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Research Article

Double-Fed Wind Power System Adaptive Sensing Control and Condition Monitoring

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This paper presents an in-depth study and analysis of improving the performance of doubly fed wind power systems using adaptive sensing control technology. The maximum wind energy tracking principle is analyzed in this paper with the wind turbine operation characteristics. Considering that the operation state and control strategy of a doubly fed wind power generation system is different before and after grid connection, the no-load simulation model and power generation simulation model are established based on the idea of separate modeling and time-sharing work. Combined with the respective control strategies and enabling modules, the overall simulation system is constituted for the continuous process from no-load operation to power generation operation. To analyze the chaotic mechanism of ferromagnetic resonance of wind farm power system and suppress the problem, based on the ferromagnetic resonance model of wind farm power system, analyze the basic conditions of the system into the chaotic state, consider the resonance phenomenon when external excitation acts, adopt the multiscale method to calculate the approximate solution at the resonance of main parameters and determine the steady-state solution and stability conditions, and explore the influence of external excitation on the dynamic characteristics of ferromagnetic resonance. In this paper, the inverse system approach, applied to the linearized decoupling of doubly fed wind power, a nonlinear, strongly coupled multivariable system, is derived for the no-load inverse system model and the inverse system model for the power control scheme and the speed control scheme to achieve maximum wind energy tracking for grid-connected power generation, respectively. The model further extended to fractional order to study the complex dynamical behavior of the system of different orders and flux chain subsquares. To suppress the system chaotic oscillation phenomenon, a fractional-order finite-time terminal sliding mode controller is proposed based on the frequency distribution model with time-frequency domain conversion, which achieves the suppression of chaotic phenomena in resonant overvoltage infinite time and is compared with the conventional sliding mode to confirm the effectiveness and superiority of the proposed controller. This paper explores and discusses the impact of adaptive sensing control technology on the practice of doubly fed wind power systems, to provide theoretical possibilities for the adaptive sensing control technology to be more effective for the practice of doubly fed wind power systems.

1. Introduction

Energy is the material basis for human survival and the driving force for social development and progress, and since the industrial revolution, global energy consumption has grown rapidly, rapidly promoting the process of world industrialization and improving the level of social development and the quality of human life. However, the reserves of nonrenewable resources such as oil, coal, and natural gas, which are the main pillars of world energy, are very limited. The rapid growth of the global economy has led to increasing demand for energy, making the energy crisis an obstacle to further human development [1]. The main advantage is that the speed can be adjusted in a wide range to keep the wind energy utilization coefficient at the best value; it can absorb and store the gust energy, reduce the fatigue damage, mechanical stress, and torque pulsation caused by the gust impact on the wind turbine, extend the life of the unit, and reduce low noise; it can also control active power and reactive power to improve power quality. With the traditional energy shortage and environmental pollution problems aggravated, vigorously developing wind energy, solar energy, tidal energy, and other renewable energy has become an inevitable choice. In many renewable energy sources, wind energy is the most promising. In the past decades, the total installed capacity of wind power generation worldwide has grown tremendously, from only 3.5 GW in 1994 to 539.6 GW in 2017, an increase of more than one hundred times. It can be said that, by far, wind power is one of the largest developed, fastest-growing, and most technologically mature forms of renewable energy generation [2]. Wind energy is a renewable and clean energy source, and a wind power generation is an important form of wind energy utilization, by using wind turbines to obtain energy from the wind, converting wind energy into mechanical energy, and then using generators to convert mechanical energy into electrical energy suitable for long-distance transmission. All the pulses received during the sampling period are taken; whether the number of received pulses is greater than the set threshold number was determined; if the number of pulses is greater than the set threshold number, the sum of the number of pulses and the time interval between the received pulses is corrected. According to the number of corrected pulses and the sum of the time intervals between the received pulses, the motor speed is determined. Due to the randomness, variability, and uncontrollability of wind speed, to obtain the maximum wind energy, the rotational speed of the wind turbine often varies with the wind speed. The use of variable speed and constant frequency doubly fed wind power generation technology allows for a constant output frequency with varying generator speeds.

In today's wind power generation field, variable speed constant frequency technology with AC excitation has been commonly adopted. Compared with the traditional constant speed and constant frequency technology, the variable speed and constant frequency wind turbine have the advantages of wide operating range, high wind energy conversion efficiency, smooth output power, and low mechanical stress [3]. The addition of vector control, in turn, allows the stator output active and reactive power of the doubly fed motor to be decoupled and controlled, improving the flexibility and stability of the whole system. In the vector control-based doubly fed motor control system, the rotor speed and position information are the key to the decoupling and stable operation of the whole control system [4]. At present, most of the doubly fed units at home and abroad perform speed detection directly by installing speed sensors such as photoelectric encoders. But the speed encoder also brings the disadvantages of increasing system cost and reducing system reliability at the same time. Therefore, a lot of research has been conducted on the control technology of adaptive sensors, and the control technology of adaptive sensors will be a development direction for future wind turbines.

Focusing on the dynamic characteristics and control methods of wind power systems and grid-connected power systems in the form of mechanical, electrical, and magnetic oscillations, revealing their influence mechanisms and change laws, and designing fast and effective suppression methods will help to improve the stability of wind power systems and grid-connected power networks [5]. Due to the nonlocal and weak singularity of fractional-order calculus operators, the control theory of fractional-order power systems is more complex than the control theory of integer-order power systems, and how to control the system to quickly stabilize and obtain good control performance when the system is uncertain and external disturbances is a difficult research point in control theory and engineering applications. Therefore, for the dynamical models in integer-order and fractional-order wind power systems, how to quickly and effectively control complex oscillation phenomena, new control methods need to be explored to improve the robustness and dynamic response performance of the system, determine the parameter control range and elimination path, provide the more and more informative theoretical basis for wind power system nonlinear control design schemes, and also provide stability analysis of wind power systems and grid-connected power systems, theoretical basis, and technical reserve.

