Construction of Power Supply Stability Control Model for Wind Connected Power Grid

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Received 14 June 2022; Accepted 14 July 2022;
Publication 13 October 2022

Abstract

There are many problems in the power supply stability control of wind power generation system, such as large fluctuations, poor control effect and so on. Therefore, a new stability control model of wind power grid connected is designed. Determine the DC grid connection mode when the wind farm is connected, convert the DC power into AC power through the converter station, and transmit it to the final AC system to realize the grid connection of wind power and power grid; According to the determined wind power access mode, calculate the mechanical operation power, mechanical torque and wind energy utilization coefficient collected by the wind turbine, complete the best collection of wind energy, and determine the shafting according to the mass block model of the wind turbine and generator, so as to realize the research on

Distributed Generation & Alternative Energy Journal, Vol. 37_6, 1873–1890.
doi: 10.13052/dgaej2156-3306.3767

the mathematical model of wind power generation. By analyzing the power flow direction of the stator and rotor of the wind turbine generator set, the unstable state of the power supply voltage of the wind turbine generator set after grid connection is determined. The PV curve method is used to calculate the steady-state voltage stability of grid connected wind turbines, and a power supply stability control model based on the voltage stability of grid connected wind turbines is established. The nonlinear objective function method is used to optimize the critical point of power supply stability, calculate the maximum load and maximum power of the system, establish the static power supply and transient power supply stability model after wind power grid connection, and realize the power supply stability control research of grid connected wind power through the analysis of power supply characteristics. The experimental results show that the model is closer to the stability of the actual power supply in the test of improving the stability of the power supply, ensuring the quality of power supply, while the test results of the other two methods have large fluctuations. In the analysis of the change of power supply after grid connection, the experimental results obtained by the model are very close to the actual data values. Therefore, this method can effectively improve the performance of power system.

Keywords: Wind power connected to power grid, power supply, stability, control model, mechanical torque, pv curve, nonlinear objective function.

1 Introduction

In the world, the sustained and rapid development of economy makes the problem of energy and environmental protection increasingly prominent. The energy storage of non renewable energy, including coal and other fuels, is becoming increasingly scarce, and the use of non renewable energy has generated a series of environmental problems [1], which have attracted global attention. In the development of many renewable energy sources, the quality of coordinated development with the natural environment is getting worse and worse, and the road of sustainable development is not smooth. Therefore, in order to obtain more effective resources that do not affect the environment, renewable energy can become an energy with certain development potential, which is loved by mankind. As the best and most stable renewable energy, wind energy has been widely used in power development [2]. Wind power generation has the advantages of clean and non polluting environment, short production cycle and no consumption of non renewable energy. As an effective power generation energy, it has effectively alleviated the problem of environmental pollution and the problem between power supply contradiction and energy structure. As wind energy is widely used in power generation, the capacity of wind turbine is increasing. The wind power generation process is affected by its own structure and structural characteristics. The impact of connecting to the power grid in the process of wind power generation is becoming greater and greater. In the process of wind power generation, due to the uncertainty of generator units and the requirements for grid power during operation, there is also a certain impact on voltage and other factors after being connected to the grid [3]. Continuous switching and other operations in the process of wind power connecting to the power grid cause the power supply and voltage of the power grid to fluctuate continuously. Power supply power, voltage deviation and other issues will affect the quality of power after being connected to the power grid, and will ultimately affect the normal operation of the power system [4]. Therefore, the stability of the power supply after the wind power is connected to the power grid has a great impact on wind power generation. How to control the stability of the power supply after the wind power is connected to the power grid has become a key problem in the current wind power generation [5]. Therefore, relevant researchers have studied the problem of power supply stability after connecting to the power grid from many aspects, and obtained some methods to control its stability.

