Research on mppt control method of doubly-fed wind power system based on sliding mode control

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Abstract. In order to solve the problem of maximum wind energy tracking wind speed measurement of wind turbine at present, a new wind energy control algorithm, sliding mode control algorithm, is proposed, which adjusts the speed of fan by sliding mode control, avoids the problem of real-time wind speed measurement in wind speed tracking control, and can respond quickly to the sudden change of wind speed and solve the problem of uncertain inherent parameters of wind speed. The proposed algorithm is compared with the PI control algorithm and the analog 660KW generator, and the effectiveness of the algorithm is verified. Results: the sliding mode control algorithm has good track tracking performance, can shorten the delay time between the actual value and the reference value, and has good performance.

1. Introduction
In recent years, national environmental protection policies have been introduced one after another, and emission indicators in various industries have become more stringent. In terms of energy, such as thermal power plants, desulfurization and denitrification have been completed, whether from the renewable use of energy or the cost of power generation. The advantages of thermal power are no longer obvious, and the development of renewable energy wind energy. With the support of national policies and the maturity of wind power generation systems in recent years, the development of wind energy has become a hot spot, and wind power generation systems also exist. Many technical difficulties, such as mppt (tracking control), commonly used tracking control methods include mountain climbing method, feedback method, speed ratio method, etc. [1-5]

2. Principle of maximum wind energy tracking control
According to the wind turbine characteristic equation, the blade tip speed ratio, blade radius R, fan speed and wind speed v are related. \( h = \frac{W}{vrh/v} \) [6-9]. To achieve the real-time monitoring of the wind speed, wind speed monitoring device based on the measurement of wind speed value to derive the best speed under wind speed, it is concluded that the best power output, in order to achieve this measure, make the fan blade tip speed ratio is in the best condition, by adjusting the generator output power, namely, through the method of adjusting the generator speed to control the output of the active power [10-12].

3. Maximum wind energy controller design
The design algorithm can accurately calculate the wind energy tracking trajectory. One of the two algorithms designed in this paper is the PI control algorithm [13-15]. The algorithm is easy to
implement, the input data is small, the performance is stable for a long period of time, and the accuracy of trajectory tracking targets is not high. It is better to choose this algorithm for trajectory tracking problems. The algorithm is more complicated to apply and more complicated than the pi algorithm, but it can achieve the best performance. This algorithm is optimal for maximum wind energy tracking.

3.1. Design of pi controller for maximum wind energy tracking

The traditional pi control loop is adjusted so that the doubly-fed generator can output the maximum power. The structure of the pi controller is shown in Figure 1.

As shown in Figure 1, the controller circuit diagram is divided into inner and outer loops, where the vector control is the inner loop and the trajectory tracking is the outer loop. The PI controller uses the basic signal b according to the settings of the inner and outer loops to configure the poles at the zero and pole points of the closed loop. In this way, the interference of system dynamic performance is removed [16].

$$u(t) = kp(by_{ref} - y) + k_p / T_1 \int_0^t (y_{ref} - y) dt$$

(1)

As shown in Equation (1), the first step power reference value is established to measure the actual power generated by the system $P_s$ and rotor angular velocity $\omega_r$ can calculate the measured value $P_i$ and reference value $P_{sref}$. Errors in the loop, and finally analysis of the external loop, current components used in the internal loop $i_{sy}$ controlled by the PI controller, the Equation (2) is obtained.

$$i_{sy} = -K_{pl} \left[ (b P_{sref} - P_s) + \frac{1}{T_{li}} \int_0^t (P_{sref} - P_s) dt \right]$$

(2)

Perform the next calculation by Equation (2), and get the closed-loop transfer function correlation calculation:

$$\frac{P_i(s)}{P_{sref}(s)} = \frac{K_g (s + \frac{1}{b T_1})(s + \frac{1}{b T_{li}})}{s^3 + a_2 s^2 + a_1 s + a_0}$$

(3)

