curve OAD

Limited by the capacity of hydropower, the maximum compensated wind power is N_h . Similar to above analysis, the compensated wind power increases linearly until arrives the limitation as hydropower increasing. While the adjustable hydropower surpasses the required hydropower that completely compensates the wind power, the amount of compensated wind power will decrease. Until the hydropower generates the maximum of capacity, the compensated wind power is decreased to zero.

4 Modeling and Solution

4.1 The combination model

For arousing the enthusiasm of wind power enterprise, and reducing the influences from thermal power to the environment at the same time, we should make full use of the capacity of regulation of hydropower to cooperate with power grid to absorb wind power. In the whole process of daily scheduling of hydropower stations, electric energy maximization model is built to maximize the sum of hydropower and compensated wind power over the whole dispatching period, then the objective function and associated constraints of the problem are formulated as follows,

Objective function:

$$F = \max \left[\sum_{t=1}^n N_{ha}(t) \cdot \Delta t + E_{wa}(t) \right] \quad (4)$$

Where $N_{ha}(t)$ is hydropower generate at time interval t , $E_{wa}(t)$ is absorption wind power at time interval t .

The limitation factors such as the output, flow and water level should be considered in the process of calculation while exploring the optimal reservoir operation schedule, all aspects of the constraints are as follows,

Hydro plant power generation limits

$$N_{min} \leq N_{ha}(t) \leq N_{max} \quad (5)$$

Where N_{min} and N_{max} are the minimum and maximum power generation of hydro plant, respectively.

Hydro plant discharge limits

$$Q_{min} \leq Q(t) \leq Q_{max} \quad (6)$$

Where $Q(t)$ is water discharge of hydro plant at time interval t , Q_{min} and Q_{max} are the minimum and maximum water discharge of hydro plant, respectively.

Reservoir storage level limits

$$Z_{min} \leq Z(t) \leq Z_{max} \quad (7)$$

Where $Z(t)$ is water level of reservoir at the end of time interval t , Z_{min} and Z_{max} are the minimum and maximum water level of reservoir, respectively.

4.2 Solution method for model

This paper considers the water level as state variables and discharge as decision variables. The specific calculation process is as follows,

Step1: Discretization of the state variables

The state variable situations can be obtained by discretization of the state variables in each phase, the amount of state variable situations marked M , and where the water level constraints can be disposed.

Step2: Decision values in first phase

Calculating the decision values through using the initial water level and the final water level in first phase, then output power can be calculated based the decision values, so does the electric quantity. The absorption wind power can be calculated in accordance with the method proposed above. Sum of absorption wind power and hydroelectric quantity is denoted as E_{sum} . It needs to consider the power and flow constraints during this course.

Step3: Decision values from the second phase to the penultimate stage

To compute the decision results by using each initial state variable situations that meet the constraints and final state variable situations in every phase from the second phase to the end of the penultimate stage. The hydroelectric quantity and absorption wind power and E_{sum} are calculated in a similar way with before during these phases, then the E_{sum} is acquired to substitute for the E_{sum} in the previous phase.

Step4: Decision values in last phase

At the final stage, discharged flows in the phase are calculated by using the initial state variables that meet the constraints and the final water level of reservoir, so do the corresponding hydropower outputs and absorption wind powers. E_{sum} is the sum of hydroelectric quantity and absorption wind power quantity, and the E_{sum} is acquired to substitute for the E_{sum} in the previous phase, too. To compare all E_{sum} that meet the constraints and the maximum is the optimal scheme that we desire.

5 Numerical Example

For verifying the effectiveness of the combinative operation method and the superiority of the combination model, a hydropower station and a wind farm are regarded as a system. The basic situation is as follows,

- A wind farm installed 99mw, wind power generation as shown in table 1.
- A hydropower station installed capacity of 300mw; the firm capacity is 37.1mw. The normal water level of the reservoir is 236 meters, a total capacity of the reservoir is 1.741 billion m³, and 0.74 billion m³ of flood storage.

Table 1: Wind power generation in a wind farm per month /.10⁴kwh

Month	1	2	3	4	5	6	7	8	9	10	11	12
Wind power	2036.5	2125.3	2621.9	1817.6	1678.4	841.7	1241.3	612.5	1191.2	1084.4	2056.5	1447

According to the above methods, the maximum adjustable output of the hydropower station is 262.9mw, while the wind power installed capacity is 99mw, that namely $N_h > N_{w, \text{Max}}$. With the increase of hydropower, wind power compensated is gradually increased to maximum until the remaining capacity of hydropower cannot bear the rest hydropower after calming wind power. In order to prevent spilling caused by the absorption of wind power, wind power compensated will gradually decrease. The quantity of wind power compensated and hydropower are calculated according to the electric power of wind per month and adjustable power plant related data, the relationship is shown in fig.5.

