Optimal Design and Application of AGC Performance Index Measurement Standards for Generating Units Adapted To the China Southern Regional Frequency Regulation Auxiliary Service Market

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Abstract. With the advancement of the construction of the China southern regional frequency regulation auxiliary service market, the calculation method of the AGC performance index of the generator set needs to be further optimized. To this end, an optimization scheme for calculating the AGC performance index of generator sets that is suitable for the China southern regional frequency regulation auxiliary service market is proposed. First, the demand for AGC unit participation in the frequency regulation market is analyzed, and a model for AGC unit participation in the frequency regulation market is established. Through theoretical analysis and data comparison, it is shown that the traditional calculation method of AGC frequency modulation performance index is not suitable for the calculation of AGC performance of FM market units. Aiming at the key content of the frequency modulation market for the AGC performance requirements of the unit, a suitable calculation method is proposed. Finally, the actual case that illustrates the applicability of the index calculation method in this paper is analyzed.

Keywords: Frequency Regulation Auxiliary Service Market; AGC Unit; Frequency Regulation Performance; Index System.

1. Introduction
The frequency modulation function of AGC power generation unit mainly means that the secondary frequency modulation of the generator can respond to the frequency control signal through an automatic device, and adjust the power generation output in real time according to a certain adjustment rate to meet the control requirements of the safe operation frequency of the power grid. The traditional calculation principle of AGC frequency modulation index is biased towards assessment, and the income differentiation of power plants with different performance is small, and the actual operation characteristics of units in the southern region are not effectively considered. With the development of the regional FM auxiliary service market in South China, the traditional calculation method of FM performance index of AGC power generation units can no longer meet the lean requirements under the market environment. It is urgent to establish a scientific and standardized FM index system of AGC power generation units to adapt to the FM auxiliary service market, further improve the system's FM
capability and lean management level, and ensure the openness, fairness and transparency of the FM auxiliary service market.

Literature [1] analyzes the problems of AGC unit participating in auxiliary service operation, compensation and quality evaluation in power market, and literature [2] puts forward the method of auxiliary AGC frequency modulation in battery energy storage system based on fuzzy control. Literature [3] proposes a hybrid energy storage optimization control and capacity planning to improve AGC performance of thermal power units. Literature [4] studies the optimization of primary frequency modulation and AGC performance of thermal power units. Literature [5] discusses the operation mechanism of FM auxiliary service market, but has not established a unified and standardized FM index system under the market. Literature [6] puts forward AGC control strategy optimization technology aiming at maximizing the benefits of multi-stage wind farms. Literature [7] puts forward AGC stability analysis and control optimization strategy for high proportion hydropower system. Literature [8] studies the frequency control strategy of photovoltaic power station under AGC control mode on grid side. Literature [9] establishes an optimal AGC control model considering market force risk constraints. Literature [10] studies AGC control strategy of hydropower station considering complex constraints.

In this paper, the frequency modulation index system of AGC power generation unit adapted to the southern regional frequency modulation auxiliary service market is optimized. Firstly, the limitations of traditional calculation methods are explained. By analyzing the general frequency modulation process of AGC power generation unit, the calculation principle, variable definition and specific formula of frequency modulation index are optimized in detail. Then, the key index system of frequency modulation market operation, such as comprehensive frequency modulation performance and frequency modulation mileage, is established. Finally, the setting ideas of related parameters are explained.

2. Optimization calculation of frequency modulation performance index

There are some limitations in the traditional calculation method of AGC power generation unit performance index. For example, the actual load distribution design and allocation calculation conditions are not considered when calculating the hydropower regulation rate of plant-level AGC, which often fails to meet the assessment target requirements; The actual coal quality of thermal power plants is far lower than the design coal quality, and the response time scale standard needs to be improved; The calculation conditions of adjustment precision error need to be further optimized.