Xu et al. [6] designed a method to control power stability by tracking the maximum power supply point of wind power generation system. Aiming at the problem that the set power of a given wind power generation system cannot be determined, this method uses the power feedback method to track. Methods in the design, the change state of power supply under the influence of stator and rotor copper consumption and iron consumption is determined, and then the iron consumption is determined by the modified control equation, the power flow of the generator is determined, and the maximum wind energy point is determined. Taking the system as the tracking node, the maximum power output is obtained and the corresponding control scheme is formulated to realize the steady operation of the power system. This method can effectively determine the maximum point of power fluctuation and effectively control this position, but the maximum power point determined by this method is affected by many factors, resulting in low accuracy of power loss determination. Pan et al. [7] designed a stability control method for weak current network access of doubly fed fan based on phase locked loop synchronous control. In view of the instability of power supply caused by the synchronous control wind turbine connected to the power grid, the causes of power supply instability are determined. Determine the relationship between the active power and terminal voltage after the single machine is connected, build the signal model, determine the equivalent relationship between the output power and voltage through the model research, introduce the branch gain into the AC network, determine the boundary conditions for the instability of the connected power supply, and design the time domain of the control model to realize the effective control of the stability of the connected power supply. This method simplifies the control process and improves the work efficiency through model control, but there is a problem that the control effect of power gain at different terminals is poor. Ken et al. [8] proposed a series type wind farm LCC HVDC transmission system without AC harmonic filter based on line commutation converter. Using the experimental device built in the laboratory, a set of steady-state equations of the system are derived, and the steady-state characteristics of the system are verified. This method is easy to implement, but the cost is high. Kim et al. [9] proposed the probabilistic modeling of wind energy potential for grid expansion planning, and estimated the wind energy potential through Weibull distribution, Monte Carlo simulation and enhanced spatial modeling based on general Kriging. It is used to formulate the expansion plan of transmission and distribution facilities, solves the variability and uncertainty of wind power resources, and significantly affects the stability and reliability of the power grid. However, this method has a large amount of calculation and cannot be widely used.

On the basis of the above research methods, a new stability control model of grid connected wind power supply is designed. The model calculates the steady-state voltage stability of grid connected wind turbine generator sets by using PV curve method, and uses nonlinear indexes to calculate the maximum load and maximum power of the system, so as to realize the stability control of power supply after grid connection.

2 Research on Grid Connection of Wind Farm and Mathematical Model of Wind Power Generation

2.1 Grid Connection of Wind Farm

As a kind of renewable energy, it is very important to consider the input and output of wind energy development scale. Therefore, the investment of wind energy in connecting to the power grid is large, and the type selection, capacity and transmission distance of wind energy conversion in this process are directly related to the way wind energy is connected to the power grid. The modes of wind node grid include AC grid connection and HVDC grid connection. This technology is now relatively mature in AC grid connection. The wind farm and the connected system are strictly required to have the same frequency and phase in terms of voltage requirements. It is necessary to add reactive power compensation devices at the outlet end of the wind power connected to the power grid to improve the fault ride through capability. This access method is generally required to be less than 100 km, while DC grid connection has no distance requirements. The transmission capacity after connecting to the power grid is small, and the power control needs continuous adjustment, so it is impossible to update in real time. DC grid connected transmission capacity and power supply are directly related to the transmission medium, which can be continuously adjusted and updated, and can fully control the change of power supply [10]. Considering the characteristics of different wind power connected to the power grid, this paper realizes the wind power connection through DC grid connection. The HVDC grid connected wind power access is realized through the converter station. The basic structure of the access is shown in Figure 1:

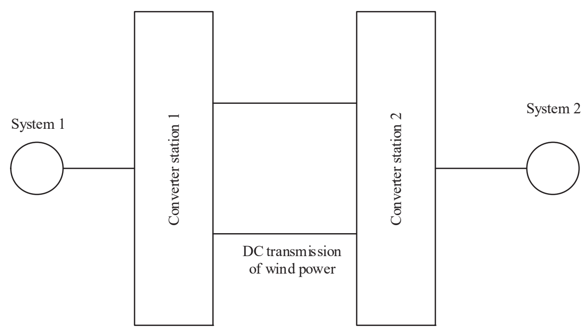


Figure 1 Basic structure of HVDC grid connected wind power access.

