

Retraction

Retracted: Simulation Analysis and Optimization Design of the Variable-Speed Constant-Frequency Doubly Fed Wind Power Generation Control System Based on PSCAD

Wireless Communications and Mobile Computing

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This article has been retracted by Hindawi following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of one or more of the following indicators of systematic manipulation of the publication process:

- (1) Discrepancies in scope
- (2) Discrepancies in the description of the research reported
- (3) Discrepancies between the availability of data and the research described
- (4) Inappropriate citations
- (5) Incoherent, meaningless and/or irrelevant content included in the article
- (6) Peer-review manipulation

The presence of these indicators undermines our confidence in the integrity of the article's content and we cannot, therefore, vouch for its reliability. Please note that this notice is intended solely to alert readers that the content of this article is unreliable. We have not investigated whether authors were aware of or involved in the systematic manipulation of the publication process.

Wiley and Hindawi regrets that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our own Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

References

- [1] J. Zhang, R. Zhang, G. Li, and B. Yang, "Simulation Analysis and Optimization Design of the Variable-Speed Constant-Frequency Doubly Fed Wind Power Generation Control System Based on PSCAD," *Wireless Communications and Mobile Computing*, vol. 2022, Article ID 9133342, 10 pages, 2022.

Research Article

Simulation Analysis and Optimization Design of the Variable-Speed Constant-Frequency Doubly Fed Wind Power Generation Control System Based on PSCAD

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The depletion of nonrenewable energy and climate lead to increasingly bad environment. The efficient development of new energy has become an urgent problem to be solved. As a kind of new energy, how to effectively develop and utilize wind energy has aroused widespread concern all over the world. In this paper, a three-phase static a-b-c coordinate system is used for transformation. Taking the variable-speed constant-frequency doubly fed wind power generation system as the control object, the technology of generator power decoupling control is realized. The rotor side and grid side power converters adopt vector control methods based on stator flux orientation and grid voltage orientation, respectively. In this paper, the motion equation, flux equation, voltage equation, and electromagnetic torque equation of the motor are established. Vector-oriented control technology is used to control the generator. The control model of the VSCF doubly fed wind power generation system is established by using the simulation software PSCAD, and the simulation experiment is carried out. The feasibility of the power decoupling control method based on vector control is verified. The change trend of the active power of the power generation system is consistent with that of the wind speed, which shows that the control system has good stability. Using the field-oriented vector control method, the dual PWM controller can independently control the active power and reactive power. This greatly simplifies the nondecoupling control function equation in the expression. The dual PWM controller is well adjusted to minimize the power loss of the wind power generation system.

1. Introduction

Social progress, economic development, and population growth have brought great pressure on the earth's resources [1]. Most resources, including oil, coal, and natural gas, have a long regeneration cycle and strict requirements for the renewable environment. How to reasonably develop, collect, and utilize resources is a problem faced by countries all over the world in the 21st century [2]. Therefore, it is necessary to find new and renewable energy sources in order to make reasonable planning for conventional energy collection. With the development of science and technology, people have a new understanding of air flow, water flow, and heat energy, which can effectively alleviate the energy shortage of the

earth [3]. As a renewable green energy, wind energy is the first recognized, developed, and utilized energy. Almost every country in the world has this kind of energy, so wind power generation has good development prospects and huge development scale [4]. Many countries attach great importance to and support wind power projects, and wind power technology has become a leader in the development of new energy. Wind power generation can effectively alleviate the problem of power shortage, which has been recognized by many countries. Developed countries are the first to realize the energy problem, and their wind power generation technology research is also in a leading position. Therefore, it is of great practical significance to promote the research on the core technology of wind power in China, strive to

narrow the gap between China's wind power technology, and the world's major power generating countries, and promote the utilization and development of wind power [5].

A constant-speed constant-frequency wind turbine and variable-speed constant-frequency wind turbine are two commonly used types of wind turbines [6]. In order to ensure that the fan is in the maximum power operation state and greatly improve the utilization efficiency of wind energy, the impeller of the variable-speed constant-frequency wind turbine can change with wind speed [7]. A variable-speed constant-frequency doubly fed wind power generation system has attracted extensive attention of researchers since a doubly fed induction generator was introduced into excitation power supply [8]. The control method of the doubly fed wind power generation system restricts the application range of the power generation system [9]. The main research achievement in the 1970s is flux-oriented vector control technology. For the control method of the doubly fed induction motor, the space vector control method was proposed in the 1960s. This method simplifies the mathematical model of the doubly fed induction motor [10]. The vigorous development of power electronic devices promoted the rapid rise of wind power industry in the 1980s [11]. In the 1980s, European scholars put forward the field-oriented control theory of the induction motor. The working principle of the doubly fed machine is analyzed theoretically and simulated experimentally. At the same time, the method of "stator voltage coordinate transformation control of the induction motor" is proposed. Later, through the continuous verification and improvement of practice, the vector control method is commonly used in the research of the doubly fed machine [12]. In the 1990s, the development of microcomputer control technology accelerated the industrialization of doubly fed wind power generation [13].

