Optimization of controlling parameters of DFIG and battery energy storage combined frequency modulation based on PSO

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Abstract. Wind power has randomicity and intermittence. As the wind power penetration rate increases, it poses a threat to the frequency of the power grid. In the power systems with high-permeability of wind power, relying solely on conventional crew tuning is no longer sufficient to ensure that the frequency is within safe limits. The battery energy storage has a fast response speed, but it is expensive. The frequency regulation provided by the wind farm itself has a short inertial control support time, the pitch control response is slow, and both frequency modulation methods are subject to wind speed. In order to improve the frequency adjustment capability of the wind farm, the battery energy storage and the wind farm's own frequency modulation means are combined to adjust the system frequency. However, how to set the battery energy storage output to make the system frequency characteristics optimal hasn't been studied. In this paper, the particle swarm optimization algorithm is used to select the optimal parameters, so that the frequency characteristics are optimal. The example shows that compared with the unoptimized energy storage frequency modulation coefficient, the optimal frequency modulation coefficient found by the PSO algorithm can greatly reduce the maximum frequency drop of the power system and improve the frequency stability of the power system.

1. Introduction

Wind power is a clean energy source, but its power varies with the fluctuation of wind speed. Its proportion in the power system is increasing, which reduces the pollution and also adversely affects the frequency of the power grid [1].

1) At present, the variable-speed doubly-fed wind turbines of mainstream wind turbines adopts the maximum power control operation mode. This control method increases the efficiency of wind energy utilization and also makes the variable speed wind turbines unable to provide frequency support to the power system [2].

2) The variable speed wind turbines replaces the traditional generator set, which reduces the inertia of the system. In order to ensure that the frequency of the power system is within the safe range, there are also technical requirements for the wind turbine to participate in frequency modulation [3].

In order to solve the problem of insufficient frequency modulation capacity in wind power high-permeability power system, the current grid-connected wind farm needs to provide the same rotating standby, inertial response and primary frequency modulation functions as conventional power plants [4-5]. At present, wind power frequency modulation research is mainly focus on three aspects, wind turbine, wind farm and system. The main research of this paper is the joint operation level of wind power and energy storage, that is, the system layer.
Compared with other energy storage methods, the energy storage battery system has the characteristics of fast response, precise tracking, large capacity, long energy storage period, etc., and coordinated with the wind farm to improve the system frequency modulation efficiency and economy. The energy storage battery device is arranged on the side of the wind farm to coordinate the energy storage battery with the wind farm to form a system for joint operation of the wind storage. The principle of energy storage battery system and wind turbine participating in power grid frequency modulation is to store electric energy when wind power generation is greater than electricity consumption, to prevent system frequency from rising; to release stored energy when wind power generation is less than electricity, to prevent further system frequency fall [6].

In [7], in order to balance the service life of battery storage batteries with the requirements of battery frequency modulation, an adaptive frequency modulation strategy based on the state of charge (SOC) is proposed, taking into account the service life of energy storage batteries and the frequency support of the power grid.

Based on the frequency characteristics model of wind farm and energy storage system, the frequency characteristic model of power system under wind-fed combined frequency modulation is established in the literature [8]. The power system frequency under wind power frequency modulation, energy storage frequency modulation and wind storage combined frequency modulation is compared and analyzed. Characteristics, but directly compare the stored energy FM parameters with the fan frequency modulation parameters, which does not optimize the joint operation of the wind storage.

In order to make the wind reservoirs better united and realize the frequency support of the grid, this paper proposes a method to optimize the energy storage FM parameters by using the improved particle swarm optimization algorithm. The maximum frequency drop is selected as the optimization objective function, and after iterative optimization, the optimal parameters are obtained.