As we known, the wind power which had strong volatility will tremendous impact on the power system frequency and load etc. if it is directly poured into the power grid. Considering the complementarity in technology and seasons from the two kinds of energy sources of hydro-wind power (hereafter termed *H-W*), the adjustable hydropower station operation with the wind farm's output is a more ideal means. The evaluation methods above are used to assess the ability of compensating wind power of hydropower by the two models of maximization generation of hydropower model and electric energy maximization model, as table 2 shows the results.

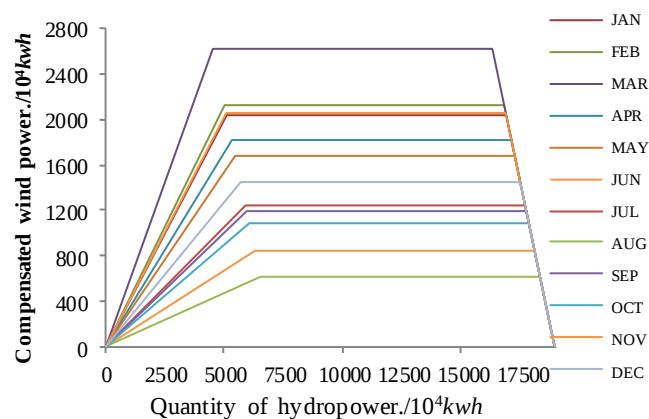


Fig. 5: Relationship between quantity of hydropower twelvemonth and compensated wind power

Table 2: Hydropower and compensated wind power by two models

Mouth	maximization generation of hydropower model			electric energy maximization model		
	Hydropower	Absorption wind power	output of H-W	Hydropower	Absorption wind power	output of H-W
1	2690.40	7.68	37.47	2690.40	7.68	37.47
2	2825.55	65.57	40.15	2825.55	65.57	40.15
3	3055.39	223.55	45.54	3055.39	223.55	45.54
4	15064.03	1817.60	234.47	6814.31	1418.07	114.34
5	3191.64	160.29	46.55	9408.04	1678.4	153.98
6	3223.79	73.99	45.80	3101.25	57.58	43.87
7	3271.47	126.58	47.20	3277.14	127.77	47.29
8	3130.74	43.20	44.08	3179.35	47.77	44.82
9	3191.53	104.40	45.78	3271.32	120.41	47.11
10	3125.93	81.59	44.55	3193.73	93.76	45.66
11	3060.97	158.05	44.71	6640.02	1609.36	114.57
12	21553.59	46.41	300.00	17943	1447	269.31
Total	67385.04	2908.91	976.30	65399.5	6896.92	1004.12
Absorption ratio	-	15.5%	-	-	36.8%	-

It can be seen from table 2 that the output of H-W is steady, and it reflects H-W method can weaken the impact to power system from the wind power's stochastic fluctuation. The amount of generation from the wind farm is 1.87543 billion KWH in the certain year, while the amount of smoothed wind power are 0.29089 billion in the first model and 0.29089 billion in the second model, respectively. The absorption ratios of wind power in each models are correspondingly 15.5% and 36.8%. Compared with the first model, the absorption ratio in the second model has been improved significantly. In particular, the absorption of wind power will be tremendously improved by using the second model while the wind power system is in a huge scale.

Wind power is limited feeding into power grid because of its strong volatility. By using the proposal model and compensated methods as previously mentioned, the absorption ratio of wind power is increased significantly. This result reduces the remaining peak pressure for wind power by the thermal power, and correspondingly reduces the economic costs and environmental costs. Given this, the effect of wind power absorption is good by combining with reservoir optimal operation, and the output of the joint is monthly stable. These provide a reliable and stable output for the power grid and promote the utilization rate of wind energy greatly.

6 Conclusion

At this stage, the problems from scarcity of energy are increasingly prominent, so it is necessary that we vigorously develop and effectively utilize the clean energy. It has great influences on the frequency and quality of power grid because of the intermittence of wind power. For weakening the influences from wind power, it is an effectual way that using hydropower and other controllable power to calm wind power fluctuations. In the aspect of the research on joint scheduling of hydro-wind power, the author has finished the following work in this study,

a. Based the perspective of power capacity, this article quantitatively evaluated the capacity that the hydropower compensated the wind power, analyzed the relationship between the hydropower capacity and the absorbing wind power, and relationship curve was given, argued the regulation of the

relationship curve at the same time. These might be an effective means for absorbing the wind power in power grid.

b. Electric energy maximization model was established, this article evaluated the ability of compensating wind power of the hydropower generation maximum model, analyzed and compared the absorption ability of the two models, respectively. It was concluded that electric energy maximization could more improve the utilization rate of wind energy than the hydropower generation maximum model. The research findings provided important theoretical support for utilization of the production of hydropower and wind in power grid.

Study on joint scheduling of hydro-wind power can promote the degree of utilization of wind power in the power system. The output of joint of hydro-wind power is stable, and the process of the hydropower output associates closely with the process of wind power output. In addition, improving the prediction accuracy of the wind power in long-term can effectively promote the practical performance of corresponding hydropower schedule.

Acknowledgments

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