A new strategy of using unstable offshore wind power by combination with pumped storage generation with reversible pump turbine

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ABSTRACT

In recent years, low-carbon society and natural energy power generation have become popular. Although wind power is one of them, because of the irregular fluctuations in power generation, the impact on power system frequency and voltage comes out to be the problem while connected to the power grid. Wind power voltage and frequency are generally adjusted by power conditioners. But it has the shortage on the lifetime and the limit of the capacity. Here, the pumped storage system is used to balance the wind power's outputs.

In this study, we assume the combination of wind power generation and sea water pumping as a power conditioning system. By taking into consideration of the reservoir's capacity and the total output of the wind turbine, here we caculated the amount of CO_2 reduction and stabilization of the total output.

Keywords: wind power generation, pumped storage system, reversible pump turbine, running strategy.

1 THE OUTLINE OF WIND POWER - PUMPED GENERATION SYSTEM

Such as transportion systems, power supply and industry, the current energy systems are built on fossil fuels. These fossil fuels to cover 90% of the current energy demand, however the high-quality reserves of fossil fuels such as oil and natural gas are not abundant.

As the mass consumption of fossil fuels has caused environmental problems such as acid rain and global warming, in order to develop energy resources and reduce the emission of CO_2, it is required the use of renewable energy such as solar power and wind power.

Wind power has been adjusted by using the battery voltage and frequency variations on power system, but to medium and large-scale wind power it is particularly unsuitable because of the limit of the capacity.

In this study, instead of battery, pumped storage system with the reversible pump turbine is used to adjust the output of the wind power [1].

Figure 1 shows the schematic diagram of a power generation system considered in this study. Power generation system is assumed to be constructed by mountain that several hundred meters from the coast.

This design is the use of pumped storage power station with reversible pump turbine to adjust the output of large-scale wind power generation and using wind power instead of thermal power to to reduce carbon dioxide emissions [2].

During the wind power's non-peak output time in the daily load curve, the system pumps water up. When the wind speed is low, wind power can not meet the requirements of the system, then perform the replenishment by using the power of pumped storage power station. By the way above to make the total output more stable.

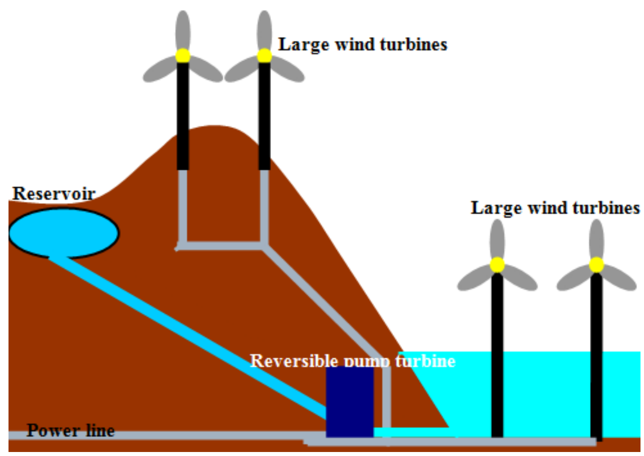

Figure 1: Schematic diagram of the system.

2 CHARACTERISTICS AND CHALLENGES OF THE PUMP TURBINE AND OFFSHORE WIND IN THIS SYSTEM

In China, most of the water wheels used in pumped storage power plant are reversible pump-turbine, so we use the pump turbine in the power generation system here. For wind power, including offshore wind, we assume that 1000 MW class large-capacity ones are used.

The installation of large-scale offshore wind is still out of the way, Europe and the United States have some applications, however. At present in China, that has not yet been realized [3].

For pump turbine, both Francis turbine and Deriaz pump turbine can be used as a pump while reversed. Rather than using both pump and turbine, the using of reversible pump turbine can lower the cost of construction.

However the reversible pump turbine needs careful electrical and mechanical design, because it is heavier and has different working characteristics.

The power flow of the pumped storage generation system is shown in Fig. 2.

