Research on frequency Control Strategy of micro grid including wind power and hybrid energy storage system

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Abstract. In view of the frequency fluctuation of the micro-grid system containing wind power, hybrid energy storage system composed of batteries and supercapacitors is adopted to coordinate the output, so as to maintain the frequency stability of the micro-grid and provide the possibility for the micro-grid to further absorb wind power and other clean energy. Firstly, by analyzing the characteristics of wind power output, the power deviation signal of the system is decomposed into low-frequency and high-frequency parts through wavelet packet decomposition, so as to maximize the consumption of wind power output power on the premise of meeting the stability of the system. Then, the high frequency part of the power gap is further divided to determine the initial FM power distribution scheme of the energy storage system. Finally, the energy storage output is modified by the Logistic regression function to take into account both the energy storage adaptive frequency modulation and the energy storage charged state self-recovery. Example analysis shows that the proposed control strategy can realize the optimal distribution of wind power, ensure the full utilization of wind farm output, improve wind power grid connection capacity, and increase efficiency and economy.

1. Introduction
Due to the influence of climate, geographical environment and other factors, the output power of wind turbines exposed after grid connection is random and unstable. Then there are hidden troubles such as system stability, frequency fluctuation of micro-grid and poor power quality in micro-grid system with wind turbine. How to work out reasonable control strategy to effectively improve the operation capability of micro-grid system after wind power is connected to the grid, it is of great significance for microgrid to absorb as much clean energy as possible.

Scholars at home and abroad have carried out a series of analysis and research on wind power generation and hybrid energy storage. Literature [7] USES two-stage real-time wavelet filtering algorithm to process wind power. The first-stage filtering obtains the power output meeting the requirements of fluctuation, while the second-stage filtering removes the noise generated by the rolling filter window and reduces the power fluctuation. For wavelet packet decomposition, the time-frequency resolution of the signal is further enhanced, which is helpful to get the detailed information of the high frequency part of the signal.

Aiming at the defect that energy storage participates in frequency modulation allocation in a fixed proportion, literature [11] proposed a secondary frequency modulation control strategy based on fuzzy control theory and dynamically allocated according to regional control deviation. The current research focuses on how to realize the regulation of wind power grid-connection frequency based on wavelet packet algorithm in a given wind power output scene, without considering the general applicability of the regulation strategy in a wind power output scene.
In order to solve these problems, according to the fluctuating characteristics of wind power under wind power generation scenario and wind power grid-connected fluctuating standard, this paper proposes an adaptive Wavelet packet decomposition method to stabilize wind power fluctuation, and realizes the universal applicability of the decomposition algorithm, at the same time, using Logistic regression function root features, and hybrid energy storage characteristics to determine the internal primary energy storage system power allocation principle, and then through the power energy storage SoC control the secondary revision instruction of energy and power energy storage power, to realize the reasonable distribution of the hybrid energy storage system power instruction, keep the hybrid energy storage SoC work within a reasonable range, so as to achieve mixed reservoir. The purpose of long-term stable operation of the system is to improve the operation stability of the micro-grid system and provide the possibility for the micro-grid to further absorb renewable energy.

2. Frequency control of MicroGrid based on adaptive wavelet packet decomposition

2.1. Theoretical basis of adaptive wavelet packet decomposition

Wavelet packet decomposition compared Yu Xiaobo packet transform, it is a kind of can provide better than the method of decomposition of wavelet packet transform higher resolution, not only the low frequency part of signal decomposition, effectively for the high frequency part can decompose, help to get more details to the characteristics of the fluctuation signal to select band, adaptive to improve the signal decomposition and resolving power. The wavelet packet decomposition tree is shown in Figure 1.

![Wavelet packet decomposition tree](image1)

In Figure 1, from left to right, represents the signal component obtained by 1-layer, 2-layer and 3-layer decomposition of the original signal; $P_n$ represents the original signal, and $n$-layer decomposition is performed to obtain the corresponding low-frequency part $P_{n,0}$ and high-frequency part $P_{n,i}$ ($i=1,2...,2^n-1$), where the bandwidth $f$ of each signal frequency band can be expressed as formula (1).

$$f_0 = \frac{f_s}{2^{n+1}}$$

Where, $f_s$ is the signal sampling frequency; $n$ is the number of wavelet packet decomposition layers.

2.2. Frequency control of micro-network with adaptive wavelet packet decomposition

For wind farms and observed after the grid frequency control, power system gaps $\Delta P(t)$ should satisfy wave allows:

$$\Delta P(t) \leq \Delta P_{ref}$$

According to the judgment of wind power original output power $P_w(t)$:

1) If the standard is met, it is directly connected to the grid.