In Figure 1, wind power is input from system 1 to system 2 when the wind power is connected to the power grid. After the wind power is converted by converter station 1 at first, it is adjusted to the appropriate voltage, and then transmitted to the next converter station. At this time, the DC power of the previous stage is converted into transaction current and transmitted to the final AC system to connect the wind power to the power grid.

2.2 Study on Mathematical Model of Wind Power Generation

Based on the determination of the above wind power grid access technology, the basic operation principle of wind power generation is studied, which lays a foundation for the subsequent research on power supply stability control of wind power grid access. Wind power is connected to the power grid through wind turbine, which collects wind energy in nature and converts it into a kind of mechanical energy through its own advantages. During this process, the mechanical operating power collected by the wind turbine is:

$$S_i = \frac{1}{2} a\pi r^2 B_p v^3 \tag{1}$$

In formula (1), S_i represents the mechanical operating power, a represents the density value of wind, r represents the length of collecting mechanical impeller radius, B_p represents the wind energy utilization coefficient, and v represents the size of wind energy.

The mechanical torque of a wind turbine is an important variable in the process of wind power collection. The calculation method is as follows:

$$Z_i = \frac{1}{2} a\pi r^2 B_p \frac{v}{\beta} \tag{2}$$

In formula (2), Z_i represents the mechanical torque size value of the wind motor, and β represents the speed ratio of the collected mechanical blade tip.

Among them, the wind energy utilization coefficient is determined by the speed ratio at the tip of the collecting machine impeller, which is directly related to the speed ratio at the tip of the impeller and the pitch angle [11], that is:

$$B_p(\beta, \alpha) = n\left(\frac{n}{\beta} - 0.4\alpha\right) e + 0.0068\beta \tag{3}$$

In formula (3), α represents the size of the pitch angle.

The variation curve between the coefficient and the ratio of impeller tip speed and pitch angle is shown in Figure 2:

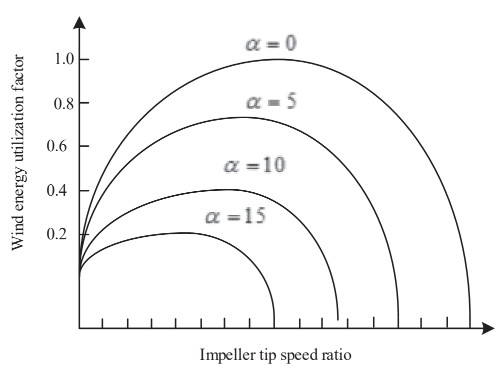


Figure 2 Diagram of relationship between wind energy utilization coefficient and pitch angle change.

As can be seen from Figure 2, when the value of α is unchanged, the size of β is different and a unique B_p exists. For any A and β and B_p, the α

value needs to be changed in the actual wind energy acquisition to adjust the amount of wind energy acquisition. After the wind speed changes, the wind motor system needs to control the speed of the wind turbine during operation to ensure that the β value is always optimal, and you can obtain more wind energy, namely:

$$Q_i = \frac{1}{2} a\pi r^2 B_{i\,\max} \frac{(wr3)}{\beta^3} \tag{4}$$

In Equation (4), Q_i represents the optimal power value of the wind turbine.

According to the collected air volume, the shafting of the wind turbine is also a key influencing factor. In normal steady-state operation, equivalent acquisition can be used. However, due to the existence of objective factors of the power grid, the shafting vibration of the wind turbine will also change to some extent. In order to more effectively reflect the disturbance state of the wind turbine after connection, the mass block model [12] of the wind turbine and generator is used to represent the shafting, that is:

$$\begin{cases} 2F_i dw_i/dt = G_n - k_i\vartheta_i - D_t \\ 2F_j dw_j/dt = -G_m + k_i\vartheta_i - D_h \\ ds/dt = w_0(D_t - D_h) \end{cases} \tag{5}$$

In formula (5), F_i/F_j represents the moment of inertia during the operation of the fan, G_n/G_{m} represents the electromagnetic torque, k_i represents the ability coefficient to resist elastic deformation when under force, D_t/D_h represents the ratio of the rated load impedance to the actual impedance of the power amplifier, and w_0 represents the average speed of the fan.