Since the 1990s, China has carried out the research on the control method of CSVF doubly fed wind power generation. According to relevant industry reports, foreign scientists have developed relevant control methods for doubly fed wind power generation through a large number of experimental analyses and practical operations [14]. The goal of wind power projects in developed countries is gradually changing from basic power supply to optimized power supply [15]. At present, the control method of the VSCF doubly fed wind power generation system in China is still in the primary stage of research and development [16].

2. VSCF Doubly Fed Wind Power Generation System

Wind power generation and power generation are growing all over the world, and wind power generation is becoming the "leader" of the power grid. It can adjust the angle of page features to ensure the power demand. Scientists have recognized the advantages of variable pitch generators. Figure 1 shows the variable-speed constant-frequency doubly fed wind power generation system [17].

The stator and rotor are connected together. The stator can induce the rotor speed of the generator and adjust it accordingly, so as to fix the current frequency and realize



FIGURE 1: Doubly fed wind power generator operation scene.

variable speed and constant frequency. The key to connecting the current directly to the power grid lies in the unique stator mechanism. The generator adopts a doubly fed wind turbine. The principle of power generation is that the rotor cuts off the magnetic field and generates current in the three converters. Figure 2 is the control schematic diagram of the variable-speed constant-frequency doubly fed wind power generation system [18].

Slip power in the generator refers to the flow power in the rotor circuit. The constant-frequency control of the doubly fed generator system is realized through rotor winding. Therefore, the space capacity required by this converter is very small, which is very suitable for the large-scale wind power generation system with the variable-speed constant-frequency doubly fed wind power generation system. The slip power usually accounts for about 1/3 of the rated power of the motor, and the specific value varies with the generator speed [19].

3. Variable-Speed Constant-Frequency Doubly Fed Wind Power Generation System

3.1. Study on the Change of the Mathematical Model of the Doubly Fed Wind Power Generation System. In order to better observe and study and avoid strong equations, it is necessary to use the idea of coordinate transformation to make the relationship of the doubly fed generator become a linear decoupling system. However, in the stator of the doubly fed generator, once the stator and rotor move relatively, the coefficient of operating equation will also change with the change of the included angle between them, which brings great difficulties to the calculation [20]. As shown in Figure 3, the vector in the three-phase stationary coordinate system is replaced by the vector in the two-phase rotating coordinate system. In the network side frequency converter and rotor frequency converter, this idea can be applied to the direction of its control strategy. The mathematical modeling of the motor usually adopts a three-phase static a-b-c coordinate system. In order to realize the complete decoupling of power

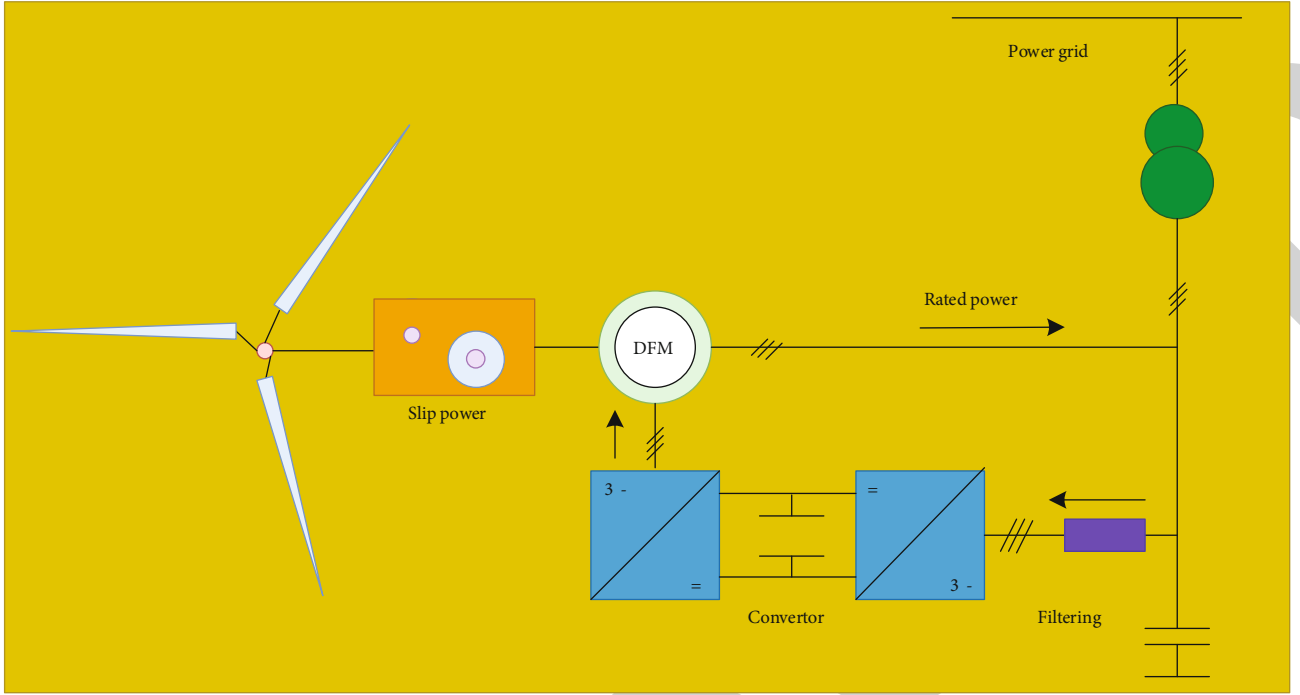


FIGURE 2: The control diagram of the doubly fed wind power generator.