2. Current Status of Research

A wind power system is a typical nonlinear time-varying dynamic system, and the two common horizontal axis permanent magnet synchronous wind power systems mainly include a wind turbine, drive shaft system (direct drive and semidirect drive), permanent magnet synchronous generator, converter, and grid-connected power system [6]. Semidirect-drive wind turbines add a single-stage gearbox to the drive shaft system, which has the characteristics of the small size of permanent magnet synchronous generator, large converter capacity, and good economy, etc. It has attracted much attention. Ltd. has independently developed China's largest (7.6 MW) offshore semidirect-drive permanent magnet synchronous wind turbine, and the technology level is in the international leading position. According to the national "new energy industry revitalization plan" draft, the cumulative installed capacity of China's wind power will reach to in the year and will be proposed in six provinces and regions to build nearly ten 10,000 MW wind power base planning, respectively, Xinjiang Hami, Gansu Jaquan, coastal and northern Hebei, western Jilin, coastal Jiangsu, Mending, and Mengzi. According to the plan, the year will be completed, accounting for about the total installed capacity of the country [7]. The doubly fed induction generator is an important part of a wind power generator. To design a high-quality wind power system, it is necessary to determine the best control method. This paper takes the vector control technology as the core and takes the wind turbine unit combining the doubly fed induction generator and the AC-DC-AC dual PWM excitation converter as the research object and conducts the theoretical analysis and simulation analysis of the system. By the end of the year, the country's cumulative grid-connected capacity wind power grid-connected capacity accounted for about the total installed capacity of the national power supply, an increase of about over the year. China's wind power market is beginning to enter a period of steady development after years of rapid growth and continues to maintain its position as the world's largest wind power market.

Doubly fed generators have become the mainstream models of variable speed and constant frequency wind power generation systems because of their superior operational performance and outstanding advantages. Compared with the permanent magnet synchronous generator wind power generation, the structure of the doubly fed wind power generation system is more complex, and the decoupling control strategy of the doubly fed power generation system through rotor AC excitation has been the focus of research by scholars at home and abroad. At present, the control of doubly fed wind power generation systems mainly include vector control, direct torque control, and nonlinear control. The industrial doubly fed induction generators usually use the traditional vector control method [8]. The basic idea of vector control, which is currently the dominant control strategy for doubly fed wind power systems, is to control the rotor current in a synchronous rotating coordinate system and to ensure that the chosen vector coincides with the horizontal axis of the coordinate system. In asynchronous motor vector control, the rotor magnetic chain orientation is usually used, and synchronous motor vector control takes the air-gap synthetic magnetic chain orientation. According to the principle of vector control, the system designed with the concept of master-slave control and cross-coupling basically solves the problem of power imbalance, but its power balance accuracy and dynamic performance are not good. To improve the power balance accuracy and improve the dynamic performance, the "differential moment feedback" link is added. In the DFIG vector control technique, the stator voltage vector and the stator magnetic chain vector are usually chosen as the orientation vectors. To achieve the goal of controlling the motor speed and reactive power, a power winding magnetic chain-directed vector control strategy without cross compensation is proposed in the literature. The literature proposes a vector control-based negative sequence compensation strategy for the excitation current with only one current loop, which can effectively suppress the pulsations of torque, power, and DC bus voltage without setting a specified target and can even minimize the current imbalance. The literature incorporates the design of a sliding mode variable structure controller based on the power winding magnetic chain directional vector control, which integrates the effect of rotor magnetic chain on electromagnetic torque and improves the accuracy of motor speed control [9].

Because of the abovementioned drawbacks and shortcomings of vector control, it is necessary to realize the fully decoupled control of active and reactive power from the nonlinear nature of a doubly fed wind power generation system to improve its static and dynamic performances. In recent years, many scholars have introduced new control strategies for the integrated control of doubly fed power generation systems. The internal mode control is a new control strategy based on the mathematical model of the controlled object, which is proved to have the advantages of simple structure, direct and clear parameter adjustment, and high robustness. In the literature, internal mode control is used to replace the general control, and a mathematical model of the doubly fed motor is established using the function, and the internal model control method is used to design the current inner loop and speed outer loop. The internal mode control reduces the requirement for system model accuracy, and the simulation results show that the control system has good steady-state performance and dynamic response speed [10].

3. Performance Testing of a Doubly Fed Wind Power System with Adaptive Sensing Control Technology

3.1. Adaptive Sensing Control System Design. Industrially, doubly fed induction generators usually use a conventional vector control method. This method is based on the principle of vector orientation and decouples the three-phase model of the doubly fed motor into two decoupled subsystems corresponding to reactive power/magnetic flux and active power/torque through a coordinate transformation from a three-phase stationary coordinate system to a two-phase rotating coordinate system and decouples the inter-system coupling relationship through a compensation term, so that the reactive power/magnetic flux and active power/torque of the doubly fed motor are, respectively, subject to only the decoupled DC voltage flux control, making its performance equivalent to that of a DC generator. Two frequently used vector control methods are stator chain-oriented vector control based on the stator and grid voltage-oriented vector control based on the grid voltage [11]. Whether stator magnet chain oriented or stator voltage oriented is used, vector control uses a double-loop control structure. Dual-loop control generally refers to power outer-loop control and current innerloop control. The doubly fed asynchronous generator we usually talk about is essentially a wound rotor motor. Since its stator and rotor can feed power to the grid, it is called doubly fed motor for short. Although the doubly fed motor belongs to the category of asynchronous motor, it can apply excitation and adjust the power factor like a synchronous motor because it has an independent excitation winding. Among them, the current innerloop control link includes PI controller and compensation term, which is responsible for decoupling between active and reactive control; the power outerloop control link is PI controller, which is responsible for generating the reference value of rotor innerloop current. For the control of the rotor-side converter, two control schemes are generally used: vector control based on stator magnetic chain oriented SFO or vector control based on stator voltage oriented SVO. The two vector control schemes have almost the same effect on the control of active and reactive power. The following will be an example of the vector control method under stator chain orientation. In this case, it is possible to control the active power part/rotor speed/electromagnetic torque of a doubly fed induction generator by controlling only the q-axis component of the rotor current and the reactive power part by controlling only the d-axis component of the rotor current.