In Equation (3), the specific decomposition is shown in Equations (4) and (5):
\[ K_g = \frac{3L_m v^*_{sL}}{2L_s L_r^*} \quad ; \quad a_0 = \frac{3L_m v^*_{sL}}{2L_s L_r^* T_i} \]

As shown in Equation (3), the built system is a closed-loop third-order system. It is necessary to continue to build a constant value and ratio that can obtain the PI controller, so that the pole assignment calculation can be obtained. Therefore, the inner loop is similar to this. Is a system that decomposes a third-order closed-loop system into an over damped second-order system, because the second-order system is similar to the first-order system and has steady-state time. \( T_i \). Similarly, the inner loop transfer function is approximated by Equation (6):

\[ \frac{I_{ry}(s)}{I_{syre}} \approx \frac{1}{1 + \frac{t_s}{4}s} \]

Bringing Equation (6) into the transfer function of Equation (3) closed-loop system can simplify Equation (3) to Equation (7):

\[ \frac{P_i(s)}{P_{ref}(s)} = \frac{6L_m v^*_{sL} K_p b_{L_i}}{L_s t_s} \left( s + \frac{1}{b_{L_i} T_i} \right) \left( s^2 + \frac{4L_s + 6L_m v^*_{sL}}{L_s t_s} + \frac{6L_m v^*_{sL}}{L_s t_s T_i} \right) \]

As shown in Equation (7), in order to meet the actual operation requirements, the outer loop PI controller in the closed loop is adjusted. For this doubly-fed induction generator, the over damped response time is \( t_s = 70 \text{ms} \), continue to bring in, the controller parameter Equation (8):

\[ K_p = \frac{L_s (5.8 t_s - 2 t_{eL})}{3L_m v^*_{sL} T_i} \]

3.2. Design of sliding mode controller for maximum wind energy tracking

After the PI controller experiment is completed, obtaining the maximum wind energy tracking optimal target based on the PI controller, it is necessary to continue to develop the sliding mode controller, and design the performance of the sliding mode controller to integrate the advantages of the PI controller, while the data of the sliding mode controller occurs [17]. Compared with the PI controller, the hardware complexity of the controller hardware is low, and the controller is selected as a Sliding mode structure. The specific method is: first replace the outer loop of the PI controller in Figure 1 with a sliding mode controller to obtain the control signal \( i_{syref} \) and control variables \( P_s \). The Expression (9)

\[ \frac{P_s(s)}{I_{syref}(s)} = \frac{3L_m v^*_{sL} K_p}{2L_s L_r^* T_i} \left( b T_i s + 1 \right) \]

As shown in Equation (9), \( b \) in the equation is the disappearance of the system zero point and has no effect on the dynamic response performance of the entire system. Equation (9) is simplified into Equation (10) and Equation (11):
\[
\left[ s^2 + \left( \frac{K_p + R_s}{L_s} \right) s + \frac{K_p}{T_s L_s} \right] P_s(s) = \frac{3L_m}{2L_s L'_s T_i} \frac{v}{K_p} I_{ref}(s)
\]

(10)

\[
\frac{d^2 P_s}{dt^2} = \left( \frac{K_p + R_s}{L'_s} \right) \frac{dP_s}{dt} - \frac{K_p}{L'_s T_i} P_s + \frac{3L_m}{2L_s L'_s T_i} i_{ref}
\]

(11)

Sliding plane \( f(x) \) and parameter \( b \) are defined as Equation (12), Equation (13):

\[ f\left( \frac{dP_s}{dt}, P_s \right) = -\left( \frac{K_p + R_s}{L'_s} \right) \frac{dP_s}{dt} - \frac{K_p}{L'_s T_i} P_s \]

(12)

\[ b = \frac{3L_m}{2L_s L'_s T_i} \]

(13)

The second-order Equation (11) can be redefined as Equation (14):

\[ \frac{d^2 P_s}{dt^2} = f\left( \frac{dP_s}{dt}, P_s \right) + bi_{ref}
\]

(14)

