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A New Real-time Estimation Method of Area's Automatic Generation Control Logic Gains Allowing for Control Performance Penalty

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Abstract: - The setting of area's automatic generation control (AGC) logic gains makes a strong impact on its control performance. Due to the limitation on the capability of computer and the robustness of algorithm, AGC logic gains generally keep unchanged within each economic dispatching control (EDC) cycle, without consideration of control performance penalty, as well as nonlinearity, time-variation and uncertainty in generating unit, which restrains the improvement of area's control performance to some extent