Research on Wind Turbine Converter Control Based on Resonant Sliding Film Controller

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Abstract: A resonant sliding mode control strategy based on the resonant sliding film surface is proposed to control the turbine-side converter of the wind turbine so that the wind turbine can be connected to the grid smoothly under the condition of unbalanced grid voltage. Taking the doubly-fed asynchronous wind generator working under unbalanced grid voltage as the control object, establish its mathematical model and its generator-side converter. Taking the instantaneous power in the $\alpha \beta$ static coordinate system as the state variable of the sliding mode controller, the resonant sliding mode controller is studied, its parameters are designed, and experiments are carried out in the simulation platform MATLAB. A 1.5MW motor model was established and tested, and it was verified that the resonant sliding mode control strategy can control the grid voltage without static error and realize the smooth grid connection of wind turbines.

1 Introduction

Doubly-fed induction generator (DFIG) has been widely used in the wind power field due to its wide range of power control, small capacity of an ac power converter, and excellent performance in power control operation, and a lot of research has been conducted. However, when the occurrence of faults leads to unbalanced grid voltage, the electric energy generated by wind turbines will have negative effects such as voltage distortion and guttering, and cannot be directly connected to the grid [1-2].

The DFIG power generation system is shown in Fig.1[3-4]. The stator winding of the doubly-fed motor is directly connected to the power grid, and the power of the wind generator is transmitted to the power grid, and the power of the rotor winding can realize bidirectional flow. When the external voltage drops, the energy generated by the motor cannot be delivered. Part of the energy is charged to the DC side capacitor through the machine-side converter, causing the capacitor voltage to rise rapidly.

When modeling the doubly-fed wind power generation system in the existing literature, it is generally considered that the inductance and mutual inductance in the motor windings are linear, the stator winding and the rotor winding are three-phase symmetrical, and the magnetomotive force is distributed according to the sinusoidal law. As a result, there is a difference between the established model and the actual running system, and the established system parameters are not consistent with the actual values.

![DFIG power generation system](https://example.com/dfig_diagram.png)

Fig.1  DFIG power generation system

When the system model parameters are inaccurate or change, the performance of the system will decrease or even become unstable. Sliding mode control, as a nonlinear control method, has the characteristics of insensitivity to model parameter errors, external disturbances, and other disturbances and simple design process. It is widely used in motor control [5-6].

There have been many studies on wind turbines operating under unbalanced voltage at home and abroad. Literature [7] proposed a sliding mode control strategy using exponential approach rate, derived the instantaneous power expansion equation, and realized the elimination of active and reactive power double frequency. Literature [8] established a converter model in a synchronous rotating coordinate system, using a feedback linearization sliding mode control method to track the DC bus voltage, and the robustness of the system was enhanced. Literature [9] introduced the fractional-order theory, analyzed the sliding mode surface and sliding mode approach rate, and adopted the...
fractional-order sliding mode control strategy, which effectively suppressed the fan jitter problem. Literature [10] established models of different wind speeds, designed a sliding mode adaptive controller, and realized real-time tracking of the generator rotor angular position, torque, and speed.

Because the vector control technology using proportional-integral relies too much on the system parameters, when the system parameters change, the closed-loop poles of the system will shift, which will lead to a decrease in control performance and even instability[11-12]. To eliminate the adverse effects of system parameters on control performance as much as possible, this paper proposes a resonant sliding mode control method based on a proportional-integral-resonant sliding mode surface. The instantaneous power in the $\alpha\beta$ static coordinate system is used as the state variable of the sliding mode controller. The mathematical model of the doubly-fed wind turbine and the generator-side converter under unbalanced grid voltage, the average active and reactive power output by the doubly-fed motor can be considered as the result of the positive sequence and negative sequence of the doubly-fed motor stator. The instantaneous active and reactive power output by the doubly-fed motor can be expressed as:

$$$egin{align*}
\mathbf{u}_a &= R_i i_a + \frac{d\psi_a}{dt} \\
\mathbf{u}_b &= R_i i_b + \frac{d\psi_b}{dt} \\
\mathbf{u}_c &= R_i i_c + \frac{d\psi_c}{dt}
\end{align*}$$$