$$P_2 + P_m = p_1 - (p_{u1} + p_{u2}). \quad (1)$$

The analysis above in this chapter, for an invertible system, can be derived to form a pseudolinear composite system with its order inverse system and the original system. However, the presence of nonlinear modeling errors and the parameter drift of the system in operation make the pseudolinear composite system not an ideal linear system, so it is necessary to design the pseudolinear system using an additional controller. The internal model control, a control strategy based on the mathematical model of the object, has the characteristics of simple design and the ability to consider the closed-loop performance and robustness compared with the traditional feedback control. If the pseudolinear composite system is formed by the inverse system of order and the original system is taken as the control object, the theoretical linearized transfer function describing the input-output relationship of the composite system corresponds to the internal model in the internal model control, and based on this idea, the internal mode control is adopted in this chapter to control the design of the above pseudolinear system [12], as shown in Figure 1.

As an important part of the wind power system, the wind turbine extracts energy from the wind and then converts it into mechanical energy to drive the wind turbine. The relationship curve between the active power of a wind turbine and its rotational speed at different wind speeds when the pitch angle β is zero. For each wind speed, the maximum power point corresponds to only one value of the wind turbine speed. The doubly fed wind turbine, as a variable speed and constant frequency wind turbine, can be operated by adjusting the rotor speed when the wind speed changes, which in turn allows the wind turbine to operate at the peak of the corresponding power curve [13]. The theoretical curve for the maximum power that a wind turbine can extract from the wind is a power-of-three function concerning the wind turbine speed, Pop = Koptω3t. The expression for the maximum electromagnetic torque is like this equation, except that it is a square function concerning the wind turbine speed. If the wind speed is below the rated value, the wind turbine operates in the variable speed mode where its rotational speed is adjusted by the doubly fed generator speed control or active power control so that Cp is maintained at the Coma point. In this mode of operation, the wind turbine pitch angle control is deactivated, when the pitch angle β is fixed. However, if the wind speed when exceeds the rated value, the pitch angle control is activated to increase the pitch angle of the wind turbine, thus reducing the mechanical energy extracted from the wind. This is shown in Figure 2.

The parameters of the proportional-integral controller used in vector control are designed based on a linearized model of the system at some stable operating point, which makes it heavily dependent on an accurate model of the system. The physical mechanical failure of IPM is largely related to the design quality defects of the device itself, from the reliability design of the device itself, the body structural design, and the internal structure layout design, comprehensive rectification, starting from the quality improvement of the device itself, to improve the quality of the device comprehensively and systematically. However, because the exact model of the system is often impossible to obtain in practice, vector control generally does not allow the system to be controlled optimally when the system is shifted from the equilibrium point [14]. The so-called equilibrium point is the state in which the turbine can operate stably, which generally refers to the rated operating state. In the system operation, due to the fluctuation of output caused by the change of wind speed and the change of grid operation status caused by the change of load, the operation points of doubly fed wind power system is constantly changing, so the vector controller designed based on a certain operation point cannot play its optimal control effect at other operation points. In recent decades, some nonlinear control methods have also been applied to the control of many power system devices, and the most representative control method is the feedback linearization method. The feedback linearization method can achieve the optimal control under the working point offset because it is a global linearization of the system model. However, its disadvantage is that it also relies on an exact model of the system and therefore lacks robustness to changes in parameters. In individual applications, the controller requires the use of many state variables that are difficult to obtain accurately in real systems, let us say in mechanical systems.

$$\frac{\left(T_s + xL_m^3/L_s^2\right)}{(3\mathrm{H}_m)}. \quad (2)$$

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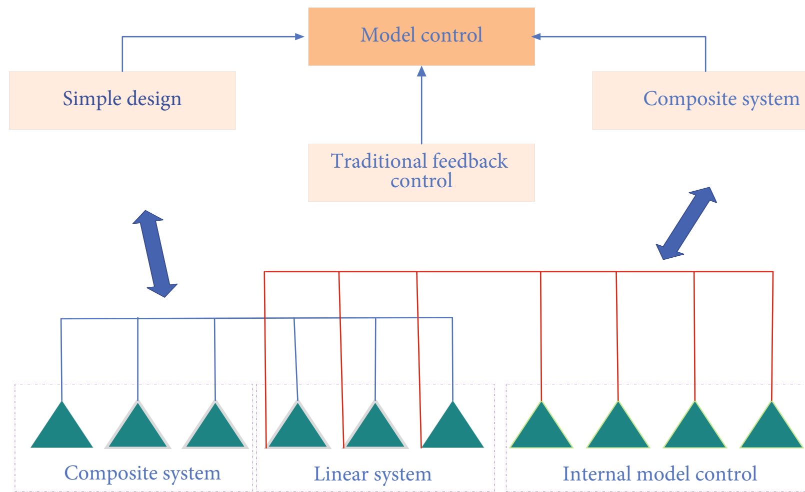

Figure 1: Control structure of internal mode of two-port structure.

