Study on Power Grid Emergency Optimization Control Based on Wind and Thermal Power Adjustable Capacity

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Abstract. In order to enhance the ability of thermal unit to participate in fault recovery under the large-scale wind power consumption and grid’s power loss, the power grid emergency optimization control method based on wind power and thermal power adjustable capacity is proposed. Based on the analysis of the influencing factors of wind power, considering the matching operating conditions of wind power output, the strategy of unit lockout control under grid over-frequency is proposed. According to the regional control error(ACE) of the power grid, one power emergency control method based on one-key climbing is constructed. The scheme can make full use of the thermal power unit load regulation space and short-term rapid adjustment rate to improve the grid’s ability to cope with large power loss and ensure grid frequency stability.

1. Introduction

In the context of the current global environmental pollution and energy crisis, renewable energy represented by wind power is regarded as one of the main energy sources that can replace traditional thermal power generation[1-2]. However, compared with traditional energy sources, the output of wind power has intermittent and random nature. There is a large error in wind power output prediction, and the error size fluctuates greatly with the difference of output level and prediction period. Large-scale wind power grid connection has an impact on the safe and stable operation of the power system [3-4]. If the wind power consumption cannot be accurately assessed, the system will have to face severe operational challenges, such as load fluctuations, congestion, insufficient climbing ability, and may even lead to the emergence of extreme operating modes, which seriously threaten the safety of the system[5-7]. Grid-connected power generation requires conventional units to provide peaking services. At the present stage, China’s peaking auxiliary service compensation mechanism has not been perfected. The peaking load regulation depth of thermal power units can only be compensated if it reaches more than 50%. It is difficult to mobilize its enthusiasm to participate in peaking load regulation[8], which makes the phenomenon of wind abandon often happen.

When high-power fluctuations occur in wind power, the safety and stability control system, primary frequency control, etc. gradually ends, and the automatic generation control(AGC) units should fill the remaining power shortage as soon as possible. In order to strengthen the control effect of AGC in the action stage, continuous improvement should be made in two aspects. For one thing, the collaborative control level of AGC units in multiple control areas need to be deepened, and the dynamic regional control need to be carried out according to the ACE[9]. For another, it is necessary
to make full use of provincial adjustment resources, and the AGC units participates in the frequency recovery adjustment in an orderly and efficiently way.

2. Wind Power Statistics Method

Uncertainties in wind power system scheduling problems are caused by uncertain wind power integration, while wind power uncertainty is caused by intermittent, random wind speeds. In the joint dispatch of wind and thermal power, when the wind power input capacity is too large, the corresponding distribution probability is small, which brings great uncertainty to the grid system operation, and thus brings high risks to the system operation.

The research results show that the Weibull distribution is more suitable for the statistical description of wind speed[10], so this paper assumes that the wind speed is subject to the Weibull distribution. The probability density function \( f(v) \) and the cumulative probability density function \( F(v) \) of the wind speed \( v \) are expressed as follows:

\[
f(v) = \frac{k}{c} \left( \frac{v}{c} \right)^{k-1} e^{-\left( \frac{v}{c} \right)^k} \tag{1}
\]

\[
F(v) = \int_0^v f(x)dx = 1 - e^{-\left( \frac{v}{c} \right)^k} \tag{2}
\]

Where, \( k \) and \( c \) are the eigenvalues of the Weibull distribution shape parameters and the distribution function respectively.

Given the probability \( \alpha \), the confidence level of the wind speed is \( 1 - \alpha \), and the upper and lower bounds of the wind speed confidence interval can be calculated by the following formula:

\[
\begin{align*}
F(v_L) &= 1 - e^{-\left( \frac{v_L}{c} \right)^k} = \frac{1}{2} \alpha \\
F(v_U) &= 1 - e^{-\left( \frac{v_U}{c} \right)^k} = 1 - \frac{1}{2} \alpha
\end{align*}
\]

Namely,

\[
\begin{align*}
v_L &= c \left\{ -\ln \left( 1 - \frac{1}{2} \alpha \right) \right\}^{\frac{1}{k}} \\
v_U &= c \left\{ -\ln \left( \frac{1}{2} \alpha \right) \right\}^{\frac{1}{k}}
\end{align*}
\]

Where, \( v_U \) and \( v_L \) are the upper and lower boundary of wind speed respectively, and the confidence interval of wind speed is \([v_L, v_U]\). The relationship between the output power of the fan and the wind speed can be approximated by equation(5).

\[
P_W = \begin{cases} 
0 & 0 \leq v < v_{ci} \\
a + bv^3 & v_{ci} \leq v < v_{na} \\
Pr & v_{na} \leq v \leq v_{co} \\
0 & v > v_{co}
\end{cases}
\]

In the formula, \( a = P_{na}v_{ci}^3 \), \( b = P_{na}v_{ci}^3 / (v_{ci}^3 - v_{na}^3) \); \( v, v_{ci}, v_{na}, v_{co} \) are actual wind speed, cut-in wind speed, rated wind speed and cut-out wind speed.
3. Calculation of Wind and Thermal Power Output Constraint

The wind power in the grid system is controlled by the normal load regulation means. Generally, the shutdown operation is not performed, and the wind power output curve of the entire power grid is obtained according to the optimization of the grid capacity. At the same time, the grid management part will stipulate the load reference value of one unit operation, and use this value as the boundary of reward and punishment. Taking the Shandong power’s peaking auxiliary service operation rule as an example, it take 70% of the thermal unit’s maximum output as the normal reference value.