2) If can't meet, the signal power to the system deviation $\Delta P(t)$ $n$ layer wavelet packet decomposition, get the low-frequency component $\Delta P_{W,n,0}$ and the high frequency component $\Delta P_{W,n,i}$, loop decomposition layer number n. Using the proposed grid fluctuation allowedrange indicator of low
frequency component $\Delta P_{W,n,0}$. When low frequency component $\Delta P_{W,n,0}$ meet grid fluctuation range for the first time, you can determine the optimal decomposition level of wavelet packet decomposition of $n$, at this point, the actual power of wind power grid connection is obtained. Thus the adaptive decomposition of wind power is realized.

2.3. Principle of primary power distribution for hybrid energy storage system

Based on the comparison of different characteristics of energy storage and power storage, how to reasonably allocate primary power within hybrid energy storage system is an important content of the whole strategy. Considering that the battery life is affected by the changing times of charge and discharge, reducing the frequency of battery power instruction is helpful to avoid frequent charge and discharge of the battery, thus extending the life of the battery. At the same time, the use of uTRACapacitors to assume higher frequency power instructions can give full play to its characteristics of fast response speed and frequent charge-discharge conversion. Thus, the primary power instructions of hybrid energy storage can be shown in Formula (3) and (4).

$$P_b(t) = -[(\Delta P_{n,1} + \Delta P_{n,2})]$$

$$P_{sc}(t) = -[\Delta P - \Delta P_{n,0} - (\Delta P_{n,1} + \Delta P_{n,2})]$$

Where, $P_b(t)$ is the battery power touch command; $P_{b,sc}(t)$ is the primary instruction of supercapacitor power; $P_{b,sc}(t) > 0$ denotes charging; $P_{b,sc}(t) < 0$ denotes discharge.

3. Soc adaptive recovery of energy storage system based on Logistic regression function

3.1. Selection of Soc adaptive recovery regression function of energy storage system

The primary power distribution method based on adaptive wavelet packet decomposition responds to the saturation or depletion of the system frequency fluctuation quantity only by controlling the energy storage charge and discharge power instruction. In previous studies, most of the maximum output power of energy storage alleviates the problem of energy storage overcharge and overdischarge to a certain extent, but there are also two problems: 1) it weakens the characteristics of rapid response of energy storage; 2) At the critical point of wind power output, it is easy to cause secondary disturbance to the system frequency.

Therefore, this paper introduces Logistic function, taking SoC as independent variable, self-adaptive factor $n$ and as reference variable, and maximum charge/discharge power of energy storage as dependent variable, to construct maximum output limt of energy storage based on SoC feedback, and carry out secondary correction of energy storage output, so as to give consideration to self-adaptive frequency modulation of energy storage and self-recovery of energy storage charged state (SoC). As shown in Equation (5) and (6).

$$P_d = \frac{P_{dm} e^{\frac{n(S_{soc,low} - S_{soc,min})}{S_{soc,low} - S_{soc,min}}}}{P_{dm} + P_{sc} e^{\frac{n(S_{soc,low} - S_{soc,min})}{S_{soc,low} - S_{soc,min}}}}$$

$$P_e = \frac{P_{cm} e^{\frac{n(S_{soc,max} - S_{soc})}{S_{soc,max} - S_{soc,max}}}}{P_{cm} + P_{sc} e^{\frac{n(S_{soc,max} - S_{soc,max})}{S_{soc,max} - S_{soc,max}}}}$$

Where, $S_{soc,min}$, $S_{soc,low}$, $S_{soc,high}$, $S_{soc,max}$ are the minimum, lower, higher and maximum values of SoC respectively. $P_{cm}$ and $P_{dm}$ are rated charge and discharge power of energy storage respectively.
As can be seen from Figure 2, when the parameter is $P_o=0.01$ and $n=15$, the maximum output constraint of energy storage based on SoC feedback can not only ensure that the energy storage can achieve the effect of smooth output, but also enable the energy storage to have the characteristic of rapid response to the frequency fluctuation of the system.

3.2. The output secondary modification based on SoC adaptive recovery of energy storage system

Therefore, according to the power-type energy storage SoC, the internal output power distribution of hybrid energy storage is further optimized, and the output power instructions of energy-type and power-type energy storage are quadratic modified according to the following rules by using the Logistic regression function theory.