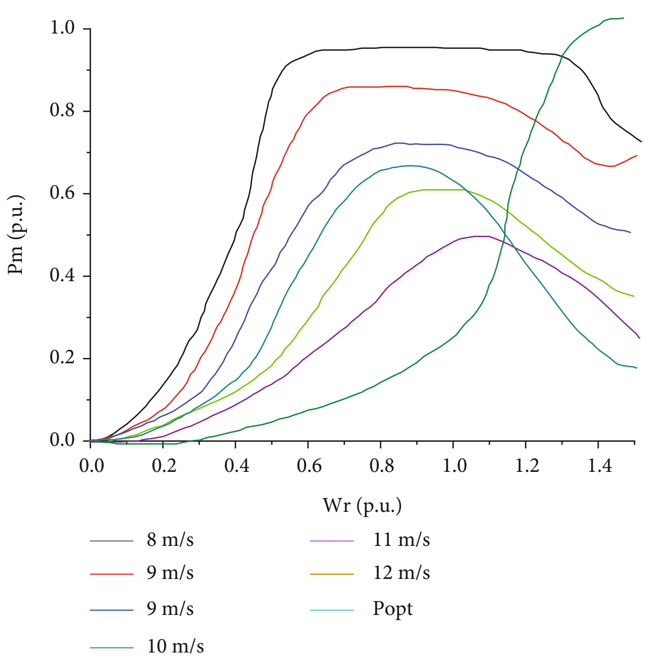

Figure 2: The relationship curve between the active power of wind turbine and its speed at different wind speeds.

design, whereas the feedback linearization method based on differential geometry is used in the current inner loop control, which ensures the responsiveness of the current inner loop controller.

3.2. Performance Testing of Doubly Fed Wind Power Systems. The name "doubly fed" is derived from the fact that both the stator and rotor of the generator can feed electricity to the grid separately. The DFIG has a rotor excitation winding and, due to its constructional advantages, offers the advantages of both synchronous and asynchronous generators. Synchronous generators are often used, but the excitation system of synchronous generators uses a DC power supply, and the excitation system can only control the amplitude of the excitation current. The DFIG excitation system uses an AC excitation power supply, which can control the frequency, amplitude, and phase of its current. The total positive electrode of the lithium battery pack is connected in series with the contactor, and the inverter and the shunt are connected to the total negative electrode of the lithium battery pack. The invention has a novel structure and a clever design; the overcurrent signal latch and reset circuit are used to memorize the overcurrent protection signal; avoiding frequent switching of the contactor can extend the life of the contactor and reduce the impact on other power devices. When the DFIG rotational speed changes, the frequency of the AC excitation power supply can be adjusted to achieve variable speed and constant frequency power generation; when the DFIG power angle needs to be changed, the phase of the AC excitation power supply output current can be controlled to produce a certain amount of displacement of the generator rotor magnetic field to ensure that the phase angle between the DFIG output voltage and the grid voltage is corrected; changing the amplitude of the AC excitation current can adjust. The magnitude of the DFIG output active power can be adjusted by changing the amplitude of the AC excitation current. By using vector control technology, the amplitude and phase of the AC excitation current in the DFIG can be controlled simultaneously, and the active and reactive power can be controlled independently, which makes the control strategy more flexible and diverse [15]. The doubly fed induction motor is an AC-excited motor, where the stator is connected to the industrial frequency grid and the rotor is excited by adjustable AC. By adjusting the frequency, amplitude, and phase of the rotor excitation current through AC excitation, the doubly fed motor can achieve variable speed and constant frequency operation, and at the same time, the active and reactive power of the stator can be adjusted. Centralized management of the servers running various e-government business systems, real-time grasp of the operation status, receiving and processing of alarm information, and timely judgment such as whether the flow of key services is normal, whether the application operation exceeds the specified threshold, and ensuring the stability of the core e-government business. For efficient and safe operation, if the stator winding and rotor winding of the doubly fed induction motor are both symmetrically wound, and the number of motor pole pairs is, when a three-phase AC voltage is applied to the stator side, an asynchronous rotating magnetic field will be generated in the air gap of the motor due to the three-phase symmetrical current in the stator winding, and the rotating magnetic field rotates at a synchronous speed, and the speed is related to the grid frequency, and the number of motor pole pairs as follows.

$$n_1 \geq \frac{60f(x)}{2p}. \tag{3}$$

The main operational objectives of the variable speed and constant frequency doubly fed wind power system is first, to achieve maximum wind energy tracking, the core of which is the control of DFIG speed or active power, and secondly, the control of DFIG stator output reactive power. Thus, the DFIG is the object of control, and the rotor side PWM converter is the executor of the control command. To achieve effective control of the control object, the rotor side PWM converter should be designed based on the mathematical model of the DFIGURE. The mathematical model of DFIG is a high-order, multivariable, nonlinear, strongly coupled system in the same three-phase stationary coordinate system as the common three-phase AC motor, which is difficult to analyze and design the control system. To realize the effective control of the active and reactive power of DFIG, both must be decoupled. Therefore, the vector control technology in AC speed control can be applied to the active and reactive power decoupling control of DFIG, i.e., the active and reactive components of rotor current can be decoupled through coordinate transformation to realize the effective and decoupling control of active and reactive power of DFIGURE. The two objectives of the variable speed and constant frequency doubly fed wind power generation system is achieved.

$$\xi = \begin{bmatrix} ak & 1 & 0 \\ 0 & k & 0 \\ 0 & \dfrac{1}{t} & 0 \end{bmatrix}. \tag{4}$$

To further improve the safety and reliability of the IPM, a “multisource, multimeasure” hierarchical IPM protection scheme is designed based on the IPM’s protection. As can be seen in the figure, in addition to the IPM’s protection, an independent IPM AC side overcurrent protection circuit and a DC side overvoltage protection circuit have been set up in the hardware. The gain of the observer designed by the pole configuration method can be adjusted online according to the previously estimated moment of inertia and viscous friction coefficient, so that the observer can still accurately observe the sudden external load disturbance when its own mechanical parameters change drastically. Compensation has greatly improved the accuracy of the servo system. In addition to the hardware protection measures, software protection is also provided in the DSP program by judging the sampling signals. Three hardware protection sources and one software protection source are logically “combined” to form the IPM protection signal. The protection signals generate several actions now of latching: blocking the PWM signal from the DSP output to the driver circuit, setting the DSP PDPINT pin low so that it sets the PWM output pin to a high resistance state through the hardware circuit, triggering a DSP protection interrupt, and blocking the input of the optical scourge in the IPM driver circuit. This redundant protection measure improves the reliability of the IPM protection work and provides safety assurance for iterative exploratory experimental studies using the prototype system, as shown in Figure 3.

