Stabilization of Power Fluctuation of Renewable Energy Based on Hybrid Energy Storage System

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Abstract. As energy shortages become more prominent, renewable energy is widely exploited. Renewable energy sources such as wind energy and solar energy are affected by the non-uniformity and non-steadiness of the natural environment, resulting in fluctuations and randomness of output power. When incorporated into the grid, it will cause fluctuations in grid voltage and frequency, affecting the power quality of the grid. The energy storage system can be used as an energy buffering device to stabilize the grid-connected power to meet the grid-connected standard. A hybrid energy storage system is proposed to stabilize the fluctuation of renewable energy generation, and the energy storage control method and energy distribution method are given. Finally, using the actual data of a wind farm, the hybrid energy storage composed of hydrogen storage energy and supercapacitor energy storage is used to stabilize the wind power fluctuations. The simulation results verify the technical rationality and economic practicability of the proposed method.

1. Restrictions on the development of renewable energy

Developing and utilizing renewable energy is an important way to solve the problem of energy exhaustion. The consumption of renewable energy is one of the key technologies that restrict the development of renewable energy. Wind energy, solar energy and other renewable energy have some shortcomings, such as discontinuity, instability, low density, time, season and climate change. The power quality of power grid decreases when these energy-generating equipment is connected to the grid[1].

Taking wind energy as an example, the output of wind turbines is stochastic and intermittent because the wind power is affected by the change of natural conditions and the wind speed and direction are changing constantly and randomly. The incorporation of wind farms into power grids may lead to serious harmonic pollution and voltage flicker in local power systems. Because of the particularity of electric energy, generation, transmission, distribution and power consumption in power system must be completed at the same time, which requires that the system should always be in a dynamic equilibrium state. Wind has uncontrollable and iradjustable characteristics, which will cause the security and stability of the system. The above factors lead to a large number of abandonment of wind and light. As shown in Table 1, the abandonment of wind power in China's major wind power provinces.
Table 1. Abandonment of wind in major wind power provinces in China.

| Province   | Power generation capacity (billion kWh) | Abandoned wind capacity (billion kWh) | Abandoned wind rate (%) |
|------------|----------------------------------------|--------------------------------------|-------------------------|
| Inner Mongolia | 46.4                                    | 12.4                                 | 21                      |
| Shanxi     | 13.5                                    | 1.4                                  | 9                       |
| Ningxia    | 12.9                                    | 1.9                                  | 13                      |
| Gansu      | 13.6                                    | 10.4                                 | 43                      |
| Xinjiang   | 22.0                                    | 13.7                                 | 38                      |
| Hebei      | 21.9                                    | 2.2                                  | 9                       |
| Liaoning   | 12.9                                    | 1.9                                  | 13                      |
| Heilongjiang | 8.8                                     | 2.0                                  | 19                      |
| Jilin      | 6.7                                     | 3.0                                  | 29                      |

It can be seen that China's wind abandonment situation is relatively serious. Therefore, how to improve the stability of renewable energy generation system and restrain the power quality problems caused by intermittent renewable energy generation system is an important issue in the grid-connected operation of renewable energy generation system [2-3]. Energy storage technology can store electric energy, release it when needed, ensure the continuous and stable output of electric energy, and improve the power grid's ability to accept renewable energy for power generation [4].

2. Renewable energy and hydrogen storage system

2.1. Energy storage technology

Energy storage technology is divided into physical energy storage, chemical energy storage and thermal energy storage. Physical energy storage includes mechanical energy storage (e.g. pumping energy storage, compressed air energy storage, flywheel energy storage) and electromagnetic energy storage (e.g. supercapacitor and superconducting energy storage); chemical energy storage is based on electrochemical principles (e.g. lead-acid battery, lithium-ion battery, sodium-sulfur battery, etc.); thermal energy storage is to store heat energy in the medium of heat-insulating container to realize thermal energy generation or direct benefit. Use. Fig. 1 is a comparison of the duration of sustainable power supply and storage capacity of commonly used energy storage.

Figure 1. Contrast Chart of Energy Storage Mode.