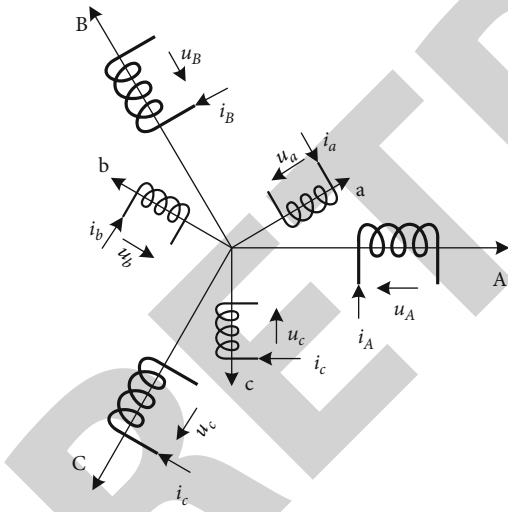


FIGURE 3: Coordinate transformation process diagram.

generation, the AC motor must adopt the same vector-oriented control idea as the DC motor.

The DGIF equation generated in the d - q coordinate system of the two-phase rotating coordinate system has better simplification, observability, and computation than the three-phase stationary coordinate equation. On the one hand, it greatly improves the computational efficiency. On the other hand, it is beneficial to the further research of the doubly fed wind power generation system. The equations include motion, flux linkage, voltage, and electromagnetic torque equations.

The voltage equation of the stator side winding is

$$\begin{cases} u_{sd} = \frac{d\psi_{sd}}{dt} - \omega_n \psi_{sq} - r_s i_{sd}, \\ u_{sq} = \frac{d\psi_{sq}}{dt} - \omega_n \psi_{sd} - r_s i_{sq}. \end{cases} \quad (1)$$

The equation of rotor side winding voltage is

$$\begin{cases} u_{rd} = \frac{d\psi_{rd}}{dt} - \omega_n \psi_{rq} + r_r i_{rd}, \\ u_{rq} = \frac{d\psi_{rq}}{dt} - \omega_n \psi_{rd} + r_r i_{rq}. \end{cases} \quad (2)$$

where the numerical value of d and q axes in the stator represents the subscripts s and the numerical value of d and q axes in the rotor represents the subscripts r . The angular velocity coordinates are expressed as $\omega_s = \omega_n - \omega_r$.

Formulas (3) and (4) are flux equations of the stator and rotor in the two-phase rotating coordinate system. The value is the sum of the inductance of the winding itself and the mutual inductance between the windings.

The stator flux linkage equation is

$$\begin{cases} \psi_{rd} = -L_s i_{sd} + L_m i_{rd}, \\ \psi_{rq} = -L_s i_{sq} + L_m i_{rq}. \end{cases} \quad (3)$$

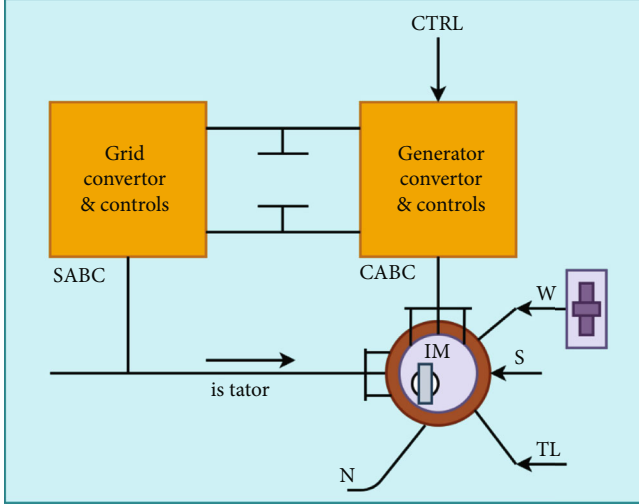


FIGURE 4: Doubly fed induction motor control model.

The rotor flux linkage equation is

$$\begin{cases} \psi_{rd} = -L_r i_{rd} + L_m i_{sd}, \\ \psi_{rq} = -L_r i_{rq} + L_m i_{sq}, \end{cases} \quad (4)$$

where the numerical value of d and q axes in the stator represents the subscripts s and the numerical value of d and q axes in the rotor represents the subscripts r . The mutual inductance between windings in the d - q coordinate system is $L_m = 1.5L_{aa}$. The two-phase stator winding inductance in the d - q coordinate system is $L_s = L_{sr} + 1.5L_{aa}$, and the two-phase rotor winding inductance in the d - q coordinate system is $L_r = L_{rr} + 1.5L_{AA}$.

