Dynamic Control Method of Thermal Power Units Compensating for Wind Power Disturbance

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Abstract. The randomness and volatility of wind power generation are the main reasons restricting the capacity of power grid to absorb wind power. Thermal power units are the main force of power grid frequency modulation. The speed of load adjustment rate determines their response ability to power grid load. Based on the analysis of the characteristics of wind power generation, the nonlinear multiscale decomposition of the automatic power generation control (AGC) load command is carried out. Combined with the different load regulation rates of different types of units, the rational allocation of unit combinations can effectively ensure the power grid load regulation capacity and compensate the random disturbance of wind power.

1. Introduction

Wind power, photovoltaic power generation and other new energy power generation technologies are one of the important means to solve the global energy crisis, but the intermittent and random characteristics restrict their large-scale access to the power grid. In recent years, renewable energy represented by wind power has achieved rapid development, and wind power has become a very important clean energy in the grid. However, due to the randomness, intermittently and inverse peak regulation[1] characteristics of wind power, large-scale grid connection of wind power can easily lead to the frequent start and stop of thermal power units within days or deep peak regulation. It brings great challenges to the actual dispatching operation of the power grid and restricts the further consumption of wind power to a large extent[2,3]. Therefore, it is particularly necessary to establish a multi-source coordination and dispatching mechanism in the power system containing wind power and give full play to the complementary characteristics of flexible power supply and power supply[4,5], so as to deal with the uncertain problem of wind power and improve the capacity of wind power acceptance.

At present, thermal power generation in China’s power structure will still occupy a large proportion. Thermal power generating load-pressure object has the characteristics of large inertia and large delay[6]. In order to improve the response rate of the unit load to meet the requirements of the power grid, it is necessary to make full and rational use of energy storage of the unit. Energy storage of thermal power unit plays an important role in the regulation of AGC. Thermal power units essentially complete the conversion process from fuel chemical energy to electric energy, and in fact, more or less energy is stored in each link of the conversion process[7,8]. At present, in the design scheme of coordinated control system, the scheme of boiler with machine makes use of the heat storage of water cooling wall, steam drum, super-heater and other steam pipe(i.e. boiler heat storage) to improve the
response rate of the unit load, but it will cause the fluctuation of the pressure before the turbine and affect the safe and economic operation of the unit. It is important that how to make full use of the heat storage of the unit, reasonably configure the type of the unit, use different load adjustment rate of different units to eliminate the fluctuation of wind power generation, and increase the absorption of new energy. The method of using unit energy storage to improve the response speed of unit load has the following characteristics. The units and wind power units in the regional power grid can realize local absorption of impact power of wind power generation. The basic theory and engineering technology of thermal process of thermal power generation are mature. The energy storage unit can be used to reduce the combustion disturbance and the fluctuation of main parameters, which is beneficial to the stable operation of the unit and reduce the coal consumption of power supply.

2. Wind Power Control characteristics
Wind power uncertainty mainly embodied in the randomness and fuzziness of the two aspects[9], its mechanism and nature sources include two type. One is natural fluctuations and intermittent randomness, divided into endogenous randomness and wake the weather system, the effect of local incentives, such as terrain of randomness, weather system transient (wind conditions occur discontinuous changes quickly, and the start time, duration, frequency characteristics, regularity of elements such as difficult to master), the presence of turbulence (amplitude and frequency pulsating wind variety with time and irregular), etc. Another is the fuzziness of the wind-electricity conversion process, such as the actual relationship between the wind speed and the output power is not clear (especially at the inflection point of the power curve).

![Figure 1. The output variation curve of one 99MW wind farm unit](image)

The output level of wind power generation is closely related to the wind speed of wind farm. As shown in the Figure 1, the output variation curve of one 99MW wind farm unit. It can be seen that the variation range and rate of wind power generation are very drastic, beyond the range of traditional thermal power units to compensate. When wind turbines are connected to the grid on a large scale, the uncertainty of their generating power will cause great disturbance to the power grid. The overall peak and frequency regulation capacity of generating units in the regional grid will largely determine the capacity of the grid to accept wind power load[10-12].

