Power Filtering Based Wind Farm Power Fluctuation Smoothing Control Strategy

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Abstract. The output active power of the wind-power generator fluctuates with the change of the wind speed, which affects the output power quality of the wind farm. In order to reduce output power fluctuation of wind farm, based on analyzing of Wind Power Fluctuation Spectrum, an active power smoothing control strategy had been proposed through the pitch angle control and speed control of the generator. The simulation results show that the proposed control strategy can effectively reduce the output active power fluctuations of wind farm.

Introduction

Wind energy is a renewable energy with the greatest potential for development and utilization at present. The output power of wind farms (WF) depends on wind speed. Due to the unexpected and stochastic fluctuations of wind speed, when the capacity of wind turbines in the power system exceeds a certain proportion, the fluctuation of wind power will cause the power system frequency to deviate from the standard frequency [1-2]. The frequency protection relay may be misoperated to threaten the safe operation of the power system.

In addition, most of wind farms are located at the end of power grid. The fluctuation of output power of wind farms will also affect the power quality of wind farms. Therefore, how to effectively use wind energy and suppress power fluctuations of input power grid is an important and meaningful research point.

Based on the analysis of the power spectrum of wind turbines, a control strategy that can effectively suppress the wind power fluctuation of wind farms is put forward. The new control strategy does not need to add new hardware devices, and uses inertial control and spatial filtering to stabilize the high-frequency wind power fluctuations. The wind power fluctuation in the low frequency section is controlled by the pitch control, and the wind power fluctuation in the middle frequency band is controlled by the generator speed. The effectiveness of the proposed control strategy is verified by the wind power simulation of 24 direct drive permanent magnet synchronous wind turbines.

2. Organization of the Text.

Frequency Spectrum Analysis of 1.WTG Power Fluctuation

Figure 1. A typical 200s wind profile and fluctuation spectrum.

Figure 1 shows a typical 200 second wind speed waveform and power fluctuation spectrum. Figure 1 (a) is wind speed waveform. Figure 1 (b) is the spectrum of wind speed fluctuation. From Figure 1, we can see that wind speed fluctuation can be divided into low frequency ` intermediate frequency and
high frequency fluctuation components. The fluctuation is mainly concentrated in low (less than 0.01 Hz) and intermediate frequency (0.01 and 1 Hz) regions, while 0.1 Hz to 10 Hz bands are also sensitive to power system, and high frequency fluctuations (1 Hz or above) are small, most of which can be absorbed by inertia of generators.

**Wind Field Power Smoothing Control Based on Frequency Division**

![Diagram](image)

Figure 2. Wind farm power smoothing control strategy.

Based on the spectrum analysis of the above power fluctuation, a wind field power smoothing control strategy based on power filtering is presented in Figure 1. First, the high frequency fluctuation is filtered through the system inertial control and spatial filtering. Secondly, because of the low frequency correlation of wind, they can't be filtered out through spatial smoothing. Variable pitch control is used to stabilize low-frequency wind power fluctuations, while the middle frequency band is controlled by generator speed control. The inertial control in Figure 1 is used to change the inertia of the wind turbine, assist in reducing the high frequency fluctuation and improve the dynamic characteristics of the system.

In this paper, the output power of the whole farm is \( \sum p_r \) as a feedback signal for smoothing control. Because the high frequency part has been eliminated by spatial smoothing, the advantage of using \( \sum p_r \) as feedback signal is that the cut-off frequency of feedback loop is higher and the dynamic response is faster.

As shown in Figure 1, the controller is synthesized by a two part filter. The low pass filter is used to deal with large and slow fluctuation of wind speed, and removes the low frequency components of wind speed fluctuation. The bandpass filter is used to deal with small and fast wind speed fluctuations, which has not been removed by spatial filtering.

In order to improve the operation of the generator stability, figure 1 will mean maximum output power multiplied by the adjustment coefficient, the maximum value of this generator is given power that is less than the corresponding wind turbine power curve, can avoid the generator speed limit, resulting in unstable operation, can be obtained through fuzzy reasoning, see section four. The given power of the generator is less than the maximum value of the power curve of the corresponding wind turbine. It can avoid the generator speed exceeding the limit and cause unstable operation. It can be obtained through fuzzy control, as shown in the fourth section.

**Pitch Control Reference Power**

The reference power \( P_{ref} \) of the pitch control is selected according to the average wind speed. The average wind speed is calculated by the exponent moving average method. So the latest wind speed data have a high weighting factor. \( P_{ref} \) is determined by formula (1).

\[
\sum p_{ref} = p_{ref1} + p_{ref2} + \ldots + p_{refs}
\]  

(1)
\[ P_{\text{refn}} = \frac{1}{2} \rho \pi R^2 C_p(\lambda^*) V_{\text{on}}^3 \]  

(2)

\[ \lambda^* \geq \lambda^{\text{opt}}, \quad C_p(\lambda^*) \leq C_p(\lambda^{\text{opt}}) \]  

(3)

\[ V_{\text{en}} = V_{\text{en}}(i) \times k + V_{\text{en}}(i-1) \times (1-k) \]  

(4)

\[ k = \frac{2}{i+1} \]  

(5)

In the formula, 1 is the average wind speed, and the 2 is the data collected by the I, and the Prefn is the reference output of nth wind turbines.