Through the balance relationship between the mechanical torque and the resulting electromagnetic torque, the generator operating equation under the “ d - q coordinate system” can be calculated as shown in

$$T_t - T_e = \frac{J_g d\omega_m}{P_n} + \frac{D_g}{P_n} \omega_r + \frac{K_g}{P_n} \theta_r, \quad (5)$$

where the pulling torque given by the wind turbine is expressed as T_t , the generator inertia is expressed as J_g , the resistance torque damping coefficient of the generator is expressed as D_g , and the torsional elastic torque coefficient is expressed as K_g .

The electromagnetic torque equation is

$$T_e = P_n (\psi_{sq} i_{sd} - \psi_{sd} i_{sq}) = P_n L_m (i_{sd} i_{rq} - i_{sq} i_{rd}), \quad (6)$$

where the generator electromagnetic torque is expressed as T_e .

3.2. Vector Control of the Dual-PWM Converter for the Doubly Fed Induction Generator. Wound rotor winding is the characteristic of the doubly fed induction motor. Its high power factor and wide speed regulation range also make this

motor do not need any external power supply equipment in operation. The output and input of power can be generated simultaneously by the rotor and stator windings. The mechanical speed of the motor can be set in a large range and has a good power factor. Each module and its internal structure are very complex. The whole control model of the wind turbine only needs to connect the module with external cables. Vector control is the most widely used control strategy in the converter of the feed wind power generation system. The modeling of the doubly fed induction motor in PSCAD software is shown in Figure 4. The main body of the model is composed of packaging modules. The modeling module mainly includes the establishment of a generator control model, wind turbine control model, rotor side converter control model, and grid side converter control model.

The stability and reliability of the wind turbine system are directly controlled by the power converter. The power converter is the connection between the generator and the power grid. It also generates current conversion to the wind turbine. It is critical to ensure that the output current is the same as the grid current. Whether the power converter is normal or not is related to the safety of the whole motor and power grid. Therefore, it is very important to improve the stability of the power converter in wind power generation design and motor control strategy. How to realize decoupling control by adjusting the power of the doubly fed generator system is the purpose and reason of the doubly fed generator converter.

At present, most power generation systems use two-stage back-to-back power converters to control doubly fed wind turbines. The converter has self-control capability. However, since there are only two levels on the DC side, the power converter itself and the motor need to be affected by high voltage stress. In the two-stage back-to-back power converter, reactors and filters are installed at both ends, which can effectively reduce the voltage harmonic interference to the power grid. The converter is composed of a rotor side converter and grid side converter.

3.2.1. Control Method of the Rotor Side PWM Converter. A vector control method, direct power control method, and direct torque control method are the three main methods of the generator control strategy. Vector control technology is the first of the three technologies. The vector control method is most used in stator voltage orientation and qualitative analysis of flux linkage. So far, the core system of this technology has been relatively perfect. Although the other two control methods appeared later, they have great advantages over the vector control method.

The necessary vector control technology of the grid side converter and rotor side converter in the doubly fed wind turbine can realize the perfect control of the whole power generation system. In the modeling process, the stator resistance is too small to be ignored. The flux direction of the stator is the same as that of the d axis. The axis of axis q is the voltage direction at the end of the stator, and the angle between axis D and axis q is 90° . In this coordinate system, the mathematical model of the doubly fed induction

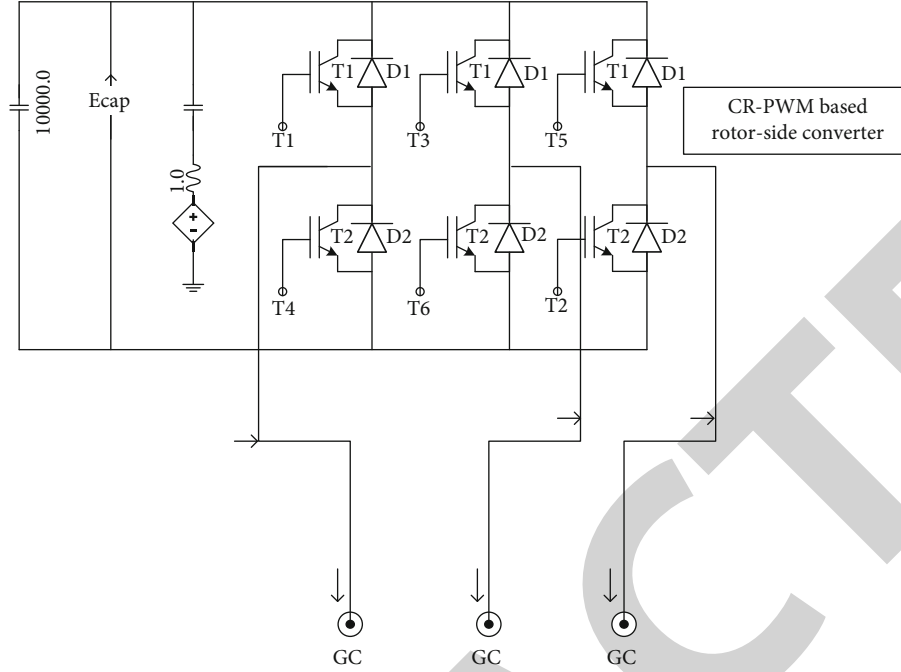


FIGURE 5: Current type PWM inverter and its rotor current controller.