According to the determined wind power access mode, calculate the mechanical operating power, mechanical torque and wind energy utilization coefficient collected by the wind turbine, complete the optimal collection of wind energy, and determine the shafting according to the mass block model of the wind turbine and generator, so as to realize the research on the mathematical model of wind power generation.

3 Research on Power Stability Control Model of Wind Power Connected to Power Grid

In fact, when the grid remains in a steady state, the power supplied by the power system to the load will vary with the current. According to the degree of interference, the power supply stability of the power grid is also different.

In fact, it is a kind of voltage instability, including small disturbance stability and large disturbance stability [13].

In the process of connecting wind power to the power grid, it is necessary to constantly control the change of power supply, especially the active power in the maximum wind energy tracking control. When analyzing the power supply stability of the wind node power grid, first analyze the power flow direction of the wind turbine stator and rotor, and then conduct more in-depth exploration on this basis. Without considering the consumption of stator, rotor and excitation converter, the active power of wind turbine connected to the power grid, the active power output of stator and the power output of rotor meet the following requirements:

$$E_t = E_c + E_d \tag{6}$$

In formula (6), E_t, E_c and E_d respectively represent the AC energy actually generated or consumed by the wind turbine, stator and rotor in unit time.

Without considering the consumption of stator, rotor and excitation converter, the existing relationship is:

$$\begin{cases} E_c = \dfrac{1}{1-h} E_t \\ Ed = \dfrac{h}{1-h} E_t \end{cases} \tag{7}$$

In formula (7), h represents the transition rate, when $h > 0$, $E_c < 0$. After passing the converter to flow from the grid to the rotor, it is now in a sub-synchronous state, when $h < 0$, $E_c > 0$, it is now in a hypersynchronous state.

As wind power has the characteristics of uncertainty, randomness and other rapid changes, although wind turbine can control a certain power after being connected to the power grid, when its number increases, the active output of wind turbine will change greatly with the wind speed, resulting in the instability of power grid voltage and power supply after being connected to the power grid.

Through the research of wind turbine stator and rotor tidal direction, the power supply voltage fluctuation of wind turbine after operation in power grid is studied. When the grid is connected to the wind turbines, the mechanical load is assumed to be constant, but the current on the stator line will change as the voltage at the end of the grid decreases. In this case, when the current value is in a high state, the voltage on the transmission line will continue to reduce, so that the speed of power supply changes, resulting in reactive power or reactive power in the power system, but also the voltage of the generator will continue to reduce, resulting in voltage imbalance. Because the voltage stability of the system is affected by the constant change of the load, there is an imbalance at the maximum power point [14]. The steady-state voltage stability of wind turbine is studied by PV curve.

In the analysis of this method, it can be determined that the key factors leading to the voltage imbalance after connection include: critical voltage and limit power. According to the changes of these two values, the voltage stability after connecting to the power grid is determined. The critical voltage is:

$$U = T - (R_i + fX_i)t \tag{8}$$

In formula (8), U represents the critical voltage size after access, T represents the critical stability threshold, R_i represents the power load change value, f represents the critical coefficient, X_i represents the PV curve infinite value, and t represents the perturbation coefficient.

The limit power after grid connection is expressed as:

$$\overline{L} = U\frac{T - U}{R_i - fX_i} \tag{9}$$

In formula (9), $\overline{L}$ represents the limit power change value after access to the power grid.