2. DFIG and battery energy storage combined frequency modulation control strategy

2.1. Wind power frequency characteristic model

2.1.1. Rotor inertia control. Rotor inertia control is to change the given current of the rotor-side converter when the system frequency is detected, the rotor speed changes accordingly, and the kinetic energy of the “hidden” of the wind turbine is quickly released/absorbed, which is similar to the inertia of the conventional unit. Role [9]. The inertia control of the rotor has short response time, fast response speed and small time scale. It is very suitable for simulating the inertial response of conventional units. The transfer function involved in frequency modulation is:

\[ G_d(s) = \frac{\Delta P_d}{\Delta f} = -\frac{K_{wd}s}{1+T_w s} \]  

In equation (1): \( K_{wd} \) is the inertia response coefficient; \( T_w \) is the rotor inertia response time constant; \( \Delta P_d \) provides power for the rotor inertia.

2.1.2. Pitch control. The pitch control is to increase the pitch angle so that the fan is not in the maximum power tracking control mode, thus leaving a certain frequency modulation capacity. Pitch angle control has strong adjustment ability and large adjustment range, which can realize power control under full wind speed [10]. However, since the actuator is a mechanical component, the response speed is slow; and when the pitch angle changes too frequently, the mechanical wear of the unit is easily aggravated, the service life is shortened, and the maintenance cost is increased. In general, pitch control is mostly used for working conditions above the rated wind speed, and the backup support is more effective when the system frequency is lowered. In this case, the time that the fan participates in the system frequency adjustment is longer. Therefore, the characteristics of the wind turbine pitch control technology are suitable for simulating the primary frequency modulation of the traditional power supply, and the transfer function of the frequency model is
In equation (2): $K_{wp}$ is a primary frequency modulation coefficient; $T_\beta$ is a pitch response time constant; $\Delta P_\beta$ provides power for pitch control.

2.2. Energy storage system frequency characteristic model

The energy storage system has the advantages of fast response, flexible controllability and stable operation. The wind farm is equipped with an appropriate amount of energy storage system to meet the frequency modulation requirements of the power system for the wind farm, so that the wind farm has an inertial response similar to that of a conventional power source. One frequency tuning capability. The energy storage model can be represented by a first-order transfer function, where $T_E$ is the energy storage response time constant and $\Delta P_E$ is the power supplied only when the energy is stored. The energy transfer system frequency model transfer function is:

$$G_E(s) = \frac{\Delta P_E}{\Delta f} = -\frac{K_{ed} + K_{ep}}{1 + T_E s} \quad (3)$$

In equation (3), $K_{ed}$ is the inertial response coefficient of the energy storage battery, and $K_{ep}$ is the primary frequency modulation coefficient of the energy storage battery.

2.3. System frequency control model under wind-storage coordinated frequency modulation

![Power system regional equivalent frequency control model](image)

In Figure 1, $K_G$ is the unit power of the traditional power supply, $K_{df}$ is the inertia response coefficient of the doubly-fed fan, the value is 8, $K_{pf}$ is the primary frequency modulation coefficient of the doubly-fed fan, the value is 20, $K_{ed}$ is the inertial response coefficient of the energy storage battery, $K_{ep}$ is the primary frequency modulation factor of the energy storage battery. $T_\beta$ is the pitch response time constant, and $T_w$ is the rotor inertia response time constant. $T_G$ is the time constant of the traditional power supply regulator, the value is 0.08s, $T_{ch}$ is the steam turbine time constant, the value is 0.3s, $T_{RH}$ is the reheater time constant, the value is 10s; $F_{HP}$ is the reheater gain, the standard value is 0.5; $M$ and $D$ are the grid inertia time constant and load damping coefficient, corresponding to the standard values of 8 and 2;

3. Parameter optimization

Particle swarm optimization is an intelligent optimization algorithm without gradient information. When using particle swarm optimization to optimize the optimal parameters of the control system, you don't need to know the detailed information of the system model. You only need to determine the optimization target and the range of values to find the system. The optimal solution for the parameter[11-12].