generator is established, and the electronic voltage flux linkage equation is simplified.

$$\begin{cases} P_s = \frac{3}{2} u_{sq} i_{sq} = -\frac{3}{2} u_s \frac{L_m}{L_s} i_{rq}, \\ Q_s = \frac{3}{2} u_{sq} i_{sd} = \frac{3u_s}{2L_s} (\psi_s - L_m i_{rd}). \end{cases} \quad (7)$$

Formula (7) is the vector equation of the rotor side converter under the mathematical model in the d - p coordinate system. It can be concluded that when the stator flux linkage output of the motor is stable, the useful power is determined by the rotor current value on the d axis, and the generated reactive power is determined by the rotor current value on the q axis. Therefore, the rotor stator power ratio is adjusted by the different components of the rotor on the d axis and the p axis, and the control strategy of the rotor AC generator is realized.

In the above formula, i_{rq} represents the component of the rotor torque current and i_{rd} represents the component of the rotor torque flux linkage. These two values are obtained when the stator is not working and the rotor speed is in the maximum. When the maximum power is tracked, the wind speed can be represented by the rotor angular velocity w_r , and the specific value is displayed by the controller. The power reference value P_{ref} is determined by the maximum tracking wind power and the motion state of the motor. Through static power flow calculation, the reference value of reactive power Q_{ref} can be obtained. Generally speaking, the reactive power of the stator is 0 in the control strategy, that is, $Q_{ref} = 0$. When the value is determined to be 0, the power factor is determined to be 1.

Direct axis current i_d and q axis current i_q constitute the amount of current generated in the rotor VSCF doubly fed generator system. The air gap flux generated by d axis component i_d has the same angle with air gap flux of stator rotation. The magnetic flux vector produced by the q shaft component i_q is at right angles to the stator rotating flux vector. The electromagnetic torque of a motor is the product of the two magnetic flux phases. Therefore, only when the precise control of i_d and i_q is achieved can the perfect control of the active component and reactive component indirectly be realized.

In solving the i_d and i_q values of the rotor, the current reference values i_{ra-ref} , i_{rb-ref} , and i_{re-ref} in the three-phase stationary phase should be input into the rotor in turn. At this point, the current type PWM current source is needed. According to Lenz's law and the vector of the rotor in the two-phase rotating coordinate system, the power factor (conversion rate minus its impedance) can be listed.

$$v_a - i_a R_a = \frac{d\lambda_a}{dt}. \quad (8)$$

The magnetic flux Clark component of the stator is converted to a polar coordinate system, for which the expression is as follows.

$$\begin{aligned} |\lambda| &= \sqrt{\lambda_\alpha^2 + \lambda_\beta^2}, \\ \phi_s &= \tan^{-1} \left(\frac{\lambda_\beta}{\lambda_\alpha} \right). \end{aligned} \quad (9)$$

ϕ_s gives the instantaneous position of the rotating

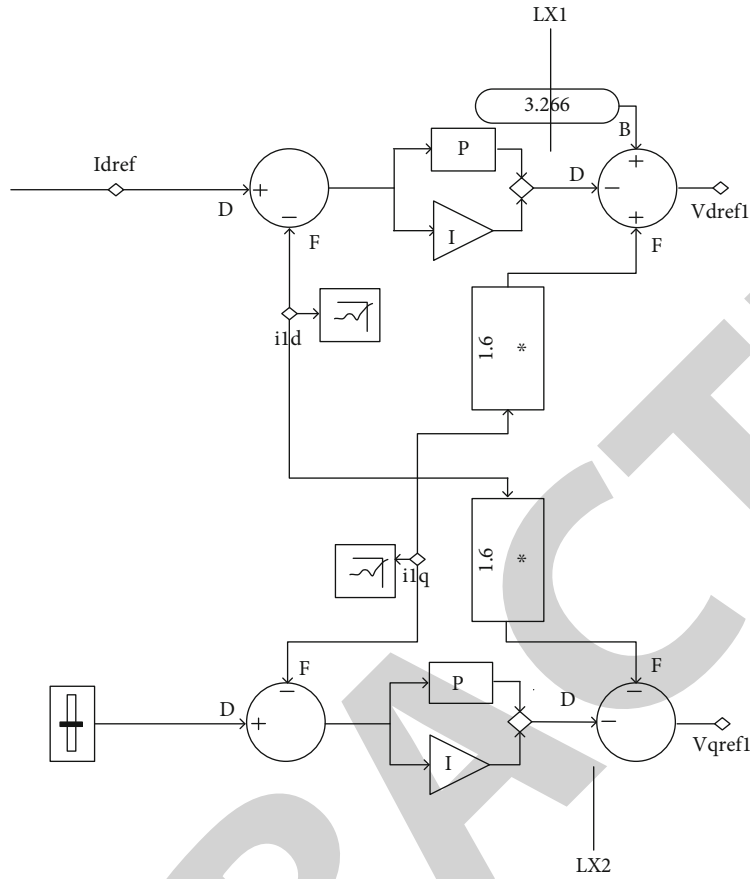


FIGURE 6: Decoupling controller.