2.1. Frequency modulation process of AGC power generation unit

In order to define the frequency modulation index of power generation unit, the output change process of AGC power generation unit in response to frequency modulation instruction is described as follows:
At time \( T_1 \), the output of the power generation unit is \( P_1 \), at which time the adjustment instruction is issued, and the target output is \( P_4 \). After a certain response time, the output of the power generation unit reaches \( P_2 \) at time \( T_2 \), which is larger than the dead zone of the power generation unit for the first time and lasts for \( U^3 \) seconds, and it is considered that the power generation unit starts to respond effectively to the adjustment instruction. At \( T_3 \), the actual output of the power generation unit reaches \( P_3 \) and reaches the target output dead zone for the first time. It is considered that the power generation unit has completed the adjustment instruction response and entered the precision calculation time until \( T_4 \) reaches the maximum calculation time of adjustment accuracy or issues a new adjustment instruction. All indexes are calculated without considering the interference of primary frequency modulation.

The action dead zone \( P_{sd} \) represents the threshold value at which the power generation unit starts to actually respond to the instruction:

\[
P_{sd} = \max / \min (S_{kj} \times R_1 \%, B_1)
\]

(1)

\( S_{kj} \) is the startup capacity, and for AGC of the whole plant, it is the total rated capacity of startup in the plant; For single AGC, it is the rated capacity of power generation unit.

The target dead zone \( P_{d} \) represents the threshold value at which the power generation unit reaches the target instruction:

\[
P_d = \max / \min (S_{kj} \times R_2 \%, B_2)
\]

(2)

\( S_{kj} \) is the start up capacity, and for AGC of the whole plant, it is the total rated capacity of start up in the plant; For single AGC, it is the rated capacity of power generation unit.

### 2.2. Adjusting rate

#### 2.2.1. Actual adjustment rate calculation:

The calculation of the actual adjustment rate needs to set the start time node, and the real adjustment rate can be obtained by calculating the adjustment rate in the time node, so as to avoid the interference such as falling and fluctuation of the calculated rate outside the start time range. That is, if \(|P_{i1} - P_{i0}| \geq P_{T1} \) and \( t_{i1} - t_{i0} > L_1 \) are satisfied, then the actual adjustment rate of AGC unit:

\[
V_i = \frac{|P_{i1} - P_{i0}|}{t_{i1} - t_{i0}}
\]

(3)

\( t_{i0} \) is the initial calculation time of the calculation period \( i \), and the time when the difference between the output of the power generation unit and the output at the initial time is greater than the threshold \( P_{sd} \) set for initial calculation for the first time; \( t_{i1} \) is the end calculation time of the calculation period \( i \), and in order to reasonably avoid the target dead zone and truly reflect the adjustment rate, select the time when the power generation unit completes the adjustment instruction \( D\% \); \( P_{i0} \) is the initial output value of the calculation period \( i \) and the output of the power generation unit at the initial calculation time \( t_{i0} \); \( P_{i1} \) is the output termination value of the calculation period \( i \) and the output of the power generation unit at the termination calculation time \( t_{i1} \); \( P_{T1} \) calculates the threshold value for the adjustment rate.

Plant-level AGC hydropower generation unit, \( P_{sd}^{H} = \max / \min (S_{dj} \times R_3 \%, B_3) \), where \( S_{dj} \) is the maximum rated capacity of single machine when the power plant starts up at this time; Other types of power generation units, \( P_{sd}^{C} = \max / \min (S_{kj} \times R_4 \%, B_4) \), for AGC of the whole plant, \( S_{kj} \) is the total rated capacity for startup in the plant, and \( S_{kj} \) is the rated capacity of power generation units for single AGC.

\( P_{sd} \) set threshold for starting calculation:

\[
P_{sd} = \max / \min (S_{dj} \times R_5 \%, B_5)
\]

(4)
For the AGC of the whole plant, $S_{dj}$ is the maximum rated capacity of single machine when it is started, and $S_{dj}$ is the rated capacity of power generation unit for single machine AGC.

2.2.2. Adjustment rate calculation conditions:
(1) The output adjustment amplitude in the calculation period reaches the adjustment rate calculation threshold value $P_{\Delta L}$;
(2) The starting calculation time and ending calculation time of the calculation period of the power generation unit are effectively captured, and the difference between them is greater than $L_1$ seconds.