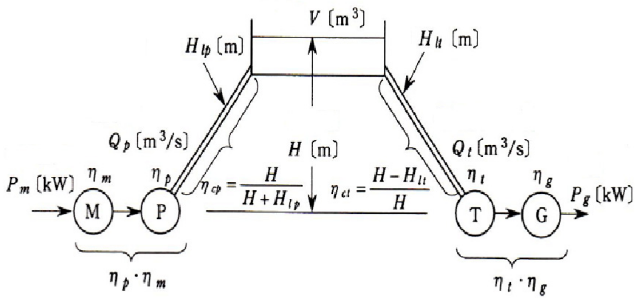

Figure 2: Power flow of the pumped storage generation system [4].

The efficiency can be presented by:

$$\eta=\frac{W_g}{W_m}=\frac{9.8Q_t(H\text{-}H_{lt})\eta_t\eta_g T_t}{\frac{9.8Q_p}{\eta_p\eta_m}(H+H_{lp})\,T_p}=\eta_t\eta_g\eta_p\eta_m\frac{(H\text{-}H_{lt})}{(H+H_{lp})}\bullet\frac{Q_tT_t}{Q_pT_p} \tag{1}$$

where η_g: Pumping efficiency; η_m : Pumping motor's efficiency; η_t : Generator's efficiency; $\eta_g\eta_t$: Waterwheel's efficiency ; Q_p: Speed of the water flow though the pump [m3 / s]; Q_t: Speed of the water flow though the turbine [m3 / s]; T_p: The pumping time [h]; T_t: generation time [h]; H_{lp}: Water loss during the pumping time; H_{lt}: Water loss during the generation time; W_g: The power required for pumping; W_m: The power generated.

If the water pumped is equal to the water used for generation ($Q_tT_t = Q_pT_p$), eq. (1) can be written as:

$$\eta=\eta_t\eta_g\eta_p\eta_m\frac{(H\text{-}H_{lt})}{(H+H_{lp})} \tag{2}$$

$$\text{With } \frac{H\text{-}H_{lt}}{H}=\eta_{ct} \text{ and } \frac{H}{H+H_{lp}}=\eta_{cp} \tag{3}$$

Equation (2) can be presented as:

$$\eta = \eta_t\eta_p\times\eta_g\eta_m\times\eta_{ct}\eta_{cp} \tag{4}$$

3 SELECTION OF THIS SYSTEM

3.1 About the location

We chose the simulation place at Qingdao City, Shandong Province. The reasons are:

(1) It belongs to the network around Beijing, the demand for power and safety is high.

(2) The wind condition is good.

(3) It has a mountain named Laoshan, and it is near to the Yellow sea that will be convient to build a pumped storage plant.

3.2 About the wind power output

Figure 3 shows the relationships between a wind turbine's output and the wind velocity. The placement of the wind turbine in the wind farm is assumed in Fig.4.

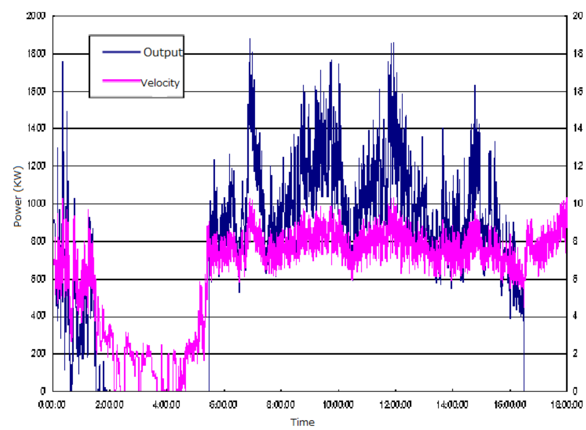

Figure 3: Wind power output and the wind velocity on 0:00 to 18:00, September 20th, 2011 [5].