The wind turbine simulation subsystem consists of a DC motor, a thyristor governor, and a PCI bus-based data acquisition card. Under the control of the host data, the acquisition card collects the voltage and current of the DC motor and the speed signal of the unit to output the control signal of the thyristor governor to control the DC motor to realize the simulation of the wind turbine characteristics. The DFIG control subsystem and the wind turbine simulation subsystem complete the DFIG control and wind turbine simulation, respectively, is the electromechanical energy conversion (power generation) unit and the power (prime mover) unit of the experimental system. Different from the real wind power system, DC machine simulation of the wind turbine and DFIG operation has a more complex interoperability relationship to ensure the normal operation of the entire experimental prototype system must be harmonized to the two subsystems so set up a monitoring and management of the two subsystems of the host computer whose hardware configuration includes PC, data acquisition card software configuration using self-developed host monitoring, and management program. The main task of the mainframe is two: one is to monitor and control the two DSPs as slaves to realize the master-slave two-level control of DFIG; the second is to control the data acquisition card to realize the wind turbine simulation to coordinate the DFIG and the DC machine simulation of the engine (wind turbine) with each other to achieve the purpose of maximum wind energy tracking. In addition, the host computer communicates with the two DSPs in real-time to obtain real-time information on the changes of each signal so that the operation of the whole experimental prototype can be monitored.

$$U = U(1+d)e^{itv_1}, t \leq 0^+. \tag{5}$$

To study the impact of grid-connected operation characteristics of large-scale wind turbines on the power system, a wind farm grid-connected model consisting of 20 wind turbines. This model consists of five feeders to connect the single 2.5 MW wind turbine to the wind farm substation via 690 V/35 kV transformer 1 T and then from 35 kV/110 kV transformer 2 T to the high-voltage transmission line and the grid-side substation fed into the grid. For modeling

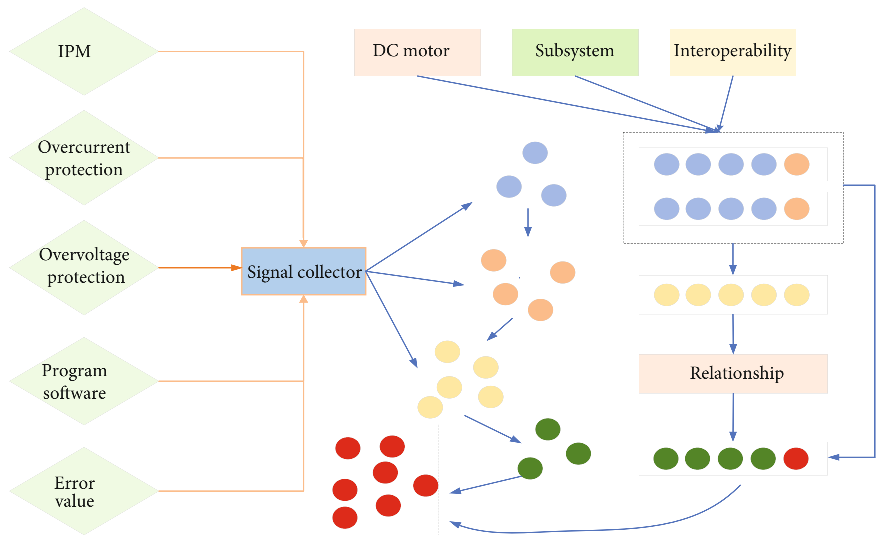

Figure 3: Schematic diagram of IPM protection scheme.

purposes, all wind turbines of the wind farm are equivalently considered as equivalent wind turbines, and the simple single interconnected power system consists of equivalent wind turbines, load model, and infinity bus. The equivalent grid-connected structure uses an IEEE3 node system, where node 1 is the equivalent wind turbine tie-in node, node 2 is the dynamic load node, and node 3 is the infinity balance node [16], where the dynamic load is usually connected in parallel with a constant P Q load. $0_E, 0_S$ are the equivalent electric potential and capacity of the infinity grid, respectively, as shown in Figure 4.

The observer is responsible for the estimation of state variables and disturbance terms, while the controller performs optimal feedback control. In addition, a compensation term is used to achieve complete decoupling between the loops. Using pole configuration techniques to select the appropriate observer gain, the perturbation observer can actively estimate and compensate for the perturbations. The rotor side controls the doubly fed generator to achieve maximum wind energy power tracking. The grid-side converter is controlled by output and grid-connected to achieve DC bus voltage stability and independent decoupling control of output power. It is worth noting that since an increase in observer gain amplifies the measurement noise, there is a trade-off between the speed of convergence and sensitivity to the measurement noise in the choice of observer gain. The stability, dynamic performance, and interference immunity of the system should be considered when selecting the observer bandwidth $\lambda\alpha$. To obtain accurate observations and satisfactory dynamic performance should be chosen as large as possible in the initial design phase. In this chapter, a nonlinear adaptive control POMAC method based on disturbance observer is proposed for the overall control of a doubly fed wind power system, and its performance is verified by simulation. Since the POMAC method compensates for the disturbances better and responds faster, it can provide more reactive power, which helps to improve the voltage outlets at the machine end.

The state and disturbance terms of the system are estimated using an extended state and disturbance high gain disturbance observer and the estimated values are used instead of the true values to achieve optimal output feedback control. The design of POMAC does not depend on an exact system model and its excellent control performance remains largely consistent under various operating conditions, which indicates its robustness to system nonlinearities and uncertainties. These advantages can be attributed to perturbation estimation and optimal output feedback control, which eliminate the effects on the system due to nonlinearities, uncertainties, and external perturbations.