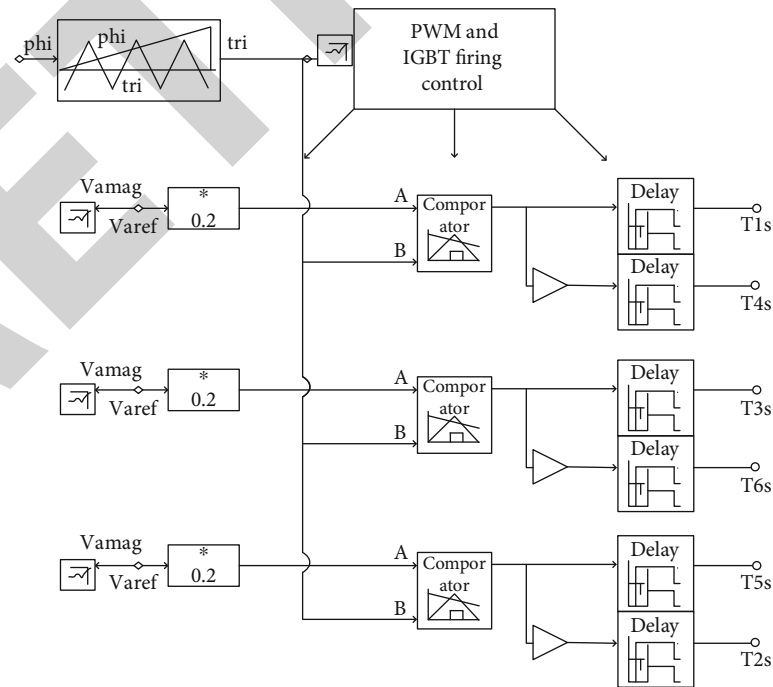


FIGURE 7: SPWM pulse generator.

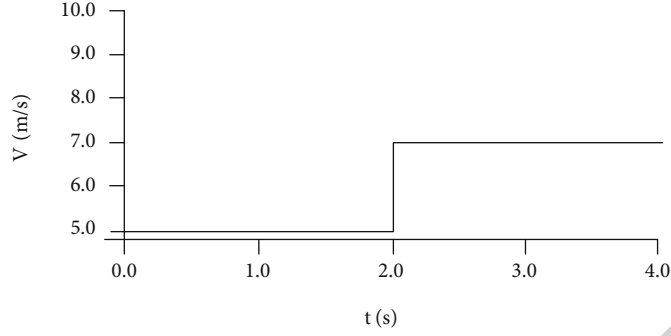


FIGURE 8: The wind speed model.

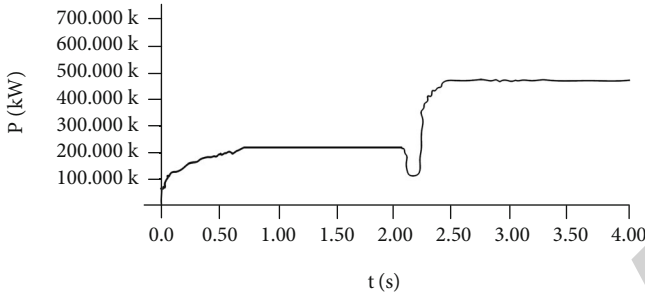


FIGURE 9: Active power of the doubly fed wind power generator.

magnetic field of the stator. In the actual control circuit, the filter connector is usually used to reduce or eliminate the residual DC component, which has an impact on λ_α and λ_β . The rotor is in a rotating state, and the instantaneous position is always at an angle. Therefore, in a coordinate system developed by the rotor, $\phi_s - \phi_r$ represents the angle of the stator magnetic flux, which is called “slip angle” ϕ_{slip} here.

As shown in Figure 5, according to the solution of ϕ_{slip} , the DP transform is used to solve the current generated by the rotor in motion. After the current is determined, the current source PWM is adjusted by the frequency conversion technique.

3.2.2. Control Method of the Grid Side PWM Converter. The voltage stable output of the DC bus is maintained by the grid side converter, and the sensitivity of the whole wind power generation system is also adjusted by the output power of the grid side converter. In the power generation system, the adjustment of stator output power and the capture of maximum wind energy depend on the change of the rotor excitation state of the dual-PWM converter. For the current generation system, the main control method of the grid side converter is the vector control of the output voltage direction. The purpose of the control strategy can be achieved by adjusting the grid voltage, which has the characteristics of fast response and stable operation. It can be seen that the normal operation and proper adjustment of the grid side converter play a vital role and significance for the whole wind power generation system.

