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Effect of Collaborative Utilization of Energy Storage and Wind Power on Wind Power Grid-connected and Carbon Emission

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In order to research the effect of collaborative utilization of energy storage and wind power on wind power grid-connected and carbon emission, this paper discussed the correlation between wind power output and load and effect of wind power connected into power grid on peak load regulation ability of power grid. For the coordination of operation of wind power and energy storage systems, select the collaborative utilization of centralized pumped storage and wind power, investigate the effect of pumped storage participation in peak load regulation and its capacity allocation on grid accommodation of wind power by wind power utilization and quantity proportion, and analyze the cause for low utilization of pumped storage power station as the pumping capacity increases. The research finds that grid accommodation of wind power varies with seasons and under the condition of large wind power installed capacity and exceeding grid accommodation of wind power with conventional power source participating in peak load regulation, the function of pumped storage can show up and collaborative utilization of pumped storage and wind power is an effective means to realize the large-scale wind power grid-connected. Therefore, wind power utilization and quantity proportion and carbon emission reduction benefit, improved by increasing pumped storage per unit capacity, decline as pumping capacity increases, so the pumped storage utilization is lower, and other peak load regulation measures shall be taken, such as time-of-use power price and charging of electric vehicles, to cover the shortage of single peak load regulation.

1. Introduction

Global warming is an enormous challenge of human society and CO2 emission reduction is a key measure for greenhouse effect (Wang et al., 2015; Kwon et al., 2015). To tackle global warming, western developed countries mainly the United Nations and European Union have worked positively. The Government of China announced the target of greenhouse gas emission control in November 2009, that is, CO2 emission per unit GDP in 2020 should decline by 40%-45% compared to 2005. (Kwak et al., 2015; Tavassoli et al., 2016), and included into medium and long-term planning of national economy and social development as obligatory target. Most power grids in China adopt thermal power generation now, over 80% thermal power generating units, and its minimum peak load regulation is 50%-60% (Khaled et al., 2016; Acar et al., 2016); power grid certainly curtails wind power curtailment because fluctuation degree of wind power output exceeds peak load regulation ability of power grid after wind power installed capacity reaches a certain scale (Gandrud et al., 2016; Sha, et al., 2016). To improve the wind power utilization of power grid and reduce the output of thermal power generating unit, collaborative utilization of energy storage and energy storage is an effective way. Pumped storage has the characteristics of wide regulation range, quick and large installed capacity and can effectively shift load (Yang and Zhang, 2016; Farmann and Sauer, 2016). Research on collaborative utilization of pumped storage and wind power has a great significance for changing the structure of power sources (Miller, 2016; Wong et al., 2016), adding the capacity of peaking unit, enhancing wind power connection capability and correcting present serious wind power curtailment of power grid (Balducci, 2016; Deyab, 2016).

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2. Effect of on collaborative utilization of wind power and pumped storage on grid accommodation of wind power

2.1 Grid accommodation of wind power on typical days in different seasons

Wind power utilization and quantity proportion are two indexes that reflect the grid accommodation of wind power (Lubke et al., 2016; Mi et al., 2016; Serincan, 2016). Wind power utilization is the ratio of wind power grid-connection power to wind power output in investigation cycle and wind power quantity proportion is the ratio of wind power generation to gross generation in investigation cycle (Wang et al., 2016; Makino et al., 2016; Campanar et al., 2016). This paper analyzed the grid accommodation of wind power on typical days in different seasons taking the example of typical days of four seasons of a provincial power grid at certain yearly load under the condition of wind power installed capacity of 15GW and regulating coefficient of thermal power generating unit of 0.5. Table 1 shows the wind power utilization and quantity proportion on typical days in spring, summer, autumn and winter calculated through model.

According to Table 1, Figure 1 and 2, we can see that load level and peak-valley ratio in spring are the lowest, power grid has smaller peak-valley difference and stronger peak load regulation ability. In spring, average wind power capacity factor is 0.7210, there is maximum wind power output, and correlation coefficient of wind power capacity factor and load is positive, presenting certain positive correlation, so the wind power utilization of power grid is high under the condition of higher wind power output and it reaches 99.27% when 1 million Kw pumped storage participates in peak load regulation. On premise of high wind power output and utilization, the wind power quantity proportion is high certainly and reaches 29.52% when 1 million Kw pumped storage participates in peak load regulation.

Table 1: Grid accommodation of wind power on typical days in different seasons

Chemical industry	Spring	Summer	Autumn	Winter
Maximum load(MW)	41176.8	47717.1	44827.5	47910.6
Load peak and valley difference (%)	28.85	33.09	32.98	34.01
Wind power capacity factor average	0.7210	0.1361	0.2298	0.2611
Correlation coefficient	0.2813	-0.0636	-0.5086	-0.7619

Load level and peak-valley ratio in summer are larger, so power grid has larger peak-valley difference and weaker peak load regulation ability, but because of little wind power output, average wind power capacity factor is 0.1361, so power grid can consume 98.73% of wind power without pumped storage participating in peak load regulation. But wind power quantity proportion is proportional to the product of wind power utilization and output, so, wind power quantity still accounts for a small proportion of grid power, about 6% in summer with high wind power utilization and very little output.