Finally, the power supply stability control model is constructed based on the voltage stability of wind power after grid connection Grid-connected wind power power stability control is essentially the control of key power points for voltage stability after grid connection. That is to say, in the power supply stability control of wind power connected to the power grid, it is necessary to control its static stability and transient stability to realize the power supply stability control of the connected power grid.

In the static stability control of power supply of wind connected power grid, the critical point of power supply stability is optimized by nonlinear objective function with the help of nonlinear programming method [15], and the maximum power load value or any maximum power supply is taken as the target for control, namely:

$$P = \max|S(x)| \tag{10}$$

In formula (10), P represents the maximum supply power and the $\max|S(x)|$ optimal nonlinear objective function.

Set the constraint conditions of the objective function, that is, determine the power constraint of the generator output when the wind is connected to the power grid, that is:

$$Y_i^{\min} \leq Y_i \leq Y_i^{\max} \tag{11}$$

Under the condition of wind power grid-connected, the safety constraints of power supply at the generator end are set as follows:

$$q_i^{\min} \leq q_i \leq q_i^{\max} \tag{12}$$

The change coefficient of the power supply power is $\gamma_i(t)$, which represents a function of time window [16]. If the total load power at a certain time after access is set to be $\Delta\xi(t)$, the relationship between the power supply power and the load change amount of each access point can be determined as:

$$\xi_i(t) = \xi_i^0 + \gamma_i(t)\Delta\xi(t) \tag{13}$$

In formula (13), ξ_i^0 represents the static power of the load node in the access state, $\xi_i(t)$ represents the power of the power load node at any time, and $\gamma_i(t)$ represents the distribution rate value of the load.

According to the determined load power value, the static stability of the power supply after connection is controlled. The control model is:

$$\gamma_i(t)\sum_{i=1}^{n}\xi_i(t) = \gamma_i(t)\sum_{i=1}\xi_i^0 - \xi_j^0 \tag{14}$$

The transient stability control of the power supply after the wind power is connected to the power grid is also the key to control the power supply. After the transient voltage stability is disturbed [17], there will be unstable fluctuations and other states, which will lead to the instability of power supply, and the two occur at the same time. Therefore, controlling the stability of transient voltage can achieve the stability control of power supply. In the transient voltage stability control, the stability control is realized by analyzing the power supply characteristics [18]. Assuming that the active power remains unchanged after being connected to the power grid, and only the reactive power changes at a certain node, the transient voltage state of the power grid after being connected is expressed as:

$$K_i = \sum_{i=1}^{n}\frac{u_i}{\sigma_i}v_{i+1} \tag{15}$$

Where, μ_i represents the left eigenvector, σ_i represents the sensitivity of the transient voltage, and v_{i+1} represents the participation factor of the characteristic pattern.

Through the transient analysis of electricity, the power of the grid is obtained, which is expressed as:

$$\wp(X, U, O) = 0 \tag{16}$$

In formula (16), X represents the state variable, U represents the control variable, and O represents the general parameter.

Finally, the transient stability control model of power supply after wind power is connected to the power grid is constructed to realize the research on power supply stability control of wind power connected to the power grid, and the following results are obtained:

$$\psi_i = \Delta\varpi \sum (X, U, O)\Delta\lambda \tag{17}$$

In formula (17), $\Delta\varpi$ represents the flexibility of state variable to power supply variable, and $\Delta\lambda$ represents the degree of state variable to parameter control.

4 Experimental Analysis

4.1 Experimental Scheme

The test object is a specific area of the grid and wind power generation connection. The structure of the system connected to the power grid is shown in Figure 3:

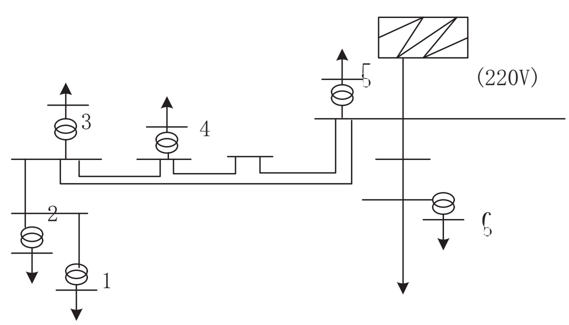


Figure 3 Schematic diagram of experimental simulation circuit of wind power connected to power grid.