In addition, a capacitor is required to eliminate ripple. The normal operation of the rotor side converter depends on the normal operation of the network side rectifier and is regulated by the rectifier. The network side PWM also ensures the voltage stability in the main flow area. The VSC converter on the rotor side also needs the support of DC power supply. The current source is usually replaced by a voltage sensitive rectifier located on the converter inside the winding.

For the above PWM current source, the biggest problem is that it is impossible to predict the reactive power and switching frequency of the power supply. The output power of PWM is adjusted according to the actual output change of PWM. The switching frequency of PWM can be determined according to the number of switches in the determination cycle. The method of controlling the current of the rotor side converter by induced power can also be applied to the grid side rectifier. Therefore, a feedback regulator is used in the experiment, and a feedback controller is connected to the current source.

In the experiment, we need to observe the values of i_q and i_d . But because the controller is added, the current source PWM will affect the current display of the d axis and the q axis at the output current. When the controller works, the output current of the current source PWM is always controlled due to the feedback effect, so that the decoupling relation between i_q and i_d is formed, which leads to the error of data reading. So we need to make further adjustments to the controller.

In the experiment, the reactance of the rectifier is L and the resistance is R . The rectifier is fixed on the DC bus network with voltage. Its expression is shown in

$$\frac{d}{dt} \begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} -\frac{R}{L}\omega \\ -\omega - \frac{R}{L} \end{bmatrix} \begin{bmatrix} i_d \\ i_q \end{bmatrix} + \frac{1}{L} \begin{bmatrix} v_d - e_d \\ -e_q \end{bmatrix} = \begin{bmatrix} -\frac{R}{L} & 0 \\ 0 & -\frac{R}{L} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix},$$

$$x_1 = \frac{v_d - e_d}{L} + \omega i_q, x_2 = -\frac{e_q}{L} - \omega i_d,$$

$$e_d = -Lx_1 + v_d + \omega Li_d, e_q = -Lx_2 - \omega Li_q, \quad (10)$$

where there is $v = v_d$, and its value is the magnitude of

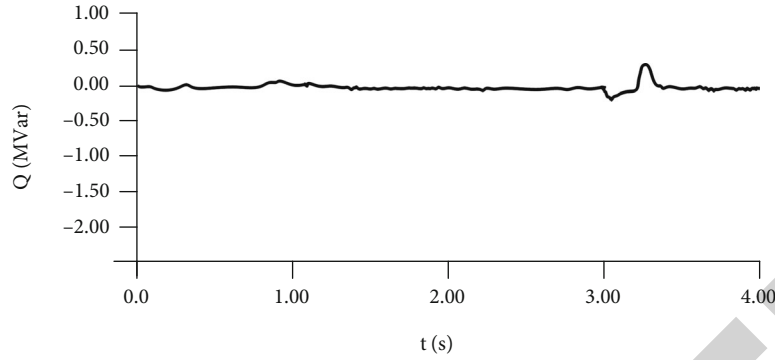


FIGURE 10: Reactive power output of the doubly fed wind power generator.

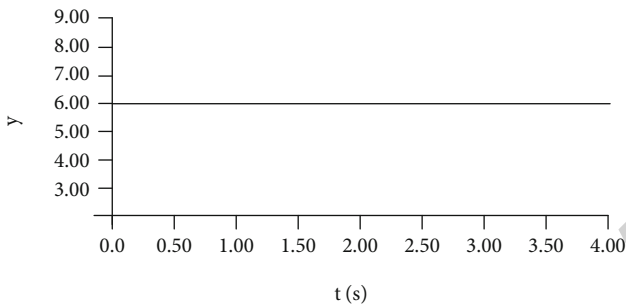


FIGURE 11: The wind speed model.

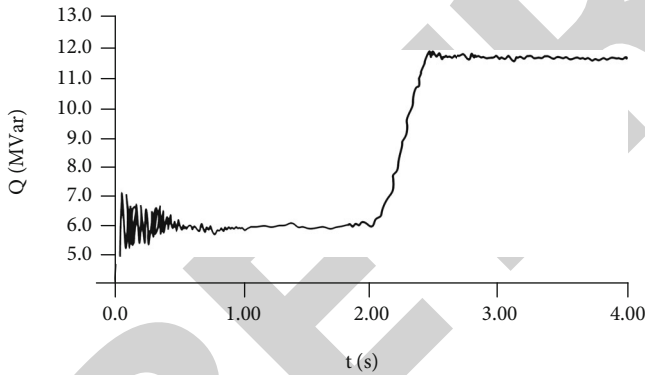


FIGURE 12: Reactive power output of the doubly fed wind power generator.