The $u_{sa}, u_{sb}, u_{sc}$ are the instantaneous phase of the stator voltage, $u_{ra}, u_{rb}, u_{rc}$ are rotor instantaneous phase voltage, $R_s$ and $R_r$ are the stator and rotor resistance, $\psi_{sa}, \psi_{sb}, \psi_{sc}$ are stator winding of each phase flux.

By means of the transformation matrix from the three-phase static coordinate system to the two-phase static coordinate system, the stator voltage equation in the static coordinate system is:

$$$egin{align*}
U_{sa} &= R_i I_{sa} + \frac{d\psi_{sa}}{dt} \\
U_{sb} &= R_i I_{sb} + \frac{d\psi_{sb}}{dt} \quad (3)
\end{align*}$$$

The rotor voltage equation is:

$$$egin{align*}
U_{ref} &= R_i I_{ref} + \frac{d\psi_{ref}}{dt} - j\omega\psi_{ref} \quad (4)
\end{align*}$$$

$U_{ref} = u_{ref} + j u_{ref}$, the $u_{ref}$, $u_{ref}$ are rotor voltage in the two-phase static coordinate system axis component $\alpha$ and $\beta$, $I_{ref} = i_{ref} + j i_{ref}$, $i_{ref}, i_{ref}$ are the $\alpha$ and $\beta$ axis component of the rotor current in the two-phase static coordinate system. $\psi_{ref} = \psi_{ref} + j \psi_{ref}$, $\psi_{ref}, \psi_{ref}$ are the $\alpha$ and $\beta$ axis components of a rotor flux chain in a two-phase static coordinate system.

The instantaneous active and reactive power equations of the doubly-fed asynchronous wind generator are:

$$$egin{align*}
P_\alpha &= -1.5(u_{ref} i_{sa} + u_{ref} i_{sb}) \\
Q_\alpha &= -1.5(u_{ref} i_{sa} - u_{ref} i_{sb}) \quad (5)
\end{align*}$$$

The control variable of the sliding mode controller is designed with the stator active power and reactive power stable without pulsation as the control objective. The control variable is the reference value of the stator active power and reactive power.

Under the unbalanced grid voltage, the average active and reactive power output by the doubly-fed motor can be considered as the result of the positive sequence fundamental wave voltage $U_{\text{ref}}$, and the stator sinusoidal current $I_{\text{ref}}$, $U_{\text{ref}}$, can be obtained by the "quarter cycle delay" method:

$$$egin{align*}
u_{\text{ref}} &= \frac{1}{2}(u_{\text{ref}} + u_{\text{ref}}) \\
P_\alpha' &= -1.5(u_{\text{ref}} i_{sa} + u_{\text{ref}} i_{sb}) \\
Q_\alpha' &= -1.5(u_{\text{ref}} i_{sa} - u_{\text{ref}} i_{sb}) \quad (7)
\end{align*}$$$

In the formula, $P_\alpha' S$ and $Q_\alpha' S$ are direct current, which is the given value of average active and reactive power. The current reference value under the control target can be solved:

![Fig.2](https://doi.org/10.1051/e3sconf/202123601020)
In order to achieve no static error control, the corresponding integral sliding mode control can only reduce the error to zero under resonant sliding mode control. It shows that the resonant sliding mode control strategy has a very strong ability to suppress the harmonic interference generated by the unbalanced grid voltage [18].