Figure 1 shows that hydrogen storage has the best comprehensive performance in terms of power supply time and energy storage capacity. The advantages of hydrogen as an energy carrier lie in: (a)
high efficiency conversion between hydrogen and electricity can be achieved through electrolytic water and fuel cell technology; (b) compressed hydrogen has high energy density; and (c) hydrogen has the potential to scale up to power grid applications.

2.2. Hydrogen storage system for renewable energy generation

Renewable energy generation hydrogen storage system uses renewable energy (solar energy, wind energy, etc.) to produce hydrogen by electrolyzing water and storing hydrogen. When needed, it generates electricity through fuel cells to supplement electricity. Its basic structure includes: electrolytic water hydrogen production system, hydrogen storage system, fuel cell power generation system, energy management and control system, etc. Its schematic diagram is shown in Figure 2.

2.3. Key technologies in hydrogen energy storage system

The hydrogen energy storage system uses the clean energy power electrolysis technology to obtain hydrogen, stores the hydrogen in the hydrogen storage device, and then uses the fuel cell technology to feed the stored energy back to the power grid, or sends the stored high-purity hydrogen to the hydrogen industry chain. In order to realize this energy conversion system, the technologies used include: hydrogen production technology, hydrogen storage technology, and hydrogen power generation technology. Further breakthroughs in these key technologies are needed. Therefore, the development of high efficiency, long life, low cost and high performance hydrogen storage technology for power grid is one of the key technologies to promote the application of hydrogen storage in new energy access.

3. Control strategy of hybrid energy storage for suppressing wind power fluctuation

The control strategy of hybrid energy storage to suppress wind power fluctuation is an important means to suppress wind power in order to improve the operation ability of wind power access[5]. The wind power hybrid energy storage power generation system includes wind turbine, hybrid energy storage system and hybrid energy storage power generation system. The structure of wind power hybrid energy storage system is shown in Figure 3.
When the grid can not absorb wind power, surplus energy can be allocated to hydrogen storage system for energy storage. The system is composed of wind power generation system, hybrid energy storage system, power distribution controller and connecting wires. When wind power is excessive, energy flows from busbar to hybrid energy storage system. When wind power is insufficient, energy flows from hybrid energy storage system to busbar and supplies power grid. Hybrid energy storage system is composed of hydrogen energy storage and supercapacitor energy storage. The response speed of hydrogen energy storage is slow, but its storage capacity is large, and hydrogen energy storage can bear low-frequency power. Supercapacitor has a fast response speed and is suitable for frequent charging and discharging. Supercapacitor bears high frequency power. Energy storage system can play a "peak cutting and valley filling" effect on the output power of wind power. The input power of the system is smoother.

At present, there are many wind power fluctuation mitigation strategies, such as empirical mode decomposition, wavelet decomposition, Kalman filter, first-order filtering, and so on[6-7]. But these suppression strategies have some limitations in real-time online control. Model predictive control (MPC) has the characteristics of early prediction, priority control and good real-time performance. Therefore, this paper adopts model predictive control (MPC) strategy to suppress wind power fluctuation. Model predictive control strategy includes rolling time domain strategy and state space model[8-9].

In actual operation, the relationship between the output power of wind farm and energy storage is as follows:

\[ P_g(k+1) = P_{es}(k) + P_w(k) \]  \hspace{1cm} \text{(1)}

In the formula: \( P_g(k) \), \( P_{es}(k) \) and \( P_w(k) \) are the grid-connected power, energy storage power and original power of wind power at \( k \) time respectively. The formula for calculating the state of charge of energy storage at \( k+1 \) time is as follows:

\[ SOC_{es}(k+1) = SOC_{es}(k) - \frac{T_c P_{es}(k)}{C_{es}} \]  \hspace{1cm} \text{(2)}

In the formula: \( T_c \) is the energy storage control period; \( C_{es} \) is the energy storage capacity.