3. Power Grid AGC Control and Load Command Decomposition
Frequency regulation of power system is inherent in the use of system load frequency characteristics, as well as the role of the generator's governor to prevent the system frequency deviation from the standard adjustment method. The grid frequency is determined by the value of generated energy and electricity consumption. AGC is one of the important measures to regulate the frequency and active power of power grid and ensure its security and economic operation.
3.1. Grid AGC control requirements

According to the rules of Dispatch center, the operation of AGC must to be run in accordance with the scheduling curve, it put forward higher requirements on control system of the unit. The full load of power generation is the test of the device; the variable load is the test of the whole control system. How to on the basis of existing equipment, optimize the control strategy, realize the load control requirements, and ensure stable operation of the unit, is a problem that must be considered.

Adjustment rate, adjustment accuracy and response time is three main criteria of AGC assessment. According to the requirement of dispatch center, the rate of pulverizing system and drum boiler unit is 1.5%Pe/min (Pe is unit's rated power), thermal power units with intermediate storage pulverizing system is 2%Pe/min, circulating fluidized bed coal-fired units is 1%Pe/min, super-critical once-through boiler unit is 1.0%Pe/min. Adjustment accuracy is the difference between the actual output of unit and the set point of EMS when unit work stably after a response, permissible deviation is 1% of unit's rated active power. Response time refers to, after the EMS system send commands, on the basis of the original output point, the time that the output of generating unit reliably adjust to across adjusting dead zone to need. AGC response time of thermal power unit should be less than 1 minute.

3.2. AGC load instruction decomposition

Different decomposition methods can be used to decompose the AGC load command of power grid. In order to analyze the characteristics of load command signal in more detail, multiscale analysis method is generally used to analyze the space-time characteristics of load command. The most common multiscale analysis method is wavelet analysis, but it has the shortcomings of unclear physical meaning and complex calculation process. Literature[13] studied a simple and clear physical meaning of signal multiscale decomposition method. However, it should be noted that the modules on the grid side that give the load rise and fall rates of the AGC command are given in a nonlinear manner. The purpose of increasing the rate limit on the command side is to prevent the control system from applying an excessive amount of control to the controlled object when the command changes, resulting in the control mechanism operating speed exceeding its performance allowable range or causing unacceptable disturbance to the controlled object. The nonlinear rate restriction has a more effective effect on the protection of the actuator and the controlled object, which can be simply interpreted as, the larger the amplitude of input command signal is, the slower the system is allowed to operate. This is consistent with the general laws of physics and engineering.

In order to analyze the characteristics of load command signals in more detail, based on the linear multiscale decomposition method, a more practical nonlinear filter decomposition method is proposed.

The signal \( x_0(s) \) can be decomposed into

\[
x_0(s) = N_0(x)x_0(s) + (1 - N_0(x))x_0(s)
\]

Let \( x_{hi}(s) = (1 - N_i(x))x_0(s), \quad x_i(s) = N_i(x)x_0(s) \), continue to decompose \( x_i(s) \) to get

\[
x_i(s) = N_i(x)x_i(s) + (1 - N_i(x))x_i(s)
\]

Let \( x_{h2}(s) = (1 - N_i(x))x_i(s), \quad x_2(s) = N_i(x)x_i(s) \), continue to decompose \( x_2(s) \).

By the same token, let \( x_{hi(n+1)}(s) = (1 - N_{i+1}(x))x_n(s), \quad x_{n+1}(s) = N_{i+1}(x)x_n(s) \)

\[
x_{n+1}(s) = N_{i+1}(x)x_{n+1}(s) - (1 - N_{i+1}(x))x_{n+1}(s) \quad n = 0,1,\ldots,N
\]

And so on, the formula can be broken down continuously. Finally available

\[
x_0(s) = x_{h1}(s) + x_{h2}(s) + \cdots + x_{h(n+1)}(s) + x_{n+1}(s) \quad n = 0,1,\ldots,N
\]

In the above equation, \( N_0(x), N_1(x), \ldots, N_{n+1}(x) \) is the description function of the nonlinear link. Rate limiting non-line is adopted here to limit the first derivative of the input signal, so that the change rate of the signal does not exceed the specified limit value.