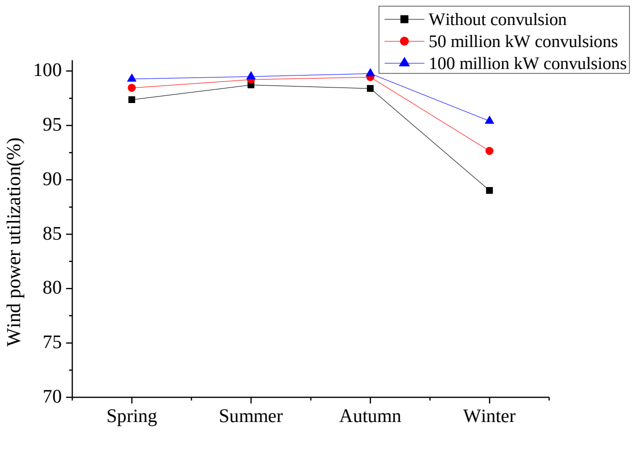

Figure 1: Wind power utilization in different seasons

In autumn, correlation coefficient of wind power capacity factor and load is -0.5086, presenting larger negative correlation, wind power has the feature of inverse peak load regulation, and wind power output is more than that in summer, so the wind power utilization of power grid without pumped storage participating in peak load regulation is smaller than that in summer. But with pumped storage participation in peak load regulation, wind power utilization is higher than that in summer, showing the advantage of collaborative utilization of wind power and pumped storage in power grid with weak peak load regulation ability.

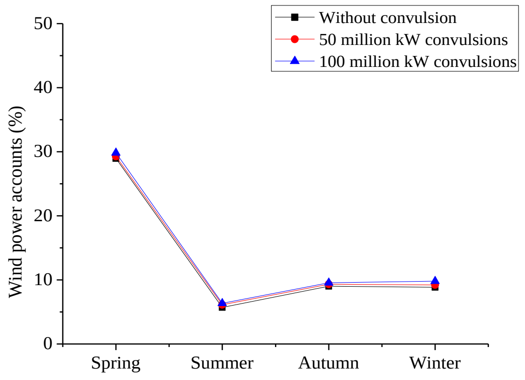

Figure 2: The proportion of wind power in different seasons

Winter has the highest yearly load level and largest peak-valley ratio, power grid has the largest peak-valley difference and poor peak load regulation ability, and correlation coefficient of wind power capacity factor and load is -0.7619, presenting strong negative correlation, and wind power output in winter has very obvious inverse peak load regulation, putting further pressure on peak load regulation of power grid. The proportion of wind power curtailment of power grid is high and 10.99% under the condition of less wind power output (average wind power capacity factor of 0.2611). Pumped storage participation in peak load regulation appears to be particularly important in winter. Wind power utilization is increased by 3.63 percentage points and 6.39 percentage points respectively when 500,000 kW and 1 million kW pumped storage participate in peak load regulation, and wind power quantity proportion reaches up to 9.50% when 1 million kW pumped storage participate in peak load regulation.

2.2 Grid accommodation of wind power under different wind power installed capacity

Taking no account of wind resource costs, some thermal power generating units must be replaced and quit running with increasing wind power installed capacity. Figure 3 and 4 show the change trend of wind power utilization and quantity proportion with changing wind power installed capacity under different pumping capacity.

