Parameter Optimization of Doubly-Fed Induction Generator Based on Intelligent Optimization Algorithm

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Abstract. The doubly-fed wind power generator control system consists of multiple PI controllers, each of which directly affects the dynamic characteristics of the wind power system. In this paper, a particle swarm optimization algorithm with improved inertia weight is used to simulate and analyze the control system optimized by algorithm. It is found that the improved characteristic curve has the advantages of small overshoot, fast adjustment speed and short adjustment time. The effectiveness and superiority of the particle swarm optimization algorithm for PI controller parameters optimization.

1. Introduction
Among various new energy power generation technologies, wind power generation has the advantages of large construction scale, high economic value, low resource consumption, and no environmental pollution [1]. Therefore, it has been widely used. The doubly-fed wind power generator has the characteristics of variable speed constant frequency, and can realize the decoupling control of active power and reactive power [2]. The controller part of the doubly-fed wind power generator is composed of multiple PI controllers. The parameters of each PI controller will affect the overall performance. Therefore, multiple controller parameters must be optimized to make the doubly-fed induction generator (DFIG) have better external characteristic.

2. Doubly-fed wind power generator model
The doubly-fed wind power generator model includes a wind turbine blade, a gearbox, a rotor winding, a stator winding, and a "back-to-back" converter. The following part mainly models the controller part of DFIG.

2.1. DFIG rotor-side controller model
The rotor-side converter transfer function model is shown in Figure 1.

In the stator field orientation mode, the rotor current active component \(i_{qr}\) can control the stator winding active power \(P_s\), the reactive component \(i_{dr}\) can control the stator winding reactive power \(Q_s\), and there is no coupling relationship between \(i_{qr}\) and \(i_{dr}\), therefore, adjust \(i_{qr}\) and control \(P_s\) does not affect \(Q_s\), and vice versa. The rotor-side converter is a double closed-loop structure, the outer ring is a speed control loop, and the inner ring is a rotor current control loop. The gain parameters of the
respective PI controllers are \( K_{pω}, K_{iω}, K_{pl}, K_{il} \) (for the convenience of the following calculation. They are denoted as \( K_{pp2}, K_{i2}, K_{pp3}, K_{i3} \), respectively. By adjusting \( K_{pp3} \) and \( K_{i3} \), the rotor current active component \( i_{qr} \) and the reactive component \( i_{dr} \) can be controlled to control the stator winding active power \( P_s \) and the reactive power \( Q_s \) of the doubly-fed motor, respectively.

**Figure 1.** DFIG rotor-side converter transfer function model.

2.2. DFIG grid-side controller model

The grid side controller is used to maintain the capacitor voltage and control the system output converter reactive power constant. The capacitor voltage is controlled by the \( d \)-axis current component of the grid side converter, and the \( q \)-axis current component controls the reactive power. Let the \( d \)-axis be along the grid voltage direction, and the \( q \)-axis lead the \( d \)-axis 90° in the direction of rotation. If the grid voltage is constant, then the grid voltage vector is constant in the \( d \) and \( q \)-axis components, then the active power exchanged between the grid-side converter and the grid \( P_g \) and reactive power \( Q_g \) will be controlled respectively by the component of the grid-side converter current vector on the \( d \)-axis and \( q \)-axis. The grid-side converter transfer function model is shown in Figure 2 below:

**Figure 2.** DFIG grid-side converter transfer function model.

In Figure 2, \( U_{dc} \) is the DC voltage, and \( \sigma = 1 - \frac{L_m}{L_s L_r} \) is the leakage flux coefficient of the generator. The grid-side converter adopts a double closed-loop cascade structure of a DC voltage outer loop and an alternating current inner loop. The PI controller including the voltage outer loop and the current inner loop has controller parameters \( K_{pu}, K_{iu} \) and \( K_{pl}, K_{il} \) (They are denoted as \( K_{pp}, K_{i} \) and \( K_{pp1}, K_{i1} \), respectively), and by adjusting \( K_{pp}, K_{i1} \) and \( K_{pp1}, K_{i1} \), the grid side current components \( i_{gd} \) and \( i_{gq} \) can be adjusted to control the active power \( P_g \) and the reactive power \( Q_g \).

3. Parameter optimization of DFIG PI controller based on improved particle swarm optimization algorithm

According to the chapter 2, there are 4 PI controllers for the DFIG: grid side voltage outer loop PI controller, current inner loop PI controller, rotor side speed outer loop PI controller, current inner loop PI controller, to be optimized. The parameters to be optimized are \([K_{pp}, K_{i}, K_{pp1}, K_{i1}, K_{pp2}, K_{i2}, K_{pp3}, K_{i3}]\).

In this paper, we will select the integral \( P_{s,ITAE} \) of the absolute value of the active power error on the stator side and the time product as the performance index. The smaller the performance index, the better the result. The expression is as shown in Equation 1 below:

\[
J_{ITAE} = P_{s,ITAE} = \int_0^{T_s} t|e(t)|dt
\]
3.1. Particle swarm optimization algorithm with improved inertia weight

Particle swarm optimization (PSO) algorithm is derived from the study of bird predation behavior. It is an iterative optimization algorithm. The system is initialized to a set of random solutions that search for the optimal value by iteration. The algorithm can approach the optimal solution at a very fast speed, and the algorithm is relatively simple. However, it has the disadvantages of being easy to fall into the local optimal solution, and being easy to premature[3].

Inertia weight is a very important parameter in the PSO algorithm, which determines the impact of particle history speed information on current speed information. It can adjust the balance between the global search ability of the algorithm and the local search ability. When the inertia factor is large, it is more conducive to global search, while the smaller inertia factor is beneficial to local search[4].

By referring to the literature, we know that when $\omega=0.9$, the global search ability is the best; when $\omega=0.4$, the local search ability is optimal[5]. Therefore, instead of keeping $\omega$ constant, a strategy of decreasing the inertia weight is used instead. $\omega$ is set to 0.9 at the beginning of the iteration. As the number of iterations increases, $\omega$ decays and eventually decays to 0.4. The law is expressed by Equation 2:

$$\omega(k) = \omega_{\text{start}}(\omega_{\text{start}} - \omega_{\text{end}})(T_{\text{max}} - k)/T_{\text{max}}$$

In the formula, $\omega_{\text{start}}$ is the initial inertia weight, in order to ensure the global search ability is better, set to 0.9, $\omega_{\text{end}}$ is the iterative termination inertia weight, in order to ensure the local search ability is better, set to 0.4. $T_{\text{max}}$ is the maximum number of iterations, and $k$ is the algebra of the current iteration. In other words, the inertia weight $\omega$ will adopt a linear decreasing manner. As the number of iterations increases, $\omega$ gradually decreases linearly until the maximum iteration algebra is reached. In theory, the global search ability and the local search ability can be optimized at the same time.

3.2. Optimization example

Six DFIGs in MATLAB/Simulink were used as optimization examples. The rated power of each generator is 1.5MW, $R_s = 0.023, R_r = 0.016, L_s = 0.18, L_r = 0.16, L_m = 2.9$, and the moment of inertia is 0.83, which are all standard values. After 120kv three-phase AC power supply, 120/25kv step-down transformer, 30km transmission line and 25/0.575kv are connected to the wind turbine and connected to the grid. The wind speed is set to 15m/s without changing. The simulation model of the example is shown in Figure 3:

![DFIG MATLAB/Simulink study simulation model](image)

Figure 3. DFIG MATLAB/Simulink study simulation model.

The model is optimized and simulated according to the optimization steps of the PSO algorithm. The adaptive value iterative curve of the improved inertia weight particle swarm optimization algorithm is
drawn by programming, and is placed in the same coordinate system as the adaptive value iteration curve obtained by the standard particle swarm optimization algorithm, as shown in Figure 4:

![Optimal individual fitness value](image)

**Figure 4.** PSO algorithm and improved PSO algorithm adaptive value iterative curve.

It can be seen from Fig. 4 that the improved PSO algorithm adapts to the fast convergence rate, reaches the steady state earlier, and obtains the global optimal solution.

In order to better verify the effectiveness of the improved PSO algorithm, three common operating conditions of voltage drop, single-phase short-circuit and wind speed step are set respectively, and the active power and reactive power are simulated to obtain the unused optimization algorithm and use improved inertia. The active power and reactive power curves optimized by the weight particle swarm optimization algorithm are shown in Figure 5 respectively:

![Active power and reactive power characteristic curves](image)

**Figure 5.** Active power and reactive power characteristic curves under two strategies (From top to bottom are voltage drop, single phase short circuit and wind speed step simulation).
4. Conclusion
Through the iterative curve of the ITAE performance under the two strategies of using the standard PSO algorithm and the PSO algorithm with improved inertia weight, it is found that the iterative curve of the improved PSO algorithm has strong global search ability and can better avoid the local optimal solution. The global optimal solution is obtained by iterating fewer times than the standard PSO algorithm.

Under the two strategies of parameter optimization without PSO algorithm and PSO algorithm with improved inertia weight, it is found that the improved PSO algorithm power curve is over-adjusted to different degrees under different operating conditions. Small, the adjustment time is shortened, which verifies the effectiveness and superiority of the improved PSO algorithm for PI controller parameter optimization.

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