**Power Allocation**

Each WTG needs to coordinate the power distribution to ensure that the output power \( P_{\text{gn}} \) of the WF is a reference value. If a WTG output decreases rapidly with the decrease of the wind speed, the other WTG should output more power. The traditional method usually determines the output power only according to the WTG capacity. The output power is allocated according to the ratio \( \hat{\varphi} \) of WF output power commands \( P_{\text{com}} \) and \( P_{g_{\text{max}}}^* \), and each WTG reference output power is \( P_{\text{gn}} \):

Each WTG reference output power \( P_{\text{gn}} \) depends on the WF reference output power of the wind farm and the allocation method.

\[ P_{\text{gn}} = P_{g_{\text{max}}}^* \times \hat{\varphi} \]  

(6)

\[ \hat{\varphi} = \frac{P_{\text{com}}}{P_{g_{\text{max}}}^*} \]  

(7)

The \( \hat{\varphi} \) is the ratio of the WF output power command \( P_{\text{com}} \) to \( P_{g_{\text{max}}}^* \).

**Simulation Results and Analysis**

In this paper, a wind farm model [3] is used. It is assumed that each WTG wind speed time series is the same. It only delays \( \Delta\text{tmn} \) in time, assuming that the average wind speed of the wind in the X direction is \( V_{\text{mean}} \), and any two spatial locations are \((x_m, y_m)\) \(\backslash\) \((x_n, y_n)\), \(\Delta\text{tmn} = (x_m- x_n)/ \tilde{V}_{\text{en}}\). In order to minimize the correlation of the wind speed model of WTGs, a random number generator is used to allocate any two WTG distances and the number of WTG of the wind farm is 24. The wind turbine model is a variable speed wind turbine (GE 1.5MW) model with a power electronic interface. The detailed parameters of the model can be referred to [4].

Figure 5 (a) is an hour time series of wind speed, with an average wind speed of 12 m/sec. Figure 5 (b) is a single WTG output power, and the power fluctuates with the wind speed. Figure 5 (c) is the total output power of the wind farm. When the wind farm is in the traditional control mode and the pitch angle is fixed, figure 5 (d) is the total output power of the wind farm, when the pitch angle is involved in smooth control.

Figure 5 Comparison (b), 5 (c), due to the spatial smoothing, figure 5 (c) high order harmonics in the total output power decreased significantly, the total harmonic distortion is reduced, but the low frequency part still exists. This is due to the correlation of the low frequency part of the output power, and the low frequency part is hardly attenuated by the space. After smoothing with pitch control, the
low frequency part basically does not exist, and the overall output is relatively straight, as shown in Figure 5 (d).

Figure 5. Wind farm power space smoothing and pitch control.

Figure 6 is the waveform of combination of pitch control and speed control. The high frequency part of wind speed fluctuation can be effectively restrained by speed control, and the low frequency of wind speed fluctuation is controlled by pitch. Figure 6 (a) is the total output power of the wind farm using pitch control.

Figure 6 (b) is a combination of pitch control and speed control of, compare Figure 6 (a) and Figure 6 (b), it can be seen that the two kinds of measurement of wind power control is almost the same, the total harmonic distortion THD is only slightly different.

Figure 6 (c) is the pitch angle waveform of the pitch control. Figure 6 (d) is the pitch angle waveform combined with pitch control and speed control.

Compared with Figure 6 (c), the change of figure 6D is obvious. Figure 6 (c) is rough, and the amplitude of high frequency component is reduced. Therefore, the contribution of the speed control to the high frequency component to suppress the fluctuation of wind speed is obvious.

Figure 6. Waveform combined with pitch control and speed control.
Conclusion

On the basis of analyzing the power fluctuation spectrum of wind power generator, a smooth control strategy of active power of wind farm combined with pitch control and speed control is proposed. The new control strategy uses inertial control and spatial filtering to suppress high-frequency wind power fluctuations, and adopts pitch control to stabilize low-frequency wind power fluctuations, and the wind power fluctuation in the middle frequency band is controlled by the generator speed.

The simulation results show that when the auxiliary device is not needed, the output of the wind farm with large number of WTG has the effect of spatial smoothing. The total output of the wind farm is used as feedback signal, and the pitch control can effectively suppress the low frequency fluctuation of the active power of the wind farm. Combined with variable speed control, the rotor inertia can absorb considerable wind power fluctuations, reduce pitch movements and mechanical wear.

The control strategy proposed in this paper is conducive to improving the power quality and grid stability of grid connected wind turbines, and reducing other energy storage devices required by smoothing means.

References