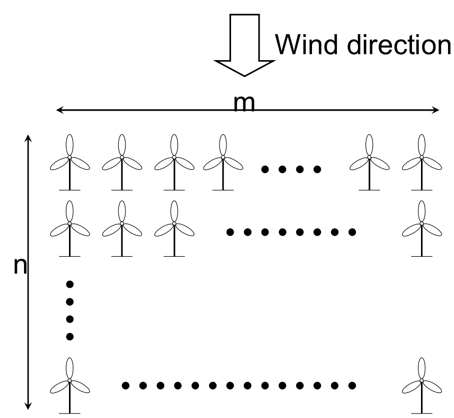

Figure 4: The wind turbine's placement in the windfarm.

The total power capacity is 3250MW in Qingdao. We choose the 2MW wind turbines Subaru80/2.0. The number of the wind turbines are designed at 500 units, 25 units in the vertical direction, and 20 are lined up in the parallel direction to the wind flow. Interval of every single wind turbine is 500 m. Total capacity of wind turbines is 1000MW. The propagation speed of the wind is assumed 10 m/s. Then we can calculate the output of wind power 24 hours a day by using the wind speed data in Qingdao.

4 THE OPERATION OF THIS SYSTEM

4.1 The operating time of the system by the daily load curve

By the daily load curve, it can be seen that the peak hours are from 8:00 until 21:00. Time zone that is not a peak is found to be from 22:00 to 7:00. Then we can see that the generation time is 14 hours from 8:00 to 21:00, and the pumping time is 10 hours from 22:00 to 7:00.

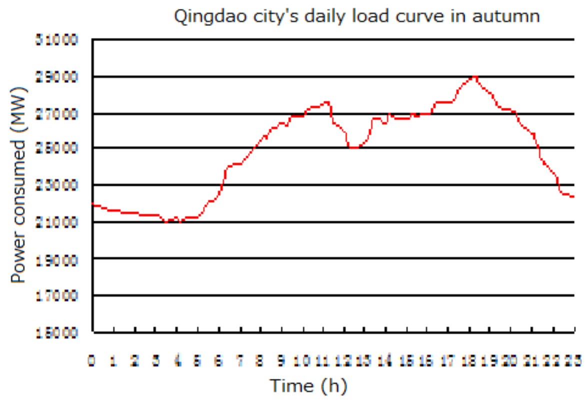

Figure 5: The daily load curve in Qingdao city, autumn 2007.

4.2 Selection of the water pump

It is suitable to choose a Francis type pump turbine flow spiral Toshiba single vertical shaft in accordance according to the conditions above. Specifications of the pump turbine are as shown in Table 1 [6].

Classification	Item	Specification
Waterwheel specifications	Effective head	Highest 214.5m Standard 177.0m Least 149.4m
	Waterwheel output	Rated 230MW Maximum260MW
	Maximum flow	150 m^3/s
	Rated speed	250min^{-1}
	Waterwheel Specific speed	140.6 m-kW-min-1
Pump specifications	Total head	Highest 218.9m Lowest 159.1m
	Maximum shaft input	240.4MW
	Maximum pumping volume	141.0 m^3/s
	Rated speed	250 min^{-1}
	Specific pump speed	56.0 m-m^3/s-min-1
Main specifications of the generator motor	Type	three-phase reversible Generator motor with air cooler
	Rated capacity (motor / generator)	250MVA/255MW
	Rated voltage	16.5kV
	Frequency	50Hz
	Power factor	0.9/0.95
	Rotation speed	250 min^{-1}
	Number of poles	24

Table 1: Specifications of the waterwheel.

Pumping power required of the motor according to the formula:

$$p_m = \frac{9.8Q_p(H+H_{lp})}{\eta_p\eta_m} = \frac{9.8Q_pH'}{\eta'}[kW] \qquad (5)$$

The pumping power is:

$$W_m = \frac{9.8V(H+H_{lp})}{3600\eta_p\eta_m} = \frac{9.8VH'}{\eta'}[kWh] \qquad (6)$$

The amount of pumping power is due to the formula:

$$W_m = \frac{9.8Q_p(H+H_{lp})}{\eta_p\eta_m}T_P[kWh] \qquad (7)$$

The time T_p is calcuated from the upper reservoir:

$$T_p = \frac{W_m}{p_m} \qquad (8)$$

Where W_m: volume pumping power [kWh]; V: pumping all water [m^3]; T_p: pumping time [h]; H: Effective head.

