Research and Application of Grid AGC Collaborative Real-time Control Method Based on Wind Power Forecast Deviation

Jun Li\textsuperscript{1,a}, Yong Wang\textsuperscript{2}, DaPeng Liao\textsuperscript{2}, XingWu Ding\textsuperscript{3} and Tao Wang\textsuperscript{4}

\textsuperscript{1}State Grid Shandong Electric Power Research Institute, Ji’nan, Shandong 250002, China
\textsuperscript{2}State Grid Shandong Electric Power Company, Ji’nan, Shandong 250001, China
\textsuperscript{3}Huaneng Shandong Power Generation Co., Ltd, Ji’nan, Shandong 250014, China
\textsuperscript{4}Shandong Naxin Electric Power Technology Co., Ltd, Ji’nan, Shandong 250101, China

\textsuperscript{a} Corresponding author: lijun_sdu@hotmail.com

Abstract. New energy sources such as wind power are developing rapidly, which contributes to the green development of society and economy. However, wind power is a fluctuating power source with uncontrollable power. It is necessary to predict the power capacity of wind power generation and reasonably allocate the operation mode of thermal power units to realize the grid's absorption of wind power. By analyzing the influence of the wind power output prediction error on the grid area control error (ACE), the number of inputs of the thermal power unit's automatic generation control (AGC) mode is dynamically adjusted in real time to meet the load adjustment rate required for the ACE change. The results show that this method can effectively improve the load regulation capacity of the power grid, improve the consumption capacity of wind power and other new energy sources, and ensure the stability of the power grid frequency.

1. Introduction

According to the White Paper 2018 on Promoting New Energy Development issued by China State Grid, by 2017, the cumulative installed capacity of China's new energy power generation is 293.39 million kilowatts, accounting for 17% of the national power installed capacity. The new installed capacity of new energy power generation is 68.09 million kilowatts, accounting for 52% of the new installed power capacity of China. Among them, the cumulative installed capacity of wind power is 163.67 million kilowatts, an increase of 10% year-on-year, and the new installed capacity is 15.03 million kilowatts. Vigorously developing wind energy resources and partially replacing conventional power generation will contribute to the realization of energy conservation and emission reduction targets. However, wind farm output is highly random due to conditions such as regional wind speed, and it belongs to the uncontrollable power fluctuating power source\cite{1-3}. At the same time, due to factors such as uncoordinated network source planning, limited local consumption space, insufficient frequency modulation and peaking capacity, the average utilization hours of wind power equipment are 1948 hours. In three north regions, there is a serious contradiction between the consumption of new energy resources and the annual rate of wind abandoning in Gansu, Xinjiang and Jilin provinces.
is over 20%. Under the state policy of priority and full deployment of wind power plants, the influence of large capacity wind power plants usually connected to UHV transmission network on the stable operation of the power system, and it is directly related to the prediction accuracy of wind power output.

Because of the intermittency of wind energy and the non-linearity of power system, there exist many uncertain variables which should be considered in the wind power prediction. Although there are many theories and methods of forecasting wind speed, the accuracy of wind forecast is still not ideal[4,5]. Generally, there will be certain errors in the prediction of wind farm output. The prediction error of wind farm output before 1h is more than 10%. The randomness and uncertainty of wind power increase the fluctuation amplitude and rate of the net load of the system. The AGC of the thermal power unit is mainly responsible for the adjustment and compensation tasks.

2. Grid AGC System and Performance Evaluation Standard

At present, the power grid dispatch control department sets the thermal power unit output plan value according to the load forecast, power generation plan, exchange plan, and unit combination, as shown in Figure 1.