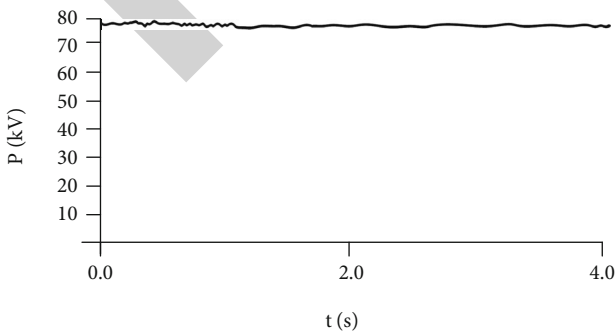


FIGURE 13: Reactive power output of the doubly fed wind power generator.

AC grid voltage. The reference value is based on the voltage, and the voltage of the q axis is 0. The VSC components of the voltage generated in the d and q axis are e_d and e_q , respectively. It can be seen from formula (10) that i_d and i_q are nondecoupling relations, and one of the numerical changes can inevitably lead to another numerical fluctuation. We also list L_{x1} and L_{x2} to show the amount of current variation. In the feedback mediation, the change of i_d is expressed by L_{x1} , and the change of i_q is expressed by L_{x2} . The model is shown in Figure 6.

A constant DC voltage can be used when the $idref$ value of the network side rectifier is solved. A pulse device that changes the output value of the rectifier is also needed. The effect is that when the reference voltages $vdref1$ and $vqref1$ (reference voltage, Figure 6) change, $idref$ and $iqref$ will change accordingly. Figure 7 shows a standard sinusoidal PWM controller. In the controller, the trigger voltage is determined by comparing the reference voltage of each phase with that of a high-frequency triangle wave.

If the change of one value has no obvious effect on the other value, it is considered that they have decoupling correlation to achieve the control goal. Under the condition that other values remain unchanged, observe whether the change of reactive power will affect the active power. On the contrary, observe whether the change of active power will affect reactive power. In the process of establishing the control model of this part, the control variable method is used to control the variables of useful power and reactive power.

4. Power Generation Decoupling Control Simulation of the Doubly Fed Wind Power Generation System Based on PSCAD

4.1. *The Reactive Power Setting Value Remains Unchanged to Control the Change of Active Power.* The change trend of active power of the power generation system is consistent with that of wind speed, which shows that the control system has good stability. In addition, it can be considered that changing the active power of the motor only needs to change the wind speed. It can be clearly seen from Figure 8 that the initial wind speed remains stable at 5 m/s, then jumps to 7 m/s after 2 s, and remains stable at 7 m/s after 2 s.

The wind speed jumps. When the wind speed increases from 5 m/s to 7 m/s, the rotor speed increases with the increase in acceleration. The active power first decreases and then increases within 2 s~2.5 s, and the active power stability point is about 460 kW after 2.5 s. Figure 9 shows the power waveform. It can be seen from Figure 8 that when the wind speed is between 5 m/s in 0 s~2 s; the active power of this section is stable at about 210 kW.

Figure 10 shows that from 0 s to 2 s, the reactive power is almost the same as the initial value. When the wind speed changes, the active power changes significantly. There is only slight jitter at 2 s; that is, the wind speed increases from 5 m/s to 7 m/s, but after the rotor speed is stable, the reactive power does not change with the increase in wind force. Figure 10 shows the reactive power waveform.

4.2. Control Reactive Power Change and Unchanged Active Power Setting Value. Experiments show that the wind speed directly controls the change trend of active power. Therefore, when the wind speed is constant, the active power is in a stable state. The basic wind speed is 6 m/s, and the waveform of constant wind speed is shown in Figure 11.

According to the reactive power output of the motor, the curve is shown in Figure 12. In the initial state, the reactive power is 6 MVar, and the jump power increases to 12 MVar after 2 s.

Figure 12 shows that the reactive power between 0 s and 2 s is maintained at about 6 MVar, and only small fluctuations occur. The reactive power increases with jitter at 2 s, then increases to 12 MVar in a short time, and finally tends to be stable. The active power has only slight jitter at the beginning, so it can be considered that the active power is not affected by the change of reactive power. Figure 13 shows the active power waveform.

The simulation results of the power control model show that the dual-PWM controller can independently control the active power and reactive power by using the field-oriented vector control method. This greatly simplifies the nondecoupling control function equation in the expression. The dual-PWM controller is well adjusted, and the power loss of the wind power generation system is reduced to the greatest extent.

5. Conclusions

- (1) In this paper, the most widely used variable-speed constant-frequency doubly fed wind power generation system in the market is taken as the research object. Aiming at the energy utilization of wind power generation, the vector control method is used to decouple the motor power, and the mathematical model of the three-phase static coordinate system of the doubly fed machine is transformed into the flux linkage equation, voltage equation, and motion equation of the two-phase rotating $d-q$ system. Therefore, the vector control model of the rotor side and grid side power converter is established to realize the decoupling of active power and reactive power

- (2) The control model of the converter is established by PSCAD software, and the single change of active power and reactive power is simulated, respectively. The simulation results show that the proposed control model successfully realizes the independent regulation of active power and reactive power, and the proposed dual-PWM control method can solve the power coupling problem of the doubly fed wind power generation system

Data Availability

The figures used to support the findings of this study are included in the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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