4. Analysis of Results

4.1. Adaptive Sensing Control System Results. The software parts of the net-side converter and rotor-side converter control systems of the dual PWM converter are also independent of each other. Both have different control objects and processed data, but their structure is the same, both are modular designs, the whole software system is composed of the main program and various interrupt service programs, and the main program and interrupt service programs are composed of subroutines. The software system uses five priority levels, with the highest priority being protection interrupts, followed by timer interrupts, serial communication interrupts, keyboard interrupts, and the lowest level is the main program. The timer interrupt implements DFIG real-time control and is the core of the software system. The serial communication interrupt and the keyboard interrupt handle the communication and interaction between the DSP and the host and the DSP and the operator, respectively, where the serial communication interrupt has a higher priority for the machine-to-machine communication task than the keyboard interrupt has for the human-to-machine interaction task. This is shown in Figure 5.

The control unit and the DSPZ control unit are relatively independent in function and structure but have many

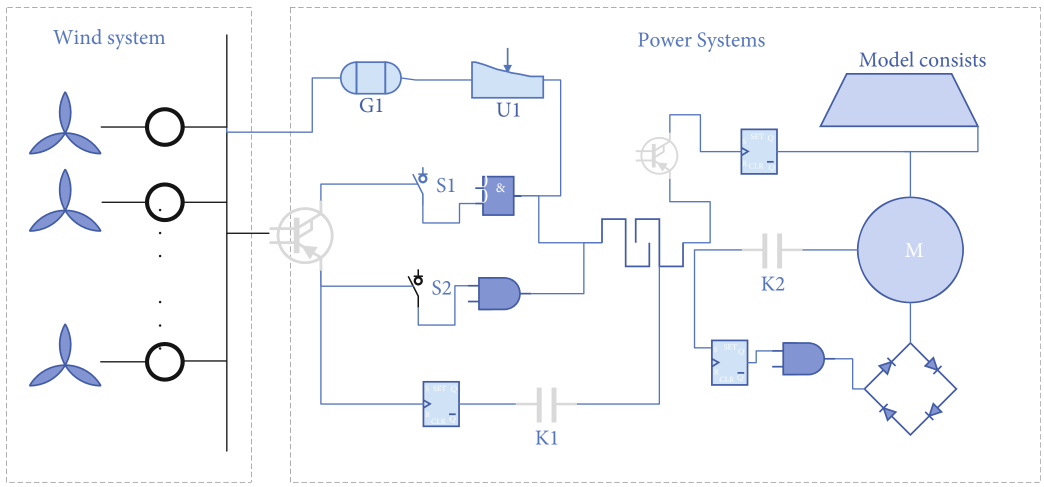

Figure 4: Simplified model of the power system of a wind farm.

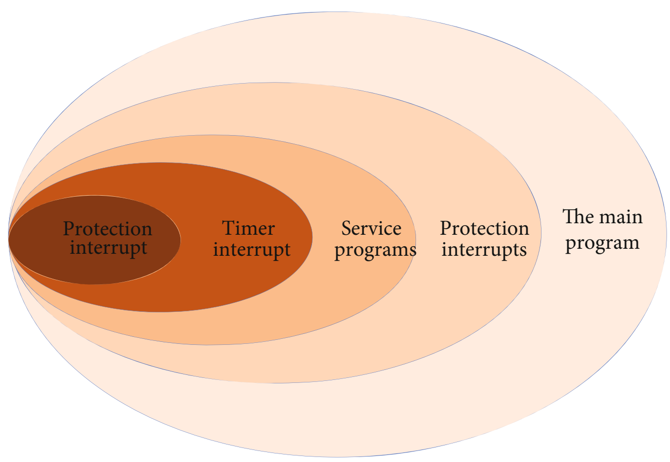

Figure 5: Module execution priority in the adaptive sensing control system.

similarities in hardware composition. The basic circuits of the two control units are the same including the DSP minimum system and extended input and output circuits, signal acquisition circuits, signal preprocessing circuits, guard M drive circuits, nd control power circuits. The DSP minimum system includes the CPU, system clock, data and program memory, and decoding circuits; extended input and output circuits are to provide interfaces for numerous peripheral circuits and extended circuits are to connect the DSP minimum The signal acquisition circuit uses voltage transformers and current transformers to convert strong power signals into weak control signals; the signal preprocessing circuit amplifies and filters the weak signals output from the signal acquisition circuit for AD conversion by the DSP. The hybrid damping suppression scheme is derived and combined with the grid impedance measurement technology to form an adaptive control strategy for grid-connected inverters based on hybrid damping, so that the grid-connected inverter can maintain relatively good performance under various grid impedance conditions. In system characteristics, the IPM driver circuit isolates and shapes the drive pulses from the DSP for driving the IPM; the control power circuit provides the 15 V and SV power supplies required by the control circuit and the four +15 V power supplies required by each IPM. The two DSP control units differ in that the DSPI control unit serves as the direct control core for the DFIG and has more functions than the DSPZ control unit and the circuitry to implement those functions. The additional circuitry for the DSPI control unit includes a keypad display circuit, a protection drives operation circuit, parallel communication, and serial communication circuits, and a DFIG speed position detection circuit. The keypad display circuit provides a 4×4 matrix keypad and a 6-digit digital tube display; parallel communication and serial communication are channels for information exchange between the slave and the host Parallel communication takes a simplex approach (data can only be passed from the slave to the host in one direction) Serial communication is a full-duplex approach (data can be passed between the slave and the host in both directions).

$$G_{\mathrm{hfp}} = \frac{T_h s - 1}{T_h s + 2}. \tag{6}$$

By combining the power generation subsystem with the grid-connected subsystem, an overall simulation system based on the rotational speed control scheme for maximum wind energy tracking is formed. The speed control scheme is straightforward compared to the power control scheme, i.e., the optimal motor speed is calculated from the monitored wind speed, and then, the optimal motor speed is tracked and controlled. The speed control scheme is simulated by setting the doubly fed generator to run at speed for seconds at no load and then connected to the grid. The wind speed is given: the wind speed is from second to second, and the optimal speed is the one that maximizes the blade tip speed ratio at that wind speed, and the speed difference is from second to second, and the optimal speed is ⊤, and the speed difference is from second to second, and the speed difference is from second to second. The reactive power is given: the reactive power is given from second to second and the reactive power is given from second to second and the reactive power is given from second to second [17]. It shows the waveforms of rotor three-phase current versus motor speed during the speed control scheme to achieve maximum wind energy tracking. It can be seen that as the motor speed increases, the rotor current amplitude increases accordingly; the rotor current frequency decreases as the speed gradually increases and the turndown rate gradually decreases in the first seconds; after seconds, as the speed increases and the turndown rate becomes larger, the rotor current frequency starts to gradually increase. The figure shows the waveform of the rotor three-phase voltage as the control quantity in this process, and it can be found that the rotor voltage amplitude is proportional to the rotation rate, as shown in Figure 6.