Therefore, the sliding plane can be expressed as Equation (15):

\[ s = \left( \frac{dP_s}{dt} - \frac{dP_{s_{ref}}}{dt} \right) + \lambda (P_s - P_{s_{ref}}) = 0
\]

(15)

The derivation between Equations (9) and (15) shows that the dynamic system is stable in the plane, and \( s = 0 \), according to the Equation (15) active power of the generator \( P_s - P_{s_{ref}} \) will decrease, and the time constant \( t \) will also decrease. \( T = \frac{1}{\lambda} \) and bring in the final Expressions (16) and (17).

\[ P_s - P_{s_{ref}} = e_{P_s}
\]

(16)

\[ e_{P_s}(t) = e_{P_s}(t = 0) e^{-\lambda t}
\]

(17)

Figure 2. Active power curve (PI control algorithm).
4. Simulation and experimental analysis

The sliding mode tracking algorithm proposed above was verified, and a model was built using the Matlab platform to establish a wind turbine simulation model. Figure 2 is the power tracking curve of the PI control algorithm, and Figure 3 is the power tracking curve of the sliding mode control algorithm. From the simulation results of Figures 2 and 3, it can be seen that when the wind speed suddenly changes, the wind tracking curve of the PI control algorithm is tracked. The effect is poor, there is a direct delay between the actual value and the reference value, and the time is about 0.11s. The sliding mode control algorithm shown in Figure 3 has a good response state to the trajectory tracking control, good real-time performance, fast response speed, and meet the reference curve and tracking curve of the generator almost coincide, and the delay time is greatly shortened compared to the PI control algorithm. By comparing the two algorithms, it is concluded that the sliding mode control algorithm has better performance than the PI control algorithm in trajectory tracking.

![Figure 3](image)

Figure 3. Active power curve (sliding mode control algorithm).

The sliding mode control algorithm is verified and a test platform is built. The test platform is mainly divided into two parts, the doubly-fed power generation system and the fan simulation system. The prime mover simulation of the wind turbine is performed during the test. The simulation parameters are shown in Table 1.

| parameter name               | Simulation wind turbine | parameter name               | Doubly-fed generator |
|------------------------------|-------------------------|------------------------------|----------------------|
| Rated power (kW)             | 600                     | Rated voltage (v)            | 690                  |
| Blade radius (m)             | 21.65                   | Rated power (kW)             | 660                  |
| Air density (kg / m$^3$)     | 1.0308                  | Rated frequency (hz)         | 50                   |
| Coefficient of friction (N·m·rad$^{-1}$·s) | 400                     | Stator and rotor resistance Ω | 0.115，0.184         |
| Gearbox speed increase ratio | 43.165                  | Stator and rotor leakage inductance (mH) | 1.65，1.68           |
| Total rotor inertia Jt (kg·m$^2$) | 3.92*10$^5$            | Mutual inductance (mH)       | 46.6                 |
| Rotor torque kN·m            | 162                     | Moment of inertia (kg·m$^2$) | 0.334                |

Table 1. Table of test platform parameters.

After the test, the results of the test are retrieved from the memory unit, and the data is graphed in Matlab. The sliding mode control tracking curve is obtained as shown in Figure 4. According to the wind speed change value in Table 1 the maximum wind energy of the sliding mode is obtained. Trace the curve.
Figure 4. Active power curve (sliding mode control generator).

5. Conclusions
This article first introduces the principle of mppt and several commonly used wind energy tracking methods, and analyzes the advantages, disadvantages, and practicability of several methods. Through comparative analysis, a new type of wind energy tracking control algorithm is proposed for wind speed measurement problems, namely sliding Simulation controller tracking algorithm, in order to verify the effectiveness of the proposed algorithm, the traditional PI controller algorithm and sliding mode control algorithm are simulated. The test results show that the traditional PI controller algorithm has flaws in the tracking effect when the wind speed changes suddenly, there is a delay between the actual value and the best power reference value; the sliding mode control algorithm has good trajectory tracking performance, can reduce the delay time between the actual value and the reference value, has a good maximum power tracking effect, and has stable performance.

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