2.1. Grid AGC System

The power supply reference point of the thermal power unit in the power grid is determined by the dispatch control center through the ultra-short-term load and wind power forecasting information in the planning process. The basis point and participation factor of each unit are the results of the planned output optimization, and the rolling optimization is performed every 15 minutes and remains unchanged during the time period. At the same time, the ACE value is allocated to the unit in AGC mode according to certain strategy, and the AGC unit will eliminate this part of power deviation, so as to ensure the stability of the power grid frequency. Since AGC is included in the auxiliary service transaction in the power market, and the order of unit input is determined by the bidding mechanism, the number of unit in AGC mode is limited within a certain period of time.

![Frequency fluctuation curve](image)

The computer system of dispatch center runs all the application software of the energy management system (EMS), which mainly includes three parts, supervisory control and data acquisition (SCADA), real-time network analysis and grid AGC. The real-time data flow between them is shown in Figure 2. The grid AGC obtains the real-time measurement data of the grid from SCADA, and obtains the sensitivity of the network loss to the unit output from the real-time network analysis, and then obtains the unit network loss correction coefficient required in the economic dispatch, also called the penalty factor. Grid AGC obtains other sensitivity information for safety correction control, etc. Grid AGC also sends unit's planning information to real-time network analysis.
2.2 Grid AGC Control Performance Evaluation Standard

The China Grid’s AGC control performance evaluation standards mainly adopt A1/A2 and CPS1/CPS2 standards of North American Electric Reliability Council[6,7]. Generally speaking, the CPS1/CPS2 standards are more favourable for ensuring the quality of power grid’s frequency, and are conducive to the mutual support of the regional power in the accident. There are two main modes of assessment of power grid PFC performance, speed governing droop method and integral power contribution index method.

The contents of CPS1/CPS2 standards are as follows, requirements of CPS1 is

\[
\epsilon \leq \Delta \times \left(\frac{1}{10/FACE_{AVG}}\right)
\]

\[
(1)
\]

\[
\text{periodAVG} \text{is the average value in parentheses. } \text{min} \text{ is the average value of 1 minute ACE, which requires to be sampled once every 2 second, and 30 values are averaged.}\n\]

\[
\text{min} \text{ is the average value of 1 minute frequency deviation, which requires to be sampled once every 1 second, and 60 values are averaged.}\n\]

\[
\text{B_i} \text{ is the deviation coefficient of the control region. } \epsilon_i \text{ is the control target value which is the mean square root of the interconnection power grid for the average annual frequency deviation of 1min. The physical significance of } \text{min} \text{ is the control region is represented by the low frequency but too much output or the high frequency when the value is negative, the control region is represented by the low frequency but too small output or the high frequency when the value is positive.}\n\]

The statistical formula of the CPS1 index for a period of time is

\[
\%100 \times (\frac{1}{\epsilon_i}) \leq \text{CFK} (2)
\]

\[
\%200 \times (\frac{1}{\epsilon_i}) \leq \text{CFK} (3)
\]

\[
\text{K_CPSI} = (2 - K_{CF}) \times 100\%
\]

\[
K_{CF} = \sum [ACE_{AVE-min} \times \Delta F_{AVE-min} / (10B_i)] / n \times \epsilon_i^2 (4)
\]

\[
\text{In the above equation, there are two key points, } K_{CPSI} = 100\% \text{ and } K_{CPSI} = 200\%.\n\]

When \( K_{CPSI} \geq 200\% \), or \( K_{CF} \leq 0 \), it must be

\[
\sum [ACE_{AVE-min} \times \Delta F_{AVE-min}] \leq 0 (4)
\]

This indicates that during this period, ACE is helpful to the quality of interconnected power grid’s frequency.

When \( 100\% \leq K_{CPSI} < 200\% \), or \( 0 < K_{CF} \leq 1 \), it must be
\[ \sum [ACE_{AVE-min} \times \Delta F_{AVE-min}] \geq 0 \]  
\[ \sum [ACE_{AVE-min} \times \Delta F_{AVE-min}] / n \leq \epsilon^2 \]  

This indicates that ACE has an adverse effect on the quality of the power grid’s frequency, but not exceeding the allowable level.

