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Wind Power Virtual Inertia Frequency Modulation Control Based on Intelligent Swarm Auto-Disturbance Rejection

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Abstract. This paper proposes a wind power virtual inertia control strategy based on the intelligent bee colony active disturbance rejection controller (ABC-ADRC). The proposed control method aims to improve the anti-interference capability of the virtual inertia control system and solve the challenge of tuning the parameters of the active disturbance rejection control (ADRC).The control strategy is developed based on the system frequency dynamic response equation. An active disturbance rejection controller is designed using a nonlinear feedback control law and an extended state observer. This controller aims to enhance the system's ability to reject disturbances. However, tuning the parameters of the ADRC can be difficult. To address this issue, an ABC algorithm based on nectar collection behavior is proposed to iteratively optimize the ADRC parameters. The proposed control method is verified through simulations using Matlab/Simulink. The results demonstrate that the ABC-ADRC control strategy is more effective compared to traditional algorithms. It successfully controls the rotor speed to adjust the frequency of the power grid system, achieves power sharing, and eliminates adaptive noise. Furthermore, this method reduces the complexity of parameter settings, improves anti-interference ability, and enhances the robustness of the system.

Keywords. DFIG Virtual inertia; Proportion-differentiation (PD); Active Disturbance Rejection Control (ADRC)

1. Introduction

In contemporary wind power systems, wind turbines (WTs) using doubly fed induction generators (DFIG) play a very important role. These turbines possess variable speed operation characteristics and are capable of achieving maximum power tracking at various wind speeds [1]. However, in maximum power point tracking (MPPT) control, the driving system of wind turbine is completely independent from the grid. As a result, the turbine's speed and power are no longer affected by changes in the grid frequency. This decoupling greatly reduces the relative inertia of the wind power generation system.

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The ability of the wind power system to automatically respond to frequency fluctuations is a crucial aspect of its frequency support [2]. Therefore, reducing the impact of grid frequency fluctuations on wind power systems and improving their anti-interference ability is crucial.

A crucial component of ADRC is the extended state observer (ESO), which demonstrates remarkable interference and noise suppression capabilities [3-4]. The ADRC not only has faster response and smaller overshoot than PID control, but also effectively attenuates unknown disturbances, exhibits excellent adaptability to external disturbances, and ensures system stability [5]. Several studies have demonstrated the successful application of ADRC in different control systems with impressive control performance [6-8]. Additionally, combining ADRC with the inertia control method has resulted in significant improvements in system frequency fluctuation amplitude and settling time [9-10].

Therefore, this paper proposes an adaptive inertia simulation strategy based on the ABC-ADRC. This method utilizes the bee colony optimization algorithm to optimize the parameters of the extended state observer. This optimization process ensures that the observer performs optimally, further improving the system's accuracy.

2. Improved Design of ADRC Using Differential Bee Colony Algorithm

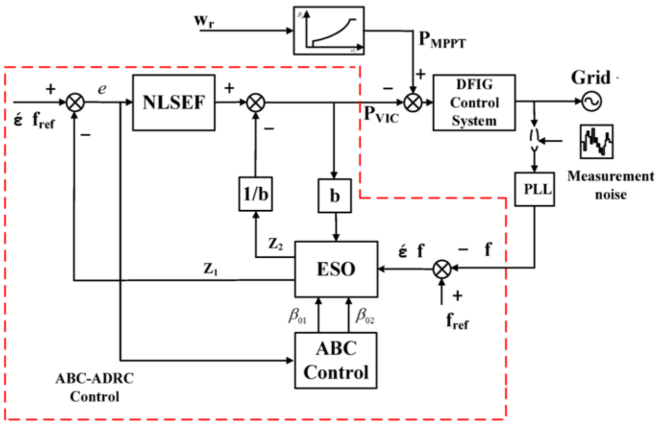

Figure 1. Structure diagram of wind power virtual inertia control based on ABC-ADRC

The bee colony auto-disturbance rejection controller mainly uses auto-disturbance rejection technology, and achieves optimal adaptive control by designing bee colony honey picking rules to adjust the specific parameters of the ESO in the auto-disturbance rejection controller online. The basic structure of the self-disturbance rejection controller designed in this section is shown in the red part of figure 1, which includes a nonlinear feedback control law and an extended state observer; f_{ref} is the target frequency, which is different from the actual measured frequency to obtain Δf; The difference of Δf_{ref} and ESO output value z_1 is reduced by NLEFS to obtain another output value of ESO as compensation power P_{VIC},as to achieve the goal of frequency stability of the whole power grid.

2.1. Design of Extended State Observer (ESO)

ESO can achieve real-time observation of state variables, as follows:

$$\begin{cases} e = z_1 - y \\ \dot{\hat{z}}_1 = z_2 + bu - \beta_{01} e \\ \dot{\hat{z}}_2 = -\beta_{02} e \end{cases} \quad (1)$$

Where, z_1、 z_2——the observed amount of the system to the state variables x_1 and x_2. β_{01} and β_{02}——the controller parameters.

2.2. Design of Nonlinear State Error Feedback (NLEFS)

The linear state error feedback law of the system can be obtained as:

$$\begin{cases} \varepsilon = \Delta f_{ref} - z_1 \\ u_0(t) = k\varepsilon \\ u(t) = u_0(t) - z_2/b \end{cases} \quad (2)$$

Where, k—the feedback proportional parameter.