2.3. Response time
The actual response time $T_{\text{del}}$ is equal to the difference between the response action time $T_{\text{schg}}$ and the start time $T_{\text{start}}$ if the response action time of the power generation unit is valid, i.e.

$$T_{\text{del}} = T_{\text{schg}} - T_{\text{start}}$$

2.4. Adjustment precision

2.4.1. Actual adjustment error calculation: If the precision time $T_{\text{accu}} > L_2$ is adjusted, then:

$$P_{\text{accu}} = \frac{\int_{T_{\text{acut}}}^{T_{\text{accu}}+T_{\text{accu}}} |P_{\text{id}} - P_{\text{des}}|}{T_{\text{accu}}}$$  

(5)

In which $P_{\text{id}}$ is the actual output of the power generation unit from the time of entering the target dead zone $T_{\text{acut}}$ to the time of calculation end ($\int$), and the acquisition time interval is 1 second.

2.4.2. Calculation conditions of actual adjustment error:
(1) The power generation unit enters the target output dead zone and lasts longer than $L_2$ seconds;
(2) The adjustment precision calculation time $T_{\text{accu}}$ is calculated from the moment when the power generation unit enters the target output dead zone, and the maximum accumulated time is $L_3$ seconds, that is, the number of valid data calculation points is $(L_3 + 1)$.

3. Comprehensive frequency modulation performance index
In order to compare the frequency modulation performance indexes of AGC power generation units horizontally and further establish the excitation mechanism of frequency modulation performance in the market environment, the actual adjustment rate, response time and adjustment accuracy of power generation units in the frequency modulation market are normalized, and the comprehensive frequency modulation performance index specification system in the southern regional frequency modulation auxiliary service market environment is established.

3.1. Comprehensive adjustment rate index
For the AGC hydropower generation unit at the plant level, the difference $(P_{\text{des}} - P_{\text{start}})$ between the target output and the initial output is used to judge the in-plant allocation form of the regulation instruction. Set the judgment threshold:

$$P_{ss}^H = \frac{\text{Max}}{\text{Min}(S_k)} \times R_{6\%}, B_6$$  

(6)
Unit: MW, where $S_{kj}$ is the total rated capacity of the power generation unit. When $P_{des} - P_{start} > P_{ss}^H$, it is judged that the adjustment instruction is shared equally by the startup units of the whole plant; In case of $P_{des} - P_{start} < P_{ss}^H$, it is judged that the adjustment instruction shall be undertaken by the single machine.

For plant-level AGC thermal power generation units, the difference ($P_{des} - P_{start}$) between the target output and the initial output is used to judge the in-plant allocation form of the regulation instruction. Set the judgment threshold:

$$P_{ss}^C = \text{Max}/\text{Min}(S_{kj} \times R\% , B\%)$$

(7)

Unit: MW. In which $S_{kj}$ is the total rated capacity of the power generation unit. When $P_{des} - P_{start} > P_{ss}^C$, it is judged that the adjustment instruction is shared equally by the startup units of the whole plant; In case of $P_{des} - P_{start} < P_{ss}^C$, it is judged that the adjustment instruction shall be undertaken by the single machine.

According to different instruction allocation forms, the performance index $k_1$ is calculated, where $k_1 = \text{actual regulation rate of power generation unit/average standard regulation rate of AGC power generation unit in frequency modulation resource distribution area (p.u.)}$.

When it is judged that the adjustment instruction is evenly shared by the startup units of the whole plant, $k_1 = \frac{V_{i\times60}}{S_{kj}\times V_{sv}}$, where $S_{kj}$ is the total rated capacity of the start up of the power generation unit. When it is judged that the adjustment instruction is undertaken by a single machine (including AGC of a single machine), $k_1 = \frac{V_{i\times60}}{S_{dj}\times V_{sv}}$ where $S_{dj}$ is the maximum rated capacity of the single machine when the power generation unit is started at this time.

The maximum value of $k_1$ shall not exceed m in order to avoid over-adjustment or over-adjustment when the generating unit of the unit responds to AGC adjustment instruction.