When \( K_{CPSI} < 100\% \), or \( K_{CPSI} < 100\% \), it must be
\[ \sum [ACE_{AVE-min} \times \Delta F_{AVE-min}] \geq 0 \]  
\[ \sum [ACE_{AVE-min} \times \Delta F_{AVE-min}] / n \leq \epsilon^2 \]  

This indicates that ACE has an adverse effect on the quality of the power grid’s frequency and exceeds the allowable range. The standard requires that the average ACE of 10 minutes must be controlled within the specified range \( L_{10} \).

\[ L_{10} = 1.65 \epsilon_{10} \times \text{sqrt}[(10B_i) \times (10B_i)] \]  

\( B_i \) is the frequency deviation coefficient of the control region, and \( B_i \) is the frequency deviation coefficient of the whole interconnected power grid. \( \epsilon_{10} \) is the control target value which is the mean square roots of the interconnected power grid for the average annual frequency deviation of 10 minute.

Using the CPS standard, the evaluation of contribution to the frequency quality of the power grid in each control area is very clear. It is particularly beneficial to support other control areas in the event of a control area accident and to give full play to the superiority of the large power grid.

3. Problems and Solutions

3.1 Problems

The existence of wind power output prediction error will inevitably affect the accuracy of the unit's output reference point setting, which will result in a deviation between the thermal power unit output and the planned value in the local time period.

If the ultra-short-term forecast value of wind power is large, such as the deviation of the forecast value of 15 min in the day, the actual wind power corresponding to the forecast value increases or decreases greatly in a single direction, which will cause the regulation ability of power grid to decrease, cause the power grid ACE over-limit problem. It cannot meet the requirements of safe and stable operation of the power grid. So, it is necessary to adjust the power output of wind power to ensure the stability of the power grid frequency, and the wind abandoning phenomenon will be generated. On the other hand, the thermal power unit has the AGC adjustment capability, the adjustment rate can be improved by the flexible adjustment of the thermal power unit, thereby achieving the maximum consumption of wind power.

3.2 Control method and System Structure

According to the deviation between the measured value and the forecast value of the wind power of the grid and the deviation of the grid area control deviation, the grid AGC system determines whether it is necessary to adjust the thermal power unit in the AGC mode. The selection of the thermal power unit needs to be adjusted from the grid side and the power side. The working conditions at both ends are determined together, the grid side depends on the rate of change of the measured value between the wind power and the predicted value, and the power source side depends on whether the thermal power unit has the AGC input condition and the load adjustment rate that the unit can achieve. The system structure of the design is shown in Figure 3.
4. Practical Application

Taking the Grid of Shandong province as an example, the data of March 14 is used for calculation. The maximum output of the grid wind power is 15360MW at 00:05, and the minimum value is 2839MW at 10:00. The upper limit of ACE is 120 MW and the lower limit is -120 MW. Take the data from 14:00 to 18:00 on March 14 as an example for analysis. The data is shown in Table 1, and the corresponding line chart is shown in Figure 4.

At 14:15, the deviation between the measured value and the forecast value of wind power is 114.32MW. At this time, the A1 value of the analog generator is $49.86 \times 3\% = 146.91$. That is, the value of the input terminal X1 of the comparator block CMP1 is 114.32, and the value of the input terminal X2 is 146.91. Since X1 is smaller than X2, the output of the comparator block CMP1 is low level 0, that is, the input terminal Z1 of the logic AND module AND is Low level 0, logic and module AND output is low level 0, that is, there is no need to adjust the number of thermal power units running in AGC mode in the grid.