Using the analysis method of the phase plane diagram, the phase plane diagram of the power error of the generator-side converter resonant sliding mode control system under different disturbances $h_t$ can be drawn, as shown in Fig. 4:

$$G_{rs}(s) = 1 + \frac{k_{rs}}{s} + \frac{s k_{rr2}}{s^2 + 2 \omega_1 s + (2 \omega_1)^2}$$  \hspace{1cm}  (11)

Where $G_{rs}(s)$ is the transfer function of the sliding surface of the sliding mode control system of the generator-side converter. $K_{rr}$ is the sliding area coefficient. $K_{rr2}$ and $K_{rr6}$ corresponding to the sliding surface resonance coefficient of double frequency and sixth frequency. $\omega_{1c2}$ and $\omega_{1c6}$ are used to adjust the cut-off frequency of the two-fold and six-fold resonance terms.

Taking the difference between the stator active power and reactive power of the doubly-fed wind generator and its reference value as the control variable of the machine-side resonant sliding mode controller, the relationship between the disturbance difference and the power difference is obtained as:

$$x_{st} = x'_r - x'_t$$  \hspace{1cm}  (12)

$$sG_{rs}(s)x_{st} = -h_t - k_{sat}[G_{rs}(s)x_{st}]$$  \hspace{1cm}  (13)

Using the analysis method of the phase plane diagram, the phase plane diagram of the power error of the generator-side converter resonant sliding mode control system under different disturbances $h_t$ can be drawn, as shown in Fig. 4:

![Fig. 4: Phase plane diagram of the power error under disturbance $h_t$.](https://doi.org/10.1051/e3sconf/202123601020)
When the resonant sliding mode control strategy is adopted, no static error control can be achieved for the direct current and the corresponding frequency of the alternating current [19], as shown in Fig. 5.

### 3 System simulation experiment

The DFIG model parameters established are shown in Table 1.

| Parameters       | Value | Parameters       | Value |
|------------------|-------|------------------|-------|
| Rated power (MW) | 1.5   | Frequency (Hz)   | 50    |
| Stator resistance (Ω) | 0.025 | Rotor resistance (Ω) | 0.013 |
| Mutual inductance (H) | 0.007 | Leakage inductance (H) | 0.002 |

Fig.6 shows the waveform diagram of phase A with a 40% drop in grid voltage, while phases B and C remain unchanged. Fig.7 is the voltage waveform diagram of the DFIG generator-side converter after adopting the resonant sliding mode controller. By comparison, it can be concluded that the sliding mode control strategy can effectively control the wind turbine side converter voltage to accurately change with the change of the grid voltage, and it can achieve no static difference control for both the DC quantity and the corresponding frequency AC quantity.

Fig.8 shows the three-phase current waveform of the stator. Although the grid voltage is unbalanced due to the fault, under the resonant synovial control strategy, the three-phase sinusoid of the stator output current of the wind generator can still be unaffected by the variation of the grid voltage.

Fig.9 shows the active power of the wind turbine generator-side converter, and Fig.10 shows the reactive power of the wind turbine generator-side converter. Since the control variable of the generator-side resonant sliding mode controller is the error between the generator power and its reference value, the control objective is that the stator active power and reactive power are stable and without pulsation. It can be seen from the figure that the final active power is 1.5MW and the reactive power is 0. The results show that the resonant sliding mode control strategy can ensure the effectiveness of the stator active power and reactive power output.

### 4 Conclusion

In this paper, the operation status of doubly-fed wind turbine under unbalanced grid voltage is studied, the mathematical model of doubly-fed wind turbine and its side converter is established, and the corresponding control relation is deduced. The control target is the stator three-phase current sinusoidal balance without harmonics, and the control quantity is the error between the stator active power, reactive power, and reference...
value. The proportional integral resonant sliding mode control strategy is adopted to adjust the side converter of the DFIG machine to realize its smooth grid connection in an unbalanced grid environment.

Through the simulation experiment in SIMULINK, through the grid voltage and the comparison of machine side converter output voltage, and the stator active and reactive power output waveform proved in unbalanced power grid voltage. A control strategy based on the proportional-integral resonant sliding mode controller can accurately control the generator-side converter so that the output power is three-phase sinusoidal balance without distortion.

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