The load balance constraint condition of the power grid is

\[ p_w(t) + \sum_{i=1}^{N_o} p_i(t) = p_t(t) \quad t = 1, 2, \ldots, T \]  \hspace{1cm} (6)

In the formula (6), \( N_o \) represents the number of operating units, \( p_w(t) \) is the total wind power at t time, \( p_i(t) \) is the power of thermal unit i at t time, \( p_t(t) \) is the total power of power grid.

System rotation reserve constraint is

\[ \sum_{i=1}^{N_o} r_i(t) \geq p_r(t) \]  \hspace{1cm} (7)

In the formula (7), \( r_i(t) \) is the rotation reserve provided by unit i at t time. \( p_r(t) \) is the rotation reserve requirement of the grid system at t time.

The unit’s output high and low limit constraints are

\[ p_{il} \leq p_i(t) + r_i(t) \leq p_{ih} \]  \hspace{1cm} (8)

In the formula (8), \( P_{il} \) is the unit’s output high limit value, \( P_{ih} \) is the unit’s output low limit value.

Unit climbing constraints are

\[ -\Delta p_i \leq p_i(t) - p_i(t-1) \leq \Delta p_i \]  \hspace{1cm} (9)

In the formula (9), \( \Delta p_i \) is the maximum value of the changeable load of the unit i at t time.

As shown in Figure 1, under one certain condition of the total load demand of the power grid, when wind power fluctuates, thermal power units need to act in reverse with wind power to maintain the balance between supply and demand, and ensure the stability of the power grid frequency. In other words, the thermal power units need to be operated with corresponding load regulation rate and load regulation space.
4. Optimization and Improvement Program
When there are the large-scale power loss in the power grid or larger wind power fluctuations, the existing AGC control strategy cannot effectively ensure that the frequency of rapid regression to 50Hz, therefore, power grid need to enhance the ACE and AGC function optimization.

4.1. Over-frequency control strategy
After the lack of power grid disturbance, the grid system frequency will drop sharply and the power flow will also be complicated. In the short term, because of the delay time of the power data acquisition in the tie-line exchange, or the frequency deviation coefficient B is bigger and different from the actual situation of the power grid, it is possible that the ACE calculated by the AGC cannot reflect the real grid region control deviation. At this time, if the ACE calculation result is positive, the AGC has the possibility to issue an instruction to the automatic mode unit to reduce the output, further deteriorating the system frequency. In addition, after the failure of the unit power generation plan if not adjusted in time, AGC plan to track the implementation of the model unit is still possible to reduce the load, it is not conducive to disturbance recovery.

![AGC block based on grid frequency](image)

Figure 2. AGC block based on grid frequency

As shown in Figure 2, the key of the over-frequency control strategy is to monitor the grid system frequency is higher or lower than the preset over-frequency threshold, the automatic mode unit to prohibit issued under the power output instructions. At present, the grid regulations that the off-limit frequency value is 0.1Hz. That is, when the grid frequency is higher than 50.1 Hz or lower than 49.9 Hz, the AGC needs to perform corresponding blocking increase or blocking decrease. To avoid power grid failure after the ACE numerical abnormalities or power generation plan is not timely adjusted to further deteriorate the system frequency. After the system frequency returns to the normal range, the over-frequency control strategy will automatically exit, and the unit will reduce the force to forbid the behavior to be canceled, and turn into the normal control strategy. Over-frequency control strategy starts or exits will have the corresponding alarm.

4.2. One-key climbing functions
When there are a large scale grid power failure, the power grid need to quickly increase the number of thermal unit, the general automatic control or telephone scheduling methods cannot to meet the operational requirements. The one-key climbing function of units only need one grid’s operator to operate one key on the screen.

![Structure of emergency control](image)

Figure 3. Structure of emergency control

As shown in Figure 3, the emergency 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 integrated intelligent alarm (ISA) monitors the power and frequency changes in real
time. When an abnormality occurs, the ISA determines the required power and power adjustment rate according to the ACE, and issues a command to the qualified unit through the load batch control system to realize rapid adjustment of the rotating standby and quickly compensate the power gap. At the same time, grid operators can set the required power value and required adjustment rate for one-key climbing in the load batch control loop based on the size of the ACE.

5. Conclusion

In order to enhance the ability of thermal unit to participate in fault recovery under the large-scale wind power consumption and grid’s power loss, the power grid emergency optimization control method based on wind power and thermal power adjustable capacity is proposed. Based on the analysis of the influencing factors of wind power, considering the matching operating conditions of wind power output, the strategy of unit lockout control under grid over-frequency is proposed. According to the ACE, a power emergency control method based on one-key climbing is constructed. The scheme can make full use of the thermal power unit load regulation space and short-term rapid adjustment rate to improve the grid’s ability to cope with large power loss and ensure grid frequency stability. Based on the practical operation strategies of the provincial ultrahigh voltage receiving-end power grid, the effectiveness of the proposed method to improve the response capacity of thermal unit under a high power loss is verified.

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