When it is needed to takes 12 hours to fill the upper reservoir, the number of pump turbine units will be 4 according to the data above.

5 THE STABILIZATION OF WINDPOWER OUTPUT

Average value of the wind power output is found to be 386MW during peak hours from 8:00 to 21:00. It is able to reduce 386MW thermal power from this system. When the actual wind power output is lower than 386MW, hydro electric generator is started, and make for the power output at 386MW. It is shown in Fig.6. By that way to reach the purpose of stabilizing large-scale wind power.

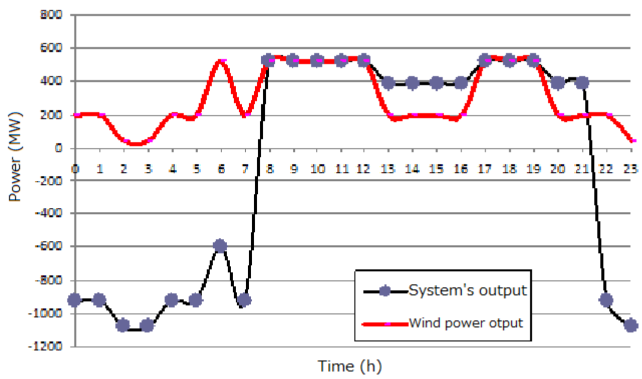

Figure 6: The wind power output and the adjusted output of the system on 18th September.

As we can see from Fig.6 that during the peak hours, the output power of the system are more stable than the output of the wind farms only. By the capacity of the Qingdao city and the data in Fig.6, the user side's voltage change rate can be caculated that from 5.4% (without adjustment) to 4.1% (after adjustment).

6 REDUCTION OF CARBON DIOXIDE

The environmental problems caused by power generation with renewable energy systems such as wind power and hydropower, especially carbon dioxide emissions, are much less than which caused by thermal power generation. The comparison of CO_2 emissions in power supplies between different ways of generation can be seen in Ref. [7].

$$R_{wind} = \frac{W_{wind}}{W_{wind} + W_{water}} \times 100[\%] \tag{9}$$

$$R_{water} = \frac{W_{water}}{W_{wind} + W_{water}} \times 100[\%] \tag{10}$$

Where W_{wind}: Total power generation of wind power; W_{water}: The total amount of pumped storage power generation.

From the value of CO_2 emission ratio was calculated by eqs. (9) and (10), it is possible to obtain the amount of carbon dioxide emitted per kWh by this system.

$$E_{wind} = R_{wind} \times 29[g - CO_2 / kWh] \tag{11}$$

$$E_{water} = R_{water} \times 11[g - CO_2 / kWh] \tag{12}$$

Thus, the entire system can be calculated by eq. (13).

$$E_{total} = E_{wind} + E_{water}[g - CO2 / kWh] \tag{13}$$

About the amount of carbon dioxide reduction, since the purpose is to reduce the thermal power plant's output, in this system, we have used a value of 0.67 [kg-CO_2/kWh] carbon dioxide emission factor of thermal power plant in China. (The value of the carbon dioxide emission factor has been defined in China's National Development and Reform Commission Energy Research Institute.) Then the CO_2 recuction can be caculated as eq. (14).

$$CO_2 \text{ reduction} = (0.67 - \frac{E_{total}}{1000}) \times W_{total}[kg] \tag{14}$$

7 CONCLUSIONS

By performing the combination of pumped storage power generation and wind power generation, in the city of Qingdao it is possible to reduce the capacity of the thermal power plant of 6.156×10^3 [MW] and can reduce the carbon dioxide emmision of 4252 [t] per day according to the data above.

While considering the actual conditions, with stronger wind or higher water head, the system that combined pumped storage generation and wind power generation can have more advantages than a thermal power plant.

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