The number 1 in Figure 3 is the node 1 connected to the power grid. The synchronous unit model of each fan connected can coordinate the system at the same time. The load is set to 55% of the constant impedance value, and 45% of the induction motor is at the impedance. The wind speed changes rapidly in the process of wind power connection. Under this background, the active power output of the generator is easy to change. Therefore, there is interference in the environment. Set the peak gust wind speed as 5 m/s, and the wind speed changes from 65 ms. The wind speed change curve during wind power connection in the experiment is shown in Figure 4:

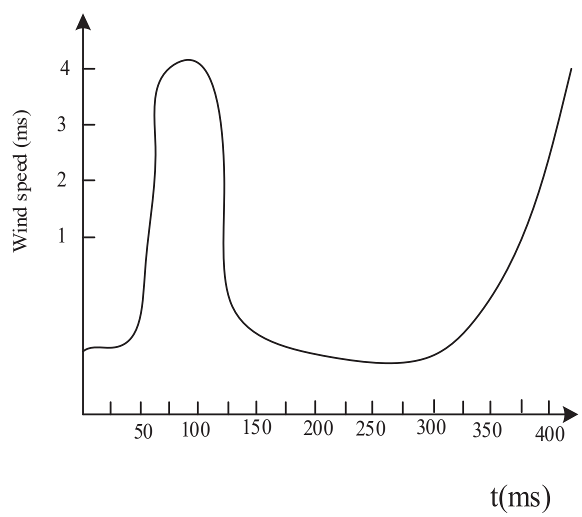


Figure 4 Schematic diagram of wind speed change during wind access.

The installed capacity of the wind farm at each access point in the experiment is shown in Table 1:

Table 1 Installed capacity of wind farm at access point

Wind Farm Number	Installed Capacity/MV
1	200
2	100
3	100
4	200
5	200
6	100

The initial results of testing the power supply of the grid after each access point is connected before the experiment are shown in Table 2:

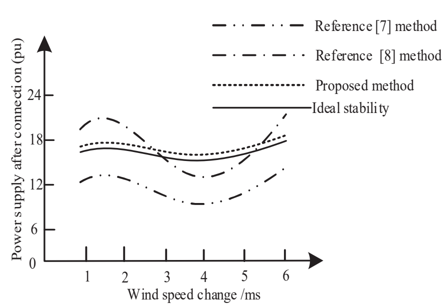
Table 2 Power supply of power grid after the access point is connected

Number	Minimum Supply Power Supply (MW)	Maximum Power Supply Value (MW)
1	4.52	5.96
2	4.51	5.95
3	4.52	5.79
4	4.53	5.79
5	4.52	5.86
6	4.52	5.68

According to the above set experimental environment, the experimental test analysis is carried out to test the stability of power supply control and the change of power supply value after connecting to the power grid under different wind speed changes of the methods in this paper, reference [7] and reference [8] respectively, so as to verify the effectiveness of the proposed model.

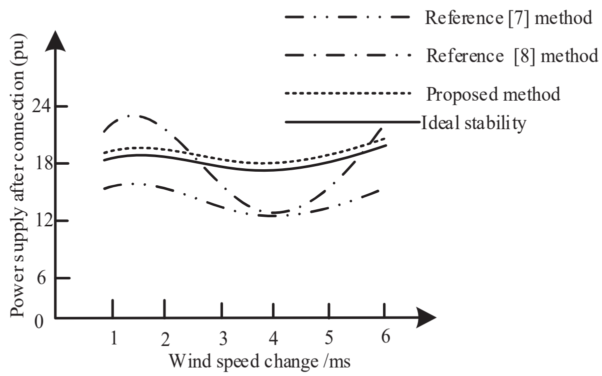
4.2 Analysis of Experimental Results

The stability of power supply is the main reason of affecting the normal operation of the whole power system. The stability of power supply reflects the quality of power supply. Therefore, in this test, the stability of power control after connecting to the power grid under different wind speed changes is tested. In the experiment, three groups of DC power with different sizes are selected, and the influence of wind speed on the stability of power supply is shown in Figure 5:

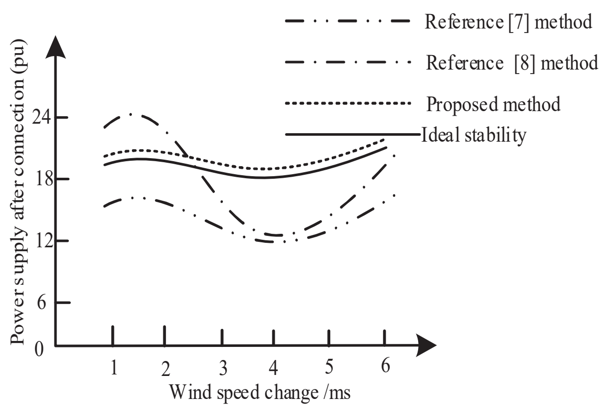


(a) stability analysis of power supply control after grid connection under different wind speeds when DC is 0.2ka

Figure 5 Continued



(b) stability analysis of power control after grid connection under different wind speeds when DC is 0.3ka



(c) stability analysis of power control after grid connection under different wind speeds when DC is 0.4ka

Figure 5 Stability analysis of power supply power control after connecting to power grid under different wind speed changes.

According to the analysis in Figure 5, the influence of wind speed on the stability of power supply when different DC power is on, the stability of control power supply by reference [7] and reference [8] methods is obviously different from the ideal situation, and there are large fluctuations. In contrast, the stability of this method is closer to that of the actual power supply. The results show that the model can effectively improve the stability of power control under different wind speeds after grid connection, and it is feasible.

Based on the stability of power supply power control after connecting to the power grid under different wind speed changes, the experiment further tested the change degree of power supply value after connecting to the power grid under different wind speed changes, and verified the performance of this method by comparing with the initial set value. The results are shown in Table 3:

Table 3 Analysis on changes of power supply value after grid connection

Number	Minimum Actual Power Supply (MW)	Maximum Actual Power Supply (MW)	The Minimum Value of Power Supply in This Paper (MW)	Maximum Power Supply Value Value of This Method (MW)
1	4.52	5.96	4.51	5.97
2	4.51	5.95	4.51	5.96
3	4.52	5.79	4.52	5.75
4	4.53	5.79	4.52	5.79
5	4.52	5.86	4.51	5.85
6	4.52	5.68	4.52	5.67

Through the analysis of the experimental data in Table 3, it can be concluded that there is a certain fluctuation in the power supply when the wind speed is affected by different access points. Among them, the value with the largest fluctuation of the minimum power supply value is in access points 1 and 4, and the value with the largest fluctuation of the maximum power supply value is in access point 3. However, it can be seen from the actual data comparison that although there is fluctuation in the power value of the power supply after connection, the fluctuation value is very small and can be basically ignored. It can be seen that the control model in this paper can well control the change of power supply power after connection and improve the quality of power supply.

5 Conclusion

In order to solve the stability problem of wind turbine, a new steady state control mode of wind turbine is proposed. Under the condition of wind power generation, the DC power is converted into AC power by a converter, and the wind power generation is combined with the power network through the final AC. The PV curve method is used to calculate the steady-state voltage stability of grid-connected wind turbines. The maximum load and maximum power supply are obtained by nonlinear index. On this basis, the dynamic simulation and analysis methods of power system are proposed. Simulation results show that this method can effectively improve the performance of power system.

References

[1] Mahdy A, Hasanien H M, Helmy W, et al. Transient stability improvement of wave energy conversion systems connected to power grid using anti-windup-coot optimization strategy[J]. Energy, 2022, 24(5):147–151.