The description function of the rate-limiting nonlinear link is obtained according to literature[14]. And the input and output characteristics of the rate-limiting nonlinear link are

\[
3
\]
\[
y(i) = \begin{cases} 
\Delta t R + y(i-1) & r > R \\
-\Delta t R + y(i-1) & r < -R \\
u(i) & -R < r < R 
\end{cases}
\]

\[R = \frac{u(i) - y(i-1)}{t(i) - t(i-1)}\]

Where, \( r \) is the speed, \( R \) is the speed limit value set. \( u(i) \), \( y(i) \) and \( t(i) \) are the input signal, output signal and time of the rate-limiting link at the current moment respectively. \( y(i-1) \) and \( t(i-1) \) are the output signal and time of the previous sampling time respectively.

4. Optimization Control and Effect

The actual load instructions of thermal power units are decomposed into three categories according to different rates. For some unit can fully accept the load instruction, load rate is 1%\( \text{Pe}/\text{min} \). For some unit reluctantly accepted load instructions, load rate is (1%~3%)\( \text{Pe}/\text{min} \). For some unit can not accept and respond to the load command, the load rate is higher than 3%\( \text{Pe}/\text{min} \). Multiscale filter are designed according to the above frequency range to decompose the actual load instructions of the unit. When the grid dispatching center issues AGC instructions to thermal power units, it generally adopts two modes, namely manual setting mode and automatic adjustment mode. Within a certain ACE range, AGC units with appropriate number of units can be matched to meet the load demand of the grid. When abnormal events occur in the power grid, such as fast fluctuation of wind power and dc blocking fault, ACE overshoot will be caused. At this time, adjustment can be made in two ways. First, the unit in the manual setting mode needs to be partially increased from the original lower load regulation rate to a faster regulation rate. Second, the unit in automatic adjustment mode compensates at a faster rate. The first approach involves changes in control mode and rate of adjustment, which are longer in time scale than the second approach. In order to speed up the restoration of power network, a multiscale control method based on dynamic monitoring and adjustment of unit regulation rate is designed. That is to say, when the ACE produces a large deviation, the adjustment rate will be adjusted differently according to the different regulating capacity of the unit.

First of all, according to the size of the ACE undertake convert by dead zone and nonlinear function, calculated the added value of power needed for the overall adjustment rate, then according to the monitoring to the unit parameters and assign it to different units, distribution need to meet \( \Delta R = \Delta R_1 + \Delta R_2 + \cdots + \Delta R_n \), among them, \( \Delta R \) is the added value of the total adjustment rate for power grid, \( \Delta R_i \) is each unit to increase the rate of regulating value, it can be zero.
Figure 2. The monitoring and control system of adjustment rate

As shown in Figure 2, the control system obtains the operating status and power status of the wind power and thermal power units from the supervisory control and data acquisition (SCADA). The system monitors the power and ACE changes in real time, and changes the unit’s rate based on the size of the ACE.

Figure 3. The frequency fluctuation curve of the power grid

As shown in Figure 3, the frequency fluctuation of the power grid is effectively guaranteed and can be controlled within ±0.1Hz after optimization and regulation.

5. Conclusion

In order to give full play to the ability of thermal units to participate in grid’s frequency control under the large-scale wind power, the optimization control method based on wind power characteristics and thermal power adjustable rate is proposed. The randomness and volatility of wind power generation are the main reasons restricting the capacity of power grid to absorb wind power. Thermal power units are the main force of power grid frequency modulation. The speed of load adjustment rate determines their response ability to power grid load. Based on the analysis of the characteristics of wind power generation, the nonlinear multiscale decomposition of the automatic power generation control (AGC) load command is carried out. Combined with the different load regulation rates of different types of units, the rational allocation of unit combinations can effectively ensure the power grid load regulation.
capacity and compensate the random disturbance of wind power. The effectiveness of the proposed method can improve the response capacity of thermal unit.

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