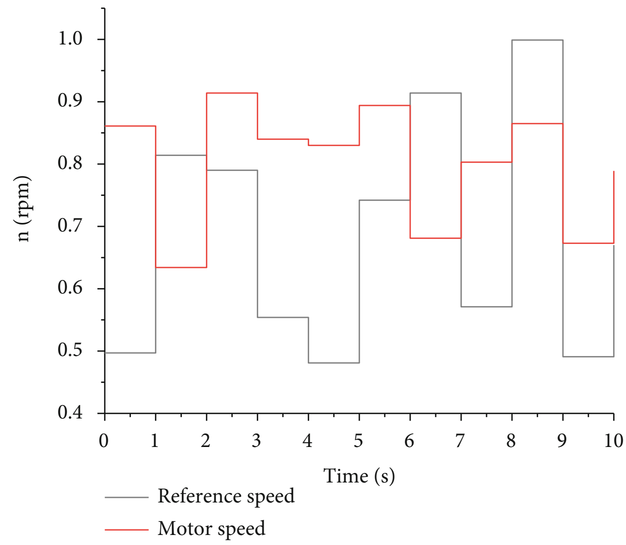

Figure 6: Motor speed tracking waveform graph.

4.2. Performance Results of the Doubly Fed Wind Power System. The control software part of the variable speed and constant frequency doubly fed wind power system consists of the main program and the interrupt service program. Here, we mainly analyze the main program and the interrupt service program of the network-side converter and the machine-side converter in the AC excitation power supply. The main program mainly completes the initialization of the system, the interrupt service of the network-side converter is mainly used to stabilize the DC-side voltage, and the interrupt service program of the machine side converter mainly implements the DFIG variable speed and constant frequency power generation operation and the fault ride-through function of the doubly fed wind power generation system. According to the active power and the virtual synchronous speed, the drag torque is generated to realize the governor function; according to the wind speed and rotor speed, the torque command of the doubly fed wind turbine at the maximum wind power output is obtained, and then, the doubly fed motor is in a steady state. According to the reactive power and stator voltage, the voltage-reactive droop controller is used to generate the excitation current command to realize the excitation regulator function. The functions of the main program include initializing the DSP registers, setting the interrupt system, initializing the analog-to-digital converter ADC module, timer, event manager, CAP unit, QEP unit, comparison unit, I/O pins, etc., and displaying the program operation status. A three-level priority design is used in the software system, where the main program has the lowest priority level, followed by the timer interrupts, and the protection interrupts have the highest priority [18]. The control programs for the net-side converter and the machine-side converter are not done in the main program, but in the corresponding timer interrupt service programs, as shown in Figure 7.

Combined with the analysis earlier in this chapter, it is known that under weak grid conditions, although the stability and passivity of the system can be improved by further adjusting and rationalizing the PI controller parameters and phase-locked loop controller parameters of the grid-side converter system and rotor-side converter system, etc., due to the grid environment in practical applications and the requirements of a weaker grid with a lower short-circuit ratio, the practical results that can be achieved by adjusting the PI controller parameters only. However, due to the actual grid environment and the requirements of weaker grids with lower short-circuit ratios, the practical results that can be achieved by adjusting the PI controller parameters alone are very limited, so there is a need to improve and enhance the stability of the system by adding additional control structures to reshape the output conductance of the doubly fed wind power system so that it can improve the passive nature of the system. The three-step prediction method and hysteresis switch are used to detect the occurrence of grid faults, control the cut-in and cut-out of the deexcitation current, and dynamically adjust the size of the deexcitation current according to the degree of the grid fault, and effectively reduce the system shock time when the grid voltage dips. While keeping the DFIG system from leaving the network, it can also well protect the purpose of the DFIG system. From the point of view of the passive

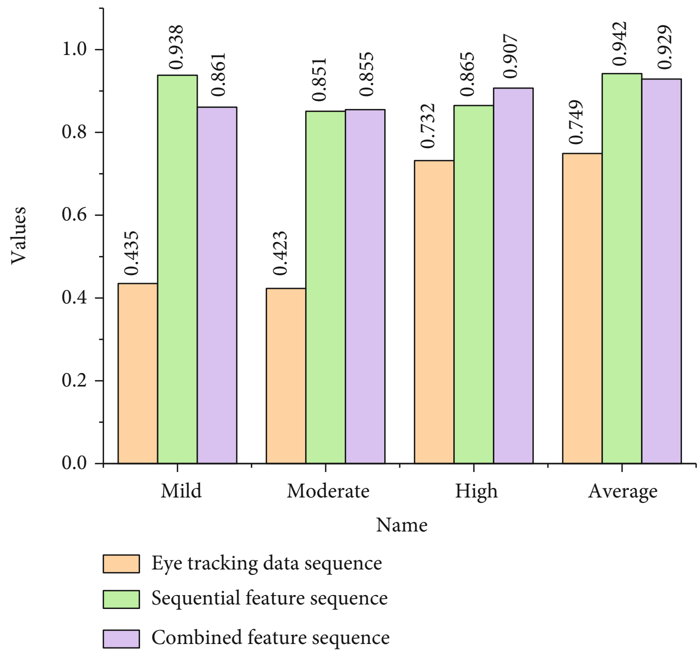

Figure 7: Flow chart of the doubly fed wind power simulation experimental system.

nature, the reason for the instability of the doubly fed wind power system when grid-connected is because its equivalent conductance has too many nonpassive regions in its dd component and Q component, active damping can be considered to suppress the nonpassive regions and reduce the conductance amplitude, the main step is to improve the damping of the system by extracting the current disturbance components after filtering and gain processing, etc., and feeding them back into the current control loop capacity, i.e., expanding the passive region of the system. To further investigate the effectiveness of the proposed control method of introducing variable dampers with the crowbar protection circuit to suppress the DFIG rotor overcurrent, the double fed wind power system can use the vector control method with the crowbar protection circuit to realize the fault ride-through when the voltage and voltage have deep symmetrical dip fault, or the control method of introducing variable dampers with the Crowbar protection circuit proposed in this paper can be used. Control method with Crowbar protection circuit is shown in Figure 8.