3.2. **Comprehensive response time index**

$k_2 = 1 - (\text{response time of power generation unit} / Q \text{ minutes})$, that is:

$$k_2 = 1 - \frac{T_{del}}{(Q \times 60)}$$

(8)

3.3. **Comprehensive adjustment precision index**

$k_3 = 1 - (\text{power generation unit adjustment error/power generation unit adjustment allowable error})$, namely:

$$k_3 = 1 - \frac{P_{accu}}{(S_{kj} \times A\%)}$$

(9)

For AGC of the whole plant, $S_{kj}$ is the maximum rated capacity of single machine for startup in the plant; For single AGC, $S_{kj}$ is the rated capacity of power generation unit; The allowable adjustment error of the generating unit is a% of its rated capacity.

3.4. **Normalized comprehensive frequency modulation performance index**

In order to directly evaluate and measure the comprehensive performance of generating units responding to AGC control instructions and establish the technical threshold of frequency modulation market access (for example, $k \geq 0.5$), the comprehensive adjustment rate, response time and adjustment precision indexes are weighted and converted to obtain the comprehensive frequency modulation performance index $K$ of AGC generating units.
\[ k = 0.25 \times (2 \times k_1 + k_2 + k_3) \]  

(10)

In order to effectively combine the comprehensive frequency modulation performance of AGC power generation units to establish a market subject quotation ranking price system, the comprehensive frequency modulation performance index of AGC power generation units is normalized, and the normalized comprehensive frequency modulation performance index is \( P \), and \( k_{\text{max}} \) is the maximum among all the comprehensive frequency modulation performance indexes of power generation units in the market.

\[ P = \frac{k}{k_{\text{max}}} \]  

(11)

4. Frequency modulation mileage calculation

If both the response action time and the target dead time time of AGC power generation unit are valid, the frequency modulation mileage is equal to the difference between the target output and the initial output of the power generation unit.

\[ P_{\text{reg}} = P_{\text{des}} - P_{\text{start}} \]  

(12)

If only the response action time is effective, the frequency modulation mileage is equal to the maximum deviation between the actual output and the initial output in the same direction as the target output during the adjustment process of the power generation unit; In which \( P_{\text{gen}} \) is the actual output of the power generation unit in the regulation process, and \( P_{\text{reg}} \) is the frequency modulation mileage of the power generation unit.

\[ P_{\text{reg}} = \text{Max}(|P_{\text{gen}} - P_{\text{start}}|) \]  

(13)

When calculating the frequency modulation mileage, it is necessary to subtract the adjustment amount that the area adjustment demand is 0 or the area adjustment demand is opposite to the adjustment instruction direction, which is called the deduction adjustment amount. For non-merged instructions, the deduction adjustment amount is the frequency modulation mileage of the instruction; For a merged instruction, the deduction adjustment amount is the absolute value of the deviation between the initial output of a single instruction to be deducted and the output at the end of the instruction.

Calculation conditions of FM mileage:

1. It is necessary to effectively capture the response time of the power generation unit. If the response time of the power generation unit is not effectively captured, the frequency modulation mileage is 0;
2. The regional adjustment demand is not 0 and the adjustment instruction is in the same direction as the regional adjustment demand.

5. Combined calculation of FM command

In the actual operation of AGC power generation units in the southern region, there is a situation that a single instruction is issued at high density and multiple times. At this time, when the power generation unit receives a new instruction, there is still a single instruction that has been responded but not completed. In order to calculate the frequency modulation index responding to such a single instruction conveniently and accurately, when calculating the response time index, adjustment precision index and frequency modulation mileage, the calculation is carried out by combining multiple single instructions into a single instruction (when calculating the adjustment rate index, the instructions are not combined). As shown in fig. 4. Combination of single AGC command should meet all the following principles:

1. Command adjustment direction is the same;
2. An instruction that the target value is greater than the target value of the previous instruction in the process of increasing the output of the power generation unit in response to the instruction; An
instruction that the target value is smaller than the target value of the previous instruction in the process of reducing the output of the power generation unit in response to the instruction;

(3) Command issued when the power generation output does not enter the last instruction target dead zone or the duration of entering the last instruction target dead zone is less than U1 seconds;

(4) The time interval between the time of issuing the instruction and the time of issuing the previous instruction is less than U2 seconds.