[2] Yao X, Yi B, Yu Y, et al. Economic analysis of grid integration of variable solar and wind power with conventional power system[J]. Applied Energy, 2020, 26(4):1147–1152.

[3] Santhoshi B K, Mohanasundaram K, Kumar L A. ANN-based dynamic control and energy management of inverter and battery in a grid-tied hybrid renewable power system fed through switched Z-source converter[J]. Electrical Engineering, 2021, 17(8):1–17.

[4] Ravada B R, Tummuru N R, Ande B. PV-Wind and Hybrid Energy Storage Integrated Multi-Source Converter Configuration based Grid-interactive Microgrid[J]. IEEE Transactions on Industrial Electronics, 2020, 32(19):15–21.

[5] Zhangwenxia, liyanzhe, sunhuangjian, et al Study on systematic stability of DC microgrid with constant power load [J] Computer simulation, 2020, 37(3):6.

[6] Xu Litong, Cheng Ming, Wei Xinchi, Ning Xinfu. Power Signal Feedback Control of Maximum Power Point Tracking Control for Brushless Doubly-Fed Wind Power Generation System Considering Loss[J]. Transactions of China Electrotechnical Society, 2020, 35(3):472–480.

[7] Pan Ersheng, Wang Zhidong, Wang Dong, Liang Liang, Hou Yunhe. Stability Analysis of Phase-locked Loop Synchronized DFIGs in Weak Grids[J]. High Voltage Engineering, 2020, 46(1):170–177.

[8] Yamashita K, Tsukamoto G, Nishikata S. Steady-state characteristics of a line-commutated converter-based high-voltage direct current transmission system for series-connected wind power plants[J]. IEEE Transactions on Industry Applications, 2020, 56(4): 3932–3939.

[9] Kim G, J Hur. Probabilistic modeling of wind energy potential for power grid expansion planning[J]. Energy, 2021, 23(15):63–70.

[10] G.Y.E.O.N.G.M.I.N. Kim, Hur J. Probabilistic modeling of wind energy potential for power grid expansion planning[J]. Energy, 2021, 23(02):120831.

[11] Ranjan V, Arora A, Bhadu M. Stability Enhancement of Grid Connected AC Microgrid in Modern Power Systems[J]. 2022, 21(17):236–240.
[12] Mahdy A, Hasanien H M, Helmy W, et al. Transient stability improvement of wave energy conversion systems connected to power grid using anti-windup-coot optimization strategy[J]. Energy, 2022, 245.
[13] Pan L, Shao C. Wind energy conversion systems analysis of PMSG on offshore wind turbine using improved SMC and Extended State Observer[J]. Renewable Energy, 2020, 16(22):1463–1472.
[14] Zhou W, Wang Y, Torres-Olguin R E, et al. Effect of Reactive Power Characteristic of Offshore Wind Power Plant on Low-Frequency Stability[J]. IEEE Transactions on Energy Conversion, 2020, 35(2):837–853.
[15] Yan C, Yao W, Wen J, et al. Modelling and Comparison Analysis of Grid-Connected DFIG-based Wind Farm in Weak Grid[J]. IET Renewable Power Generation, 2020, 36(02):35–41.
[16] Nagaraj R, Murthy D T, Rajput M M. Modeling Renewables Based Hybrid Power System with Desalination Plant Load Using Neural Networks[J]. Distrib. Gener. Altern. Energy J, 2019, 34:32–46.
[17] Ghouari A, Hamouda C, Chaghi A, et al. An Experimental study on the smart home concept with PV and energy management and control strategy using an open source platform[J]. Distributed Generation & Alternative Energy Journal, 2019, 34(1):61–80.
[18] Mahajan S, Vadhera S. Optimal location and sizing of distributed generation unit using human opinion dynamics optimization technique[J]. Distributed Generation & Alternative Energy Journal, 2018, 33(2):38–57.

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