$$v_{i+1} = w v_i + c_1 r_1 (p_i^1 - x_i^1) + c_2 r_2 (p_i^2 - x_i^2) \quad (4)$$
The flow of the basic PSO algorithm can be summarized as:
1) Set basic parameters such as the corresponding population size and maximum number of iterations, and assign values to the initial position and velocity of the particles;
2) Solving the fitness value according to the corresponding objective function;
3) updating the individual optimal value;
4) updating the global optimal value;
5) Calculate the velocity and position of each particle according to formula (4) (5);
6) Stop the calculation when the maximum number of iterations is reached, otherwise return to step 2 to continue the iteration. (Fig. 2)

3.1. Objective function
So that the system frequency drop amplitude is the smallest when the load suddenly increases

3.2. Flow chart

Figure 2. PSO algorithm optimization flow chart.

4. Case analysis
According to Figure 1, a power system regional equivalent frequency control model with conventional thermal power units, doubly-fed fans and energy storage batteries is built in MATLAB/simulink. The total load of the system is taken as 2000MW, and the rated power of the wind turbine is 400MW. The energy storage battery is concentrated in the wind farm connected to the power grid, and the load disturbance is 120MW. It is assumed that the capacity of the energy storage battery is sufficient and the state of charge of the battery (SOC) is within the optimal state of charge.

4.1. Frequency characteristics analysis when rated wind speed
At rated wind speed, the wind power penetration rate is 20%. The simulation analysis shows that wind power does not participate in frequency modulation, wind power separately participates in frequency modulation, and energy storage separately participates in frequency modulation and wind storage combined with frequency modulation. The system frequency characteristics change is shown in Fig. 3. At this time, the method in the literature "Analysis of Frequency Characteristics of Power System
under Combined Wind Turbine Frequency Modulation" is adopted to take the same parameters of energy storage parameters and doubly-fed wind turbines.

![System frequency response curve under different frequency modulation strategies.](image)

**Figure 3.** System frequency response curve under different frequency modulation strategies.

It is found from Fig. 3 that the wind power participates in the frequency modulation to provide the inertial response and the frequency modulation spare capacity, so that the lowest frequency of the system frequency is increased under disturbance, the steady-state frequency deviation is reduced, the frequency characteristics are better than the fan and the energy storage are not involved in the frequency modulation; When frequency modulation is used, the lowest frequency of the power system is also improved; compared with the single frequency modulation and the energy storage battery alone frequency modulation of the doubly-fed wind turbine, the wind storage combined frequency modulation further reduces the system frequency change rate, raises the lowest frequency point, and enhances the system transient frequency stability.

4.2. After using particle swarm optimization algorithm to optimize

After optimization by PSO algorithm, the obtained parameters are $K_{ed}$ of 5.509 and $K_{ep}$ of 26.997.

![Frequency response curve under different parameters.](image)

**Figure 4.** Frequency response curve under different parameters.

As can be seen from Fig. 4, after the parameter is optimized by the particle swarm optimization algorithm, when the system frequency lowest point is directly the same as the frequency modulation coefficient of the energy storage battery and the frequency modulation coefficient of the doubly-fed fan, the maximum frequency drop of the system frequency is significantly reduced, and the frequency rises also faster.

5. Conclusion

In view of the frequency drop caused by insufficient inertia of the system after wind power grid connection, the control strategy of wind storage and joint participation in frequency modulation is studied. It is found that compared with the double-fed fan alone, the frequency modulation and energy storage battery are separately frequency modulated, and the wind storage combined frequency modulation can improve the frequency stability of the power system. For the problem that the output parameter of the energy storage battery cannot be determined to minimize the maximum drop point of the system frequency, the particle swarm optimization algorithm is used to optimize the energy storage output parameter, and the energy storage frequency modulation parameter is directly the same as the
inertia frequency modulation and the primary frequency modulation parameter of the doubly-fed fan. The comparison found that the frequency stability of the power system is greatly improved.

6. References

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Acknowledgements

This work is supported by Postgraduate Research &Practice Innovation Program of Jiangsu Province (KYCX18_1228).