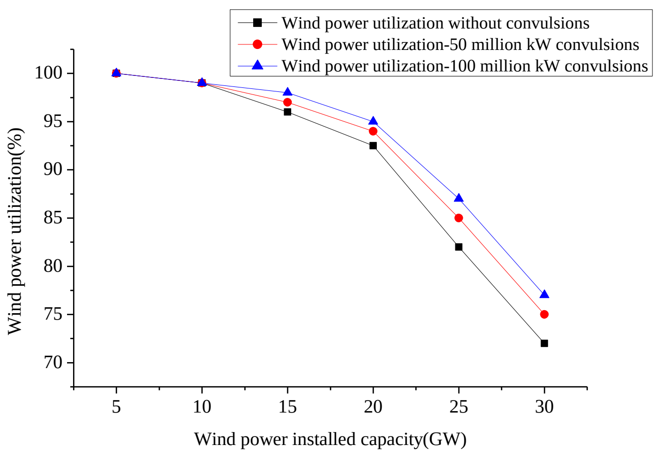

Figure 3: Wind power utilization under different pumping capacity

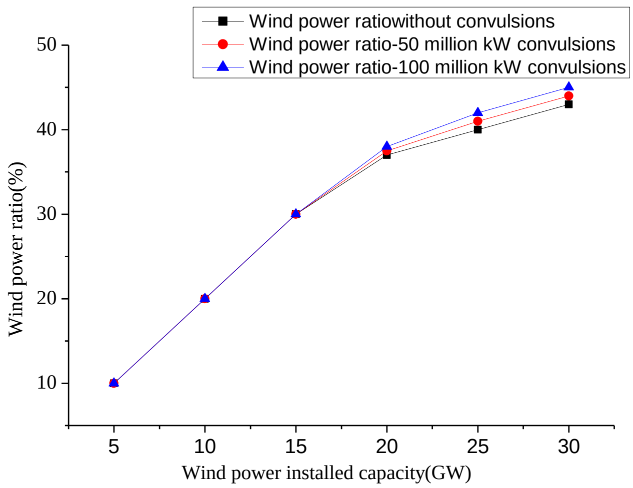

Figure 4: Wind power ratio under different pumping capacity

According to above figures, we can see that wind power utilization declines as wind power installed capacity ascends at the same pumping capacity. When wind power installed capacity is 30GW, wind power utilization is about 70%, and power grid possibly curtails most wind power. But wind power quantity proportion is always increasing, and because wind power capacity factor in spring is larger and presents certain positive correlation, benefiting wind power connection, the wind power quantity proportion reaches over 40% at the time of wind power installed capacity of 30GW.
When wind power installed capacity is less than 10GW, power gird does not curtail wind power, the wind power utilization is 100% and whether pumped storage participates in peak load regulation and its capacity change have no effect on wind power grid-connected; only when wind power installed capacity is more than 10GW and power gird curtails wind power, pumped storage can pump water to consume surplus wind power, and collaborative utilization of wind power and pumped storage is an effective means for large-scale wind power grid-connected.

3. Effect of collaborative utilization of wind power and pumped storage on carbon emission of power grid

3.1 CO2 emission per unit thermal power generation

CO2 emission per unit on-grid energy through thermal power generation is calculated according to annual thermal power generation capacity of power grid, power consumption rate of the plant, fuel consumption and type (Mi, et al., 2016), as shown in Formula (1):

$$EF_{OM,\mathrm{simple},y} = \frac{\sum_i F_{i,y} COEF_i}{GEN_y} \tag{1}$$

Where, $F_{i,y}$ is the consumption of fuel i of thermal power generation of power grid in y year(s) (by mass or volume unit); $COEF_i$ is mass of CO_2 emitted by generating unit consuming fuel i per unit mass; GEN_y is on-grid energy of generating unit in y year(s).

3.2 Carbon emission reduction benefit with pumped storage participating in peak load regulation under different pumping capacity

Figure (2) shows calculation method for CO2 emission per unit electric quantity of power grid:

$$EF = \sum_{i=1}^{n} R_i \cdot EF_i \tag{2}$$

Where, i is power source type of power grid; n is number of power source types; Ri is the proportion of the i power source in gross generation; EFi is CO_2 emission coefficient of the i power source per unit electric quantity. Under the condition of load data of certain year of a provincial power grid and wind power installed capacity of 15GW, CO_2 emissions per unit electric quantity under different pumping capacity in four seasons are obtained by weighted average of electric quantity. The results are shown in Table 2.

Table 2: CO_2 emissions per unit electric quantity of a provincial power grid

Pumped storage capacity (myriad kw)	Unit of electric quantity CO_2 emission load (kg/kWh)				
	Spring	Summer	Autumn	Winter	Weighted average
0	0.6472	0.8554	0.8269	0.8302	0.7939
50	0.6442	0.8551	0.8260	0.8269	0.7920
100	0.6420	0.8550	0.8257	0.8244	0.7908
150	0.6405	0.8549	0.8255	0.8224	0.7898
200	0.6401	0.8548	0.8255	0.8210	0.7894
250	0.6400	0.8548	0.8255	0.8203	0.7892
300	0.6400	0.8548	0.8255	0.8202	0.7891

According to the table, we can see that CO_2 emission per unit electric quantity gradually declines as pumping capacity ascends; compared to that without pumped storage participating in peak load regulation, yearly CO_2 emission reduction is increased and reaches 1,614,400 tons when pumping capacity is 3 million kW; compared with that with pumped storage participating in peak load regulation, yearly CO_2 emission reduction declines as pumping capacity ascends for a unit pumping capacity and the pumped storage utilization is reduced.

4. Conclusion

Pumped storage unit mainly generates power in heavy load period and pumps water in the period of light load and larger wind power output. Pumped storage unit carries out the peak load regulation through water pumping and power generation in different periods, helping the power grid to reduce wind power curtailment and increasing wind power grid-connected capacity. Meanwhile, wind power accommodation capacity varies with seasons and wind power utilization is high in seasons with high load, small load peak-valley ratio, small wind power capacity factor and large correlation coefficient of wind power capacity factor and load. Pumped storage can better play its advantages in seasons with large load peak-valley ratio, small correlation coefficient of wind power capacity factor and load and high pressure of peak load regulation of power grid when participating in peak load regulation, and can better show the effectiveness of collaborative utilization of wind power and pumped storage. Where power gird does not curtail wind power, pumped storage participation in peak load regulation and its capacity change has no effect on wind power grid-connected. Only when wind power installed capacity reaches certain level and power gird curtails wind power, pumped storage can pump water to consume surplus wind power, and collaborative utilization of wind power and pumped storage shows its advantage in large-scale wind power grid-connected. Hence, with increasing pumping capacity and wind power utilization and quantity proportion, CO_2 emission per unit electric quantity declines and yearly carbon emission reduction ascends.

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