According to the principle of state space model, \( P_g \) and \( SOC_{es} \) are taken as state variables \( x_1 \) and \( x_2 \), \( P_{es} \) as control variables \( u \), \( P_w \) as disturbance input \( r \), \( P_g \) and \( SOC_{es} \) as output variables \( y_1 \) and \( y_2 \), and then the state space expression is constructed as follows:

\[
\begin{bmatrix}
    x_1(k+1) \\
    x_2(k+1) \\
    y_1(k) \\
    y_2(k)
\end{bmatrix} = \begin{bmatrix}
    0 & 0 & 1 \\
    0 & 1 & -T_c \\
    1 & 0 & 0 \\
    0 & 1 & 0
\end{bmatrix} \begin{bmatrix}
    x_1(k) \\
    x_2(k) \\
    u(k) \\
    r(k)
\end{bmatrix} \hspace{1cm} \text{(3)}
\]

According to the idea of rolling time domain strategy, iterative calculation of equation (3) can predict the output of variables in the future \( k+M \) (\( M=1, 2, 3,... \)), and then use the quadratic programming method in each control. Optimization in the time domain, you can get the corresponding control instructions.

The above analysis is transformed into an optimization model solution, in which the objective function is the minimum energy storage usage \( J \) in each optimization cycle, namely:

\[ J = \min \sum_{i=1}^{k+M} P_{es}^2(i) \]  \hspace{1cm} \text{(4)}

Accordingly, the constraints of energy storage power, power fluctuation rate gamma of wind power Grid-connected and energy storage charging state should be satisfied, and the constraints are as follows:
In the formula: $P_{es_{\text{min}}}$ and $P_{es_{\text{max}}}$ are the lower and upper limits of $P_{es}$ respectively; $P_{g_{\text{min}}}$ and $P_{g_{\text{max}}}$ are the minimum and maximum values of $P_g$ respectively; $P_{\text{rated}}$ is the rated installed capacity of wind power.

4. Case analysis

A day’s actual power data of a wind farm is selected as the research object. The sampling time is 1440 minutes, the sampling rate is 1 minute, and the installed capacity is 200 MW. Figure 4 shows the waveform of the actual output power of a wind farm.

![Figure 4](image)

Figure 4. Actual output power of wind power

4.1. Stabilization strategy

According to the constraints of Formula (5), 1 minute fluctuation rate $\leq 2\%$ and 30 minute fluctuation rate $\leq 7\%$ are selected as the wind power Grid-connected fluctuation rate constraints. The storage power constraints $P_{es}$ takes 9MW and the storage $SOC$ range is $0\sim 1$. The model predictive control algorithm is used to suppress the wind power curve. The wind power before and after the suppression is shown in Figure 5.

![Figure 5](image)

Figure 5. Actual output power of wind power

It can be seen that the wind power fluctuation after smoothing is relatively smooth, and the fluctuation rates of 1 min and 30 min after smoothing are shown in Figs. 6 and 7 respectively.
From Figs. 6 and 7, we can see that the volatility after stabilization decreases greatly. The maximum volatility after stabilization is 1.19% in one minute and 6.17% in 30 minutes. To meet the grid-connected requirements: 1 minute fluctuation rate after stabilization is less than or equal to 2%, 30 minute fluctuation rate is less than or equal to 7%.

4.2. Electric power distribution
Considering the large storage capacity and slow charge-discharge response of hydrogen energy storage, hydrogen energy storage is used to undertake fluctuating low-frequency power instructions. The charging and discharging response time of supercapacitors ranges from milliseconds to tens of minutes, which is used to undertake high-frequency power instructions with frequent fluctuations. In order to meet the performance characteristics of hydrogen energy storage and supercapacitor, the energy distribution of hydrogen energy storage is shown in Figs. 8 and 9.
5. Summary
The randomness and fluctuation of wind and photovoltaic renewables bring great challenges to the stability and reliability of voltage and frequency of large power grid when wind and photovoltaic are connected to the grid. Energy storage system can be used as energy buffer device, which can be widely used in the field of renewable energy generation control with intermittent output power to enhance the stability and controllability of its output power and improve the power quality to meet the grid-connected standard of wind power. Through the simulation and analysis of hybrid energy storage system, the results demonstrate that the hybrid energy storage system can effectively suppress the random, intermittent and fluctuating characteristics of wind power output, greatly enhance the wind power absorption capacity and the stable operation of wind power, thereby improving the utilization rate of renewable energy generation, and provide technical support for the large-scale development and utilization of renewable energy.

6. References
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