Research on Modeling of New Energy Power Plant Interface Characteristics Based on Computer Power Flow Calculation Model

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Abstract. In view of the adverse effects of wind power and photovoltaics as the representative of new energy power stations' active power output fluctuations on the security and stability of the grid, a solution to smooth the active power output of intermittent power sources using energy storage systems is presented. In this paper, the boundary coordination equation in the form of implicit function is used to model the coordinated solution of dynamic power flow equations in the whole network. This model can uniformly consider the reasonable distribution of boundary node power balance and unbalanced power among the district grids.

Keywords: Computer power flow calculation; new energy power station; grid connection; modelling.

1. Introduction
Dynamic power flow is the basic function of EMS and DTS systems. Its characteristic is to consider the adjustment characteristics of load and generators, and multiple generators share the unbalanced power of the system. Distributed dynamic power flow analysis based on decomposition and coordination mode is a new solution for online integrated power flow analysis of multiple dispatch centers that is suitable for the management characteristics of my country's power system. As an online application, distributed dynamic power flow calculation requires not only accurate calculation, but also a high calculation speed. The total time for a whole network power flow calculation should be less than the SCADA collection period (1-5 seconds). At present, research on intermittent new energy power stations that include energy storage systems are mainly focused on two aspects: energy management and energy storage technology applications. The former studies how to adjust the power output of wind and solar energy into high-quality power output; the latter is mainly aimed at the control strategy of energy storage systems under different control modes, as well as the use of energy storage systems to smooth out fluctuations in wind power and photovoltaic power generation, and improve the grid’s response to new energy. Acceptability [1].

Aiming at the adverse effects of the fluctuation of active power output of new energy power stations on the security and stability of the power grid, this paper presents a coordinated control strategy for smoothing the active power output of intermittent power supplies using energy storage systems, and
then establishes a model of hybrid wind-storage new energy power stations and connects them to the grid. Analysis of operating characteristics.

2. Grid-connected characteristics of wind and solar energy storage new energy

2.1. Working principle

The doubly-fed variable-speed constant-frequency wind power generator is mainly composed of a wind turbine, a gear box, a doubly-fed induction motor, a dual PWM converter, and a detection and control system. Its structure is shown in Figure 1.

The doubly-fed induction motor is mainly composed of stator windings and rotor windings. The number of poles of each winding is equal and the connection mode is three-phase symmetry [2]. The stator winding of the generator is directly connected to the grid, and the rotor winding is connected to the grid through two back-to-back converters. The doubly-fed induction motor completes the conversion of mechanical energy to electric energy. Under normal operation, its speed does not maintain a constant value. As an asynchronous motor, its speed range is relatively wide, which provides a prerequisite guarantee for variable-speed operation of doubly-fed asynchronous wind turbines.

1) Wind turbine power characteristics

The wind turbine captures the kinetic energy in the wind resource to drive the wind wheel to rotate, completing the process of capturing wind energy by the doubly-fed wind turbine. The efficiency of the wind turbine capturing and converting wind energy determines the efficiency of the power output of the doubly-fed asynchronous wind turbine. According to the principle of aerodynamics, when the sweeping area of the wind turbine wheel is $\pi R^2$ and the wind speed is stable at $v$, the wind power captured by the wind turbine is

$$P_v = \frac{1}{2} \rho v^3 \pi R^2$$  \hspace{1cm} (1)
In the formula, $\rho$ is the current air density and $R$ is the radius of the wind wheel. In fact, not all the wind energy captured by the sweep surface of the wind turbine blades can be absorbed and used. The conversion efficiency of wind energy depends on the utilization coefficient $C_p(\lambda, \beta)$ of wind energy.

$$C_p(\lambda, \beta) = \frac{P_m}{P_p}$$

In the formula, $\lambda$ is the ratio of blade tip speed, and its value is the ratio of the linear speed of the wind wheel to the wind speed when the wind wheel rotates at the angular speed $\omega_m$, namely $\omega_m R / V$; $\beta$ is the pitch angle; $P_m$ is the mechanical power output by the wind turbine. The expression is:

$$P_m = \frac{1}{2} \rho V^3 \pi R^2 C_p(\lambda, \beta)$$

2) Wind speed model construction

Wind energy is the energy source of wind power generation, and wind energy generates mechanical torque through wind turbine blades. The generated mechanical torque is directly related to wind speed. Therefore, the study of wind speed is the basis for simulating the entire wind power generation system. The wind shear on the ground surface causes the wind speed to change with height (the hub height effect). The mountain wind turbine converts the wind energy on the hub degree into mechanical energy, but the general wind speed measurement has a certain height difference from the wheel load. Suppose the hub degree is $H$, the wind speed at this height is $V_W$, the height of the wind speed measuring instrument is $H_0$, and the measured wind speed is $V_{W0}$. The relationship between $V_W$ and $V_{W0}$ is as follows:

$$V_W = V_{W0}(H / H_0)^{\alpha}$$

2.2. Reactive power compensation device

The SVC static reactive power compensator is composed of power electronic devices, and its high-frequency switch can realize fast and smooth compensation of reactive power. The static var compensator connects the capacitor and the controllable reactor in parallel, so that it cannot only send out reactive power through the capacitor, but also absorb reactive power through the controllable reactor, and realize the two-way dynamic adjustment of reactive power. In the wind power generation system, the static reactive power compensator can quickly make dynamic reactive power compensation for the voltage fluctuation of the wind farm caused by the wind speed change, and suppress the voltage fluctuation of the wind farm. For the system voltage drop caused by a short-circuit fault, when the protection device operates to remove the fault, the static var compensator can speed up the voltage recovery at the point of system voltage drop and improve the operation stability of the wind power system.

Commonly used static reactive power compensators include thyristor-controlled reactor TCR and thyristor switching capacitor TSC type. Thyristor control reactor TCR has the characteristics of fast speed, small size and light weight. It can be controlled by thyristor to realize fast and frequent adjustment. Reactive power compensation can also be carried out in phases, and accurate compensation can be achieved. There is no over compensation and under compensation. The situation occurs, but its single use can only output inductive reactive power. Thyristor switching capacitor TSC can only be switched in groups, and smooth compensation cannot be achieved when used alone. Therefore, the static var compensator often uses the thyristor control reactor + thyristor switching capacitor (TCR+TSC) compensation method for reactive power compensation. The structure of TCR+TSC static var compensator is shown in Figure 2.
Fig. 2 Schematic diagram of the structure of TCR+TSC static var compensator

The connection mode of the TCR+TSC static var compensator is triangular, the thyristor switches the capacitor for the coarse adjustment of the reactive power, the thyristor controls the reactor to perform the fine adjustment of the reactive power in phases, and the TCR+TSC type static var compensation A filter is installed in the device to effectively suppress harmonic generation. Adjust the reactive power output of the static var compensator, set the reference value of the voltage, realize the voltage adjustment of the compensation bus, and make it within the stable range [3].

3. Computer power flow calculation

3.1. Mathematical model of optimal power flow

Like power system reactive power optimization and distribution network failure recovery, the optimal power flow problem in the power system can also be expressed by mathematical formulas, and its mathematical model can be expressed as:

\[
\begin{align*}
\min f &= f(u,x) \\
s.t. & \ g(u,x) = 0 \\
& \ h(u,x) \leq 0
\end{align*}
\]

Among them, \( f(u,x) \) is the objective function; \( g(u,x) = 0 \) is the nodal balance equation; \( h(u,x) \leq 0 \) is the inequality constraint; \( u \) is the control variable, and \( x \) is the dependent variable of the control variable, including the node voltage to be determined. It can be seen from the above formula that the optimal power flow calculation of the power system is a typical multi-constraint problem, which integrates the objective function and the constraint function of the nonlinear programming problem. By using different objective functions and selecting different control variables, combined with the corresponding constraint conditions, the optimal power flow problem suitable for different solving objectives can be constructed [4].

3.2. Common objective functions of optimal power flow

For the multi-objective, nonlinear optimal power flow problem, the optimal power flow has multiple objective functions, and there are two most commonly used objective functions:

1) The total cost of power generation fuel for thermal power units in the whole system

\[
\min f = \sum_{i=1}^{NG} F_i(P_{Gi})
\]

Where: \( NG \) is the total number of generators, including the generators at the balance node; \( F_i(P_{Gi}) \) is the consumption characteristic of the \( i \) generator set; \( P_{Gi} \) is the active power generation of the generator set \( i \). The consumption characteristics of the unit are usually expressed by a quadratic function:

\[
F_i(P_{Gi}) = a_i P_{Gi}^2 + b_i P_{Gi} + c_i
\]

In the formula: \( a_i, b_i, \) and \( c_i \) are coefficients.