A disturbance observer-based OFCC method for magnetic chain compensation control is proposed for the LVRT problem of doubly fed wind power systems. Firstly, the transient characteristics of the doubly fed wind power system during voltage dips are studied, and it is concluded from the analysis that accurate compensation of the dynamics of the stator magnetic chain is the key to achieving LVRT. Based on the multiloop adaptive control proposed in Section 3, an observer-based magnetic chain compensation control method is designed considering a system model in which the stator-rotor magnetic chain interacts with each other. The disturbances caused by stator magnetic chain variations are accurately observed by using an observer, and the observed values are controlled instead of the real values. The results of the simulation lead to the following conclusions. The proposed OFCC can achieve the same control effect of low voltage ride-through as FFTCC, which is much better than the low ride-through effect of vector control [19].

To verify the feasibility of the control algorithm of doubly fed wind power system and the control algorithm of the doubly fed motor without speed sensor which will be studied later, the thesis establishes a doubly fed wind power simulation system in the environment. The doubly fed wind power system is a complex nonlinear multivariate high-order system with various symmetric relationships internally, so vector control technique is used to control the instantaneous values of voltage and current to achieve power or torque dissymmetric control.

Unlike the FFTCC method, the design of the proposed method does not rely on an accurate system model; it can well estimate the disturbances due to the magnetic chain dynamics and compensate for the control. Based on the magnetic chain compensation, the controller can output a suitable rotor voltage to offset the induced electric potential and achieve a suppression effect on the rotor overcurrent. The proposed magnetic chain compensation control method does not require accurate observation of the magnetic chain, and there is no problem with switching the control strategy during a fault.

$$h_1 = \frac{\omega_{ds}\mu_s}{L_g}. \tag{7}$$

In this paper, in the studied doubly fed wind power system without position sensor control system, firstly, the simulation study of the system is required, so the simulation models of the components that make up the doubly fed power system must be constructed. Many functional modules are provided,

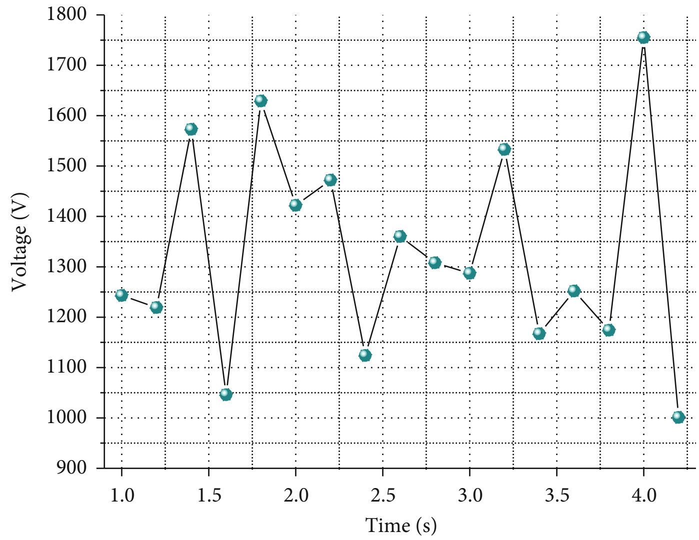

FIGURE 8: DC-side voltage for Crowbar+variable damper method.

and together with simple programming using the language, it is relatively easy to implement the above model and control block diagram so that the feasibility of the control strategy of the doubly fed wind power system can be verified through simulation, and the dynamic and static performances of the whole system model can be simulated and analyzed for the study. The simulation of various load cases is used to guide the design of the hardware circuit and to give viable thinking and steps for the software writing to provide adequate preparation instructions for the prototype experiments.

5. Conclusion

In this paper, the doubly fed wind power variable current system is taken as the research object, with the objective of effectively improving the grid stability of the doubly fed wind power variable current system; starting from the basic structure of the doubly fed wind power system, it is analyzed that the system can be divided into two subsystems, namely, the net-side converter system and the rotor-side converter system, and the impedance model is established for the subsystems, respectively, along these lines; in the control structure of the doubly fed wind power system, the control parameters of the net-side converter subsystem and the rotor-side converter subsystem are parametrically designed, respectively, and then, the theory of grid-connected impedance stability analysis and the theory of passivity are introduced in detail, and the port impedance characteristics of the system and the grid-connected stability under different grid strengths are analyzed by combining the resulting impedance model and the design parameters [20]. The adaptive control of the doubly fed wind power system is studied and applied to the control strategy of low voltage ride-through, mainly focusing on the poor control effect of traditional vector control at the operating point offset and the lack of robustness to the system modeling errors and external disturbances.

The adaptive sensing control method for doubly fed wind power systems mentioned in this paper considers the system under the condition of three symmetric faults. The probability of asymmetric faults in the grid is much larger than that of symmetric faults. Therefore, it is of great practical importance how to apply the proposed adaptive sensing control method to asymmetric fault conditions. Finally, how to apply the proposed adaptive control method to other power system devices and achieve coordinated control among multiple devices can be our future research direction, thus making the grid stability and robustness of the whole doubly fed wind power system optimized and improved.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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