Table 1. Short-term Data of Wind Power

| Time   | Measured Value | Forecast Value for 15min | Deviation | Rate of Deviation Change |
|--------|----------------|--------------------------|-----------|--------------------------|
| 14:00  | 4969.83        | 5009.97                  | -40.14    | 0.78                     |
| 14:15  | 5011.18        | 4896.86                  | 114.32    | 10.30                    |
| 14:30  | 4993.28        | 4755.17                  | 238.11    | 8.25                     |
| 14:45  | 4842.75        | 4805.75                  | 37.00     | -13.41                   |
| 15:00  | 4793.47        | 4815.11                  | -21.64    | -3.91                    |
| 15:15  | 4770.24        | 4831.06                  | -60.82    | -2.61                    |
| 15:30  | 4851.50        | 4906.69                  | -55.19    | 0.38                     |
| 15:45  | 4884.51        | 4869.62                  | 14.89     | 4.67                     |
| 16:00  | 4913.28        | 4818.83                  | 94.45     | 5.30                     |
| 16:15  | 4848.30        | 4827.18                  | 21.12     | -4.89                    |
At 14:30, the deviation between the measured value of wind power obtained by DEV1 and the forecast value of wind power is 238.11 MW. At this time, the value of the analog generator A1 is \(4755.17 \times 3\% = 142.66\).

That is, the input terminal X1 of the comparator block CMP1 has a value of 238.11, and the input terminal X2 has a value of 142.66. Since X1 is greater than X2, the output of the comparator block CMP1 is at a high level 1, that is, the input terminal Z1 of the logic AND module AND is high level 1. At this time, the ACE is 108, and the analog generator A2 value is 100, so the value of the input terminal X1 of the comparator block CMP2 is greater than the value of the input terminal X2, and the output of the comparator block CMP2 is high level 1. That is, the input terminal Z2 of the logic AND module AND is high level 1, the output of the logic AND module AND is high level 1, which informs the number of thermal power units in the AGC mode operation in the grid needs to be adjusted.

5. Conclusion
According to the deviation between the measured value and the forecast value of the wind power of the grid and the deviation of the grid area control deviation, one grid AGC collaborative real-time control method is considered. The grid AGC system determines whether unit’s AGC mode operation is required. The adjustment of the thermal power unit needs to be adjusted. The choice of the thermal power unit is determined by the working conditions of the power supply side and the power supply side. The power grid side depends on the rate of change of the measured value between the wind power and the predicted value. The power supply side depends on whether the thermal power unit has AGC input conditions and the load regulation rate that the unit can achieve. The method proposed in this paper comprehensively considers the change of grid regional control deviation and the variation and trend of grid-connected wind power generation, dynamically adjusts the input quantity of grid AGC mode unit, improves the load regulation capacity of the grid, and ensures the stability of grid frequency.

References
[1] Rawn B G, Lehn P W, Maggiore M. Control methodology to mitigate the grid impact of wind turbines[J]. IEEE Transactions on Energy Conversion,2007,22(2):431-438.
[2] Xiaoqing Han, Yushu Chen, Zhong Wu. Research on frequency regulation of power system containing wind farm[J]. Probabilistic Methods Applied to Power Systems(PMAPS), 2010:14-17.

[3] Tang Xisheng, Miao Fufeng, Qi Zhiping, et al. Survey on frequency control of wind power[J]. Proceedings of the CSEE, 2014, 34(25):4304-4314.

[4] Kristoffersen J R, Christiansen P. Horns rev offshore wind farm: its main controller and remote control system[J]. Wind Engineering 2003, 27(5):351-359.

[5] Fu Yuan, Wang Yi, Zhang Xiangyu, et al. Analysis and integrated control of inertia and primary frequency regulation for variable speed wind turbines[J]. Proceedings of the CSEE, 2014, 34(27):4706-4716.

[6] Li Bin, Wei Hua, Nong Weitao, et al. Study of minimum AGC capacity under control performance standard for interconnected power grid[J]. Proceedings of the CSEE, 2009, 29(13):59-64.

[7] Gao Zonghe, Ding Yi, Wen Bojian, et al. AGC-in-advance based on super-short-term load forecasting[J]. Automation of Electric Power Systems, 2000, 24(11):42-44.