2) Active network loss
5

5

\[
\min f = \sum_{i,j \in \text{NL}} (P_i + P_j)
\]

Where: NL represents the set of all branches.

\[
f = \sum_{i=1}^{NG} P_{li}
\]

4. Grid-connected power flow calculation of new energy power stations

The type of intersection of the power angle swing curve of the doubly-fed asynchronous wind power generator and the synchronous generator determines the stability of the doubly-fed wind power system. Therefore, this section proposes to adopt a reasonable control strategy for the converter of the doubly-fed asynchronous wind power generator to change the active intersection point into a passive intersection point, so that the stability of the doubly-fed wind power generation system is enhanced. According to Figure 3, the goal of the control strategy is set to keep \( \delta_{\text{DFIG}} \) constant, and the conversion from the active intersection to the passive intersection can be completed.

Fig. 3 Vector diagram of a doubly-fed asynchronous wind turbine

4.1. Coordinate system transformation analysis of doubly-fed asynchronous wind turbine

The traditional double closed-loop control of doubly-fed asynchronous wind turbines pays attention to the decoupling control of active power and reactive power, and the control of the power angle is insufficient, which leads to large-scale fluctuations in the power angle of the doubly-fed wind turbine when the system has large disturbances. In order to effectively solve the problem of large-scale fluctuations of the power angle after the system is disturbed, an effective control strategy should be adopted for the power angle \( \delta \). The key to solving the problem is that it is necessary to measure the bus terminal voltage \( U \) at the access point of the doubly-fed wind turbine to obtain the power angle \( \delta \) during feedback control. However, the bus terminal voltage fluctuates greatly when the system is faulty and cannot be kept constant, making the measurement more difficult. Therefore, it is proposed to adopt a backup coordinate system when observing the bus terminal voltage to ensure that \( U \) remains unchanged during the fault. In the conventional vector control of doubly-fed asynchronous wind turbines, the coordinate system adopts the real-time coordinate system, that is, the rotating coordinate system formed by real-time observation of the motor flux value or voltage value. When the system is running normally, the real-time coordinate system rotates at a synchronous speed, and the standby coordinate system is only applicable when a fault occurs. The real-time coordinate system is still used before the fault occurs and after the fault is removed [5].
After accurate observation of $\theta_1$, it is concluded that $\sin \theta, \cos \theta$ is the key to establishing the alternate coordinate system. The conventional control of the doubly-fed wind turbine adopts a real-time coordinate system, and the three-phase voltage $v_a, v_b, v_c$ at the terminal is transformed by $3/2$, and then the rotation transformation is performed to obtain the output $\theta = \omega t + \theta_0$. The standby coordinate system obtains its output variable $\theta_j$ through real-time tracking of the changes $\omega_1$ and $\theta$ in the real-time coordinate system. The standby coordinate output $\theta = \theta_j$ under the normal operation of the system; when the system fails, the fault recognizer quickly responds to the fault state, and the tracking filter makes the time $t_j$ when the fault occurs. The output of the real-time coordinate system is $\theta_{f0} = \omega_1 t_j + \theta_0$. The control process adopts the standby after the fault the coordinate system output is $\theta_j = \omega_1 (t - t_j) + \theta_0$. The transformation relationship between the two coordinate systems is shown in Figure 4.

![Fig. 4 Coordinate system transformation relationship diagram](image)

### 4.2. Additional power angle control strategy

After the standby coordinate system is established, the power angle control of the doubly-fed asynchronous wind turbine can be completed when a fault occurs. The excitation control of the doubly-fed asynchronous wind turbine is a double closed-loop control, the current control loop is used as the inner loop, and the power control loop is used as the outer loop. The double closed-loop control strategy is improved to form an additional control strategy for power angle. The additional part of the control strategy is calculated from the reference values $\delta_{ref}$ and $p_{ref}$ of the power angle and active power to $dq$ obtain the command values $\psi_{r}'$ and $\psi_{l}'$ of the rotor flux axis component, and compare them with the rotor component feedback values $\psi_{r}^*$ and $\psi_{l}^*$ to obtain the deviation. The additional control values of the G-axis components $i_{qr}^*$ and $i_{dr}^*$ of the rotor current are obtained by the PI regulator, as shown in Figure 5. The additional control part is shown in the dashed box in the figure.

![Fig. 5 Additional power angle control strategy](image)
disturbance ability of the power angle of the doubly-fed wind turbine and improves the power angle stability of the doubly-fed wind turbine.

4.3. Example analysis

Build a simulation model of the power angle control system of the doubly-fed asynchronous wind turbine in the MATLAB/Simulink simulation platform, connect the doubly-fed asynchronous wind turbine to the single-machine infinity system, and connect the doubly-fed asynchronous wind turbine and the synchronous generator to infinity in parallel. In the two cases of the system, simulations verify and analyze the effectiveness of the additional power angle control strategy proposed in this chapter [6].

1) Connecting a doubly-fed asynchronous wind turbine to a single infinite bus

The wiring diagram of the doubly-fed asynchronous wind turbine connected to the infinity system is shown in Figure 6. It is assumed that a disconnection fault occurs in the double-circuit transmission line at t=0.75s, and the disconnection fault is eliminated at t=1.0s. Power transmission back.

Fig. 6 Wiring diagram of double-fed asynchronous wind turbine connected to large system

The power angle swing curve when the doubly-fed wind generator adopts the traditional double closed-loop control strategy is compared with the power angle swing curve when the additional power angle control strategy is adopted, as shown in Figure 7. When the system has a fault disturbance, when the traditional double closed-loop control strategy is adopted, the maximum swing of the power angle of the doubly-fed asynchronous wind turbine reaches 126°. When the additional power angle control strategy is adopted, the maximum power angle swing of the doubly-fed asynchronous wind turbine is 63°. The comparison of the two power angle swing curves shows that when the additional power angle control strategy is applied, the power angle swing amplitude is significantly reduced when the disturbance occurs, which greatly enhances the power angle stability of the doubly-fed asynchronous wind turbine [7].

Fig. 7 Comparison of power angle swing curves
2) Parallel connection of doubly-fed asynchronous wind generators and synchronous generators to the infinity system

The parallel operation of the doubly-fed asynchronous wind generator set and the synchronous generator shown in Fig. 7 are connected to the infinity system to analyze the additional power angle control strategy. Suppose that at $t=0.35\text{s}$, a disconnection fault occurs in one of the double-circuit transmission lines of the system, and the disconnection fault is eliminated at $t=0.4\text{s}$ and the double-circuit transmission restarts. The power angle swing curve of synchronous generator G1 when the doubly-fed asynchronous wind turbine adopts the traditional double closed-loop control strategy and when the additional power angle control strategy is adopted is compared, as shown in Fig. 8.

![Fig. 8 G1 power angle swing curve comparison chart](image)

When a fault occurs in the system, when the traditional double closed-loop control strategy is adopted, the G1 power angle of the synchronous generator set parallel to the doubly-fed wind turbine has a maximum swing of $91^\circ$. When the additional power angle control strategy is adopted, the maximum swing of G1 power angle is $69^\circ$. The comparison of the two power angle swing curves shows that when the additional power angle control strategy is applied, it can not only reduce the power angle swing of the doubly-fed wind turbine, but also strengthen the power angle stability of the synchronous generator set running in parallel with it, which is beneficial to improve the overall stability of the wind power system when it is disturbed.

5. Conclusion

Optimal power flow is one of the most important tools in current power system dispatch and operation. At present, more and more wind farms are integrated into the grid on a large scale and in a centralized manner. In order to improve the utilization rate of wind power, reduce the operating cost of the system, and meet the economic and safety requirements of power system operation, it is necessary to conduct in-depth research on the optimal power flow problem. In the traditional optimal power flow of the power system, the output power of the generator set is adjustable and deterministic. After the wind power is connected to the grid, the uncertain factors in the operation of the power system increase, which raises the economic and safe operation of the power system. new challenge. Therefore, studying the optimal power flow problem under large-scale wind power integration is an important content of modern power system operation, and it is of great significance to ensure the safe and economic operation of the system. Compared with traditional energy, the biggest feature of new energy represented by wind power is its uncertainty, which is an intermittent and random energy. However, the current optimal power flow procedures mostly presuppose the principle of determinism, and it is difficult to deal with the uncertainty brought about by large-scale wind power integration. In the power system, there are two main ideas for
dealing with uncertainty. The first is to improve the accuracy of wind power prediction; the second is to consider the impact of uncertainty in the model.

Acknowledgments
Fund Projects: Scientific Research Program Funded by Shaanxi Provincial Education Department (Program No.20JK0749).

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