Figure 2 Combine interpretation of single AGC instruction

6. Example analysis

6.1. System description
In this paper, taking 5 minutes as the scheduling period, the performance index scores of a FM unit in this period are calculated, and the sampling period is assumed to be 10 seconds. The unit data is shown in the following Table1 [10].
Table 1 Output data of a unit

| Time       | Unit plan | Frequency modulation signal | Output of AGC unit |
|------------|-----------|----------------------------|--------------------|
| 0:00:00    | 500       | 0                          | -34                |
| 0:00:10    | 500       | 17.5                       | -37.5              |
| 0:00:20    | 500       | 32.5                       | -134.5             |
| 0:00:30    | 500       | 44.5                       | -166.5             |
| 0:00:40    | 500       | 66.5                       | -179               |
| 0:00:50    | 500       | 82.5                       | -251               |
| 0:01:00    | 500       | 99.5                       | -284               |
| 0:01:10    | 500       | 116                        | -362.5             |
| 0:01:20    | 500       | 131.5                      | -302               |
| 0:01:30    | 500       | 148.5                      | -288.5             |
| 0:01:40    | 500       | 169.5                      | -344               |
| 0:01:50    | 500       | 182.5                      | -319.5             |
| 0:02:00    | 500       | 198                        | -230.5             |
| 0:02:10    | 500       | 215.5                      | -179               |
| 0:02:20    | 500       | 231                        | -264.5             |
| 0:02:30    | 500       | 246                        | -205.5             |
| 0:02:40    | 500       | 263                        | -238               |
| 0:02:50    | 500       | 253                        | -164.5             |
| 0:03:00    | 500       | 297                        | -119.5             |
| 0:03:10    | 500       | 314                        | -180               |
| 0:03:20    | 500       | 329                        | -173.5             |
| 0:03:30    | 500       | 334.5                      | -35.5              |
| 0:03:40    | 500       | 363.5                      | 8.5                |
| 0:03:50    | 500       | 379                        | 22.5               |
| 0:04:00    | 500       | 396                        | 178                |
| 0:04:10    | 500       | 413                        | 241                |
| 0:04:20    | 500       | 425.5                      | 291.5              |
| 0:04:30    | 500       | 443.5                      | 377                |
| 0:04:40    | 500       | 462                        | 382.5              |
| 0:04:50    | 500       | 463                        | 328                |
| 0:05:00    | 500       | 498.5                      | 312.5              |

6.2. Example analysis

6.2.1. Disadvantages of traditional computing. For some asynchronous power grids in South China, the scale is smaller than that of the main power grid. For asynchronous power grids, the threshold values in the relevant chapters of performance index calculation are generally too large, which may cause some power plants to fail to meet the starting conditions all the time.
For example, for a power plant with installed capacity of about 300 MVA, when the difference between the initial output and the target output of the generating unit is 7 MW, $t_0$ takes $\Delta P=5$ MW (i.e. $P_{ud}$ value), but $t_1$ takes $\Delta P=4.9$ MW ($7 \times 70\% = 4.9$ MW), which will cause $t_1 < t_0$, resulting in the failure to calculate relevant indexes.

6.2.2. **Index calculated in this paper.** It can be seen from the table that the average value of output arrangement in the scheduling period is 500 MW, and the sum of absolute values of the difference between the FM signal and the actual output value is 9970 MW between 0:00:00 and 00:04:50, so the accuracy score in this period is:

$$1 - \frac{9970}{15000} = 0.3353$$

Accordingly, other indexes can be optimized by the method proposed in this paper. Including correlation score and delay score, the total system FM response index is obtained by linear weighting method.

Some thresholds are properly adjusted, and the response capability of units under different operating environments is considered, so as to provide more comprehensive services for system frequency modulation.

7. **Conclusions**

In this paper, the performance index of A-G-C power generation units adapted to the market of frequency modulation auxiliary services in southern China is optimized. Firstly, the limitations of traditional calculation methods are explained. By analyzing the general frequency modulation process of Ag-C power generation units, the related frequency modulation performance indexes are optimized. Then, the key index system of market operation, such as comprehensive FM performance index and FM mileage, which is suitable for FM auxiliary service market, is established, and the idea of setting related parameters is explained. At present, the relevant FM indicators have been popularized and applied to the actual operation of the FM market in South China, and achieved substantial application results.

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