1) When the SoC value $S_{oc,sc}(t)$ of the ultracapacitor is moderate at the end of time period, the primary power instruction $P_b(t)$ and $P_{sc}(t)$ Charge and discharge.

2) When $S_{oc,sc}(t)$ is small, it proves that the remaining capacity of ultracapacitor is insufficient. In the case of $P_{sc}(t)<0$, $P_{sc}(t)$ needs to be modified to increase it to a reasonable range, and the excess power shall be borne by $P_b(t)$ through corresponding adjustment. If $P_{sc}(t)>0$, it stays the same.

3) When $S_{oc,sc}(t)$ is large, it proves that the capacity of ultracapacitor tends to saturation state. If $P_{sc}(t)>0$, is at this time, $P_{sc}(t)$ needs to be modified to reduce it to a reasonable range, and the power correction part of $P_b(t)$ needs to be undertaken by adjusting $P_{sc}(t)$. If $P_{sc}(t)<0$, it stays the same.

The ultracapacitor SoC value $S_{oc,sc}(t-1)$ at the end of time period $t-1$ and the change in ultracapacitor SoC value $S_{oc,sc}(t)$ at time period $t$ were taken as inputs. The power instructions of battery and supercapacitor optimized by Logistic regression function are calculated according to Formula (7) and (8).

\[
P_{b}(t) = P_{b}(t) + (P_{sc}(t) - P_{sc}'(t)) \quad (7)
\]

\[
P_{sc}'(t) = P_{c/d} \quad (8)
\]

4. The simulation analysis

4.1. Adaptive wavelet packet decomposition of wind power

For simulation analysis, the actual output power of a wind farm with a capacity of 90MW is adopted as the main data to verify the method in this paper. According to the data simulation, the output power of wind power and the hybrid energy storage system can cooperate to achieve the stability effect of microgrid frequency. In this paper, DB9 wavelet is used to decompose the wind power output in 8 layers to obtain the power curves of its low-frequency part $S_{8,0}$ and high-frequency part $S_{8,1}$ among them, the wind power curve of wavelet packet decomposition is shown in Figure 3. The wind power output curve obtained by adopting the adaptive wavelet packet decomposition method is shown in Figure 4.

(a) Original power signal and low frequency signal  
(b) Sub-high frequency signals
4.2. Primary power Distribution analysis of hybrid energy storage system

The sub-high frequency part and the high frequency part obtained from the adaptive wavelet packet decomposition are all connected to the hybrid energy storage system. When the energy storage system is connected, the hybrid energy storage system will make a reasonable allocation of primary power according to the different characteristics of energy storage and power storage. In this paper, the high-frequency signals obtained by the wind power wavelet packet decomposition are taken as the basis for the preliminary division of the internal power instructions of energy storage, and the primary power instructions of battery and ultracapacitor can be obtained through analysis, as shown in Figure 5.

4.3. Maintenance effect of energy storage SoC

In this paper, according to the characteristics of the Logistic regression function, due to the existence of energy storage self-recovery, the energy storage Soc is always maintained within the normal range \( (S_{\text{soc,low}} \text{ and } S_{\text{soc,high}}) \). The lower or upper limit of the energy storage Soc will stop discharging and charging. The SoC maintenance effect of the method in this paper is compared with that under fuzzy control, as shown in Figure 6. It can be seen from Figure 6 that the reasonable control strategy of this paper makes the SoC maintenance effect more and more obvious after the pressure of frequency modulation increases at 40min, and its SoC maintenance effect is 1.17 times that of fuzzy control. Therefore, the method in this paper has a better SoC on the premise of meeting the frequency modulation requirements of the system, effectively preventing excessive charge and discharge of energy storage, so as to extend the service life of energy storage.
5. Conclusion

According to the power output characteristics of wind farm, this paper designs the reasonable mixed energy storage in wind turbines micro power grid frequency control strategy through simulation analysis, the simulation for wind power grid power fluctuations standard put forward by the optimal decomposition level of wavelet packet decomposed number to determine the optimal decomposition value of wind power output, for stable wind power output fluctuation has good adaptability, the effect of the wind power grid. Through the control of primary power distribution of energy storage and the comparison of energy storage performance, the power distribution between the two energy storage modes is realized, and the influence of wind power output power on the grid is better stabilized. The use of Logistic regression function not only limits the maximum output of the energy storage system, but also improves the regulation characteristics and application economy of the hybrid energy storage system. In practical engineering, the micro grid frequency modulation control of wind power and other types of power sources and hybrid energy storage systems needs further research and verification in the future.

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