2.3. Design of Auto-disturbance Rejection Controller Based On ABC

This chapter combines the mutation operation in differential evolution algorithm with artificial bee colony algorithm to improve the search mode of hired bees, and applies the algorithm to the self-disturbance rejection controller.

1) Initialize parameters, generate an initial solution set x_{ij} within the set range, where x_{ij} represents a set of parameters $\{\beta_{01}, \beta_{02}\}$ for a set of ADRC controllers, and calculate the fitness value of each solution.

2) Hire bees to search for nectar sources and calculate their adaptability. Improve the search mode of hired bees and apply the differential evolution model to the search process of hired bees.

$$x'_{ij} = x_{ij} + F \cdot \left(x_{best,j} - x_{ij}\right) + F \cdot (x_{r_1,j} - x_{r_{2,j}}) \quad (3)$$

Where, F is an adaptive scaling factor, the value of which will affect the diversity and convergence speed of the evolutionary process, the value range in this article is between [0, 1].

3) Hiring bees adopts a greedy selection approach towards new and original solutions, which preserves control parameters that improve ADRC's control performance as a high-quality solution. The probability value of this solution is calculated using the following formula, where f_i represents the applicability of the i-th solution:

$$P_i = \frac{f_i}{\sum_{n=1}^{SN} f_n} \quad (4)$$

4) Search for bees to select new and original solutions (hiring bees to select the solution), and retain the optimal solution. After several cycles, if the applicability of a solution is worth improving, it is recorded as the best solution. Otherwise, the solution is discarded. And hire bees to become reconnaissance bees and continue searching. Determine whether the stop condition has been met (usually reaching the maximum number of cycles), if so, output the optimal solution, otherwise continue with step 2.

3. Simulation Verification

This article simulates the frequency support capability of wind turbines when the load suddenly increases at a wind speed of 11m/s, and compares and analyzes the frequency modulation performance of different control methods under the same conditions:

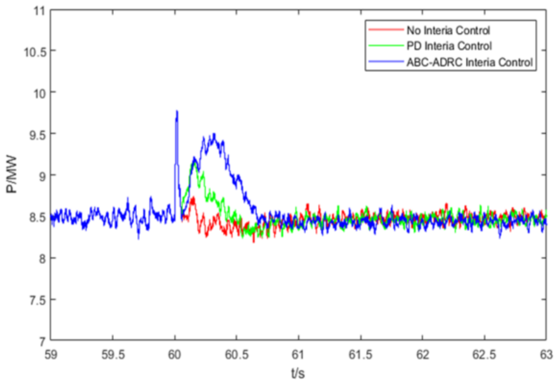

Figure 2. Active power output of wind turbines under different control methods.

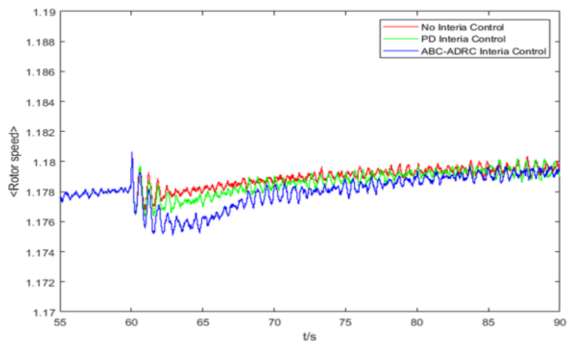

Figure 3. Rotor speed of wind turbines under different control methods.

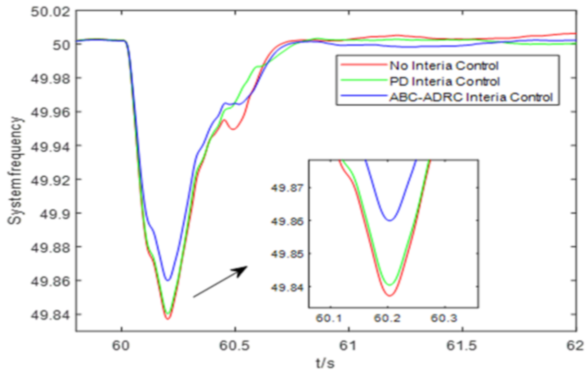

Figure 4. Frequency of wind power system under different control methods.

Figure 2, figure 3 and figure 4 show that the virtual inertia control can effectively suppress the frequency drop by reducing the rotor speed to release the rotor energy when the wind power system frequency decreases. Compared with traditional PD virtual inertia control, the proposed ABC-ADRC inertia control method can more effectively release rotor energy, increase wind turbine output power, and thus reduce the peak value of wind power frequency decrease. Therefore, the proposed ABC-ADRC inertial control method can more effectively suppress wind power frequency fluctuations, thereby providing better inertial support for the power grid.

4. Conclusions

This article proposes an improved ADRC virtual inertial control method for frequency fluctuations in doubly fed wind power generation. The controller utilizes an ADRC that is established using the parameter optimization function of the Bee Colony Algorithm (ABC). The ABC optimizes the parameters of the ESO in the ADRC in real time by monitoring and providing feedback on the system frequency. From the simulation results, it can be seen that the proposed ABC-ADRC inertial control can effectively improve frequency fluctuations in the power grid. Thus improving the safety and stability of the wind power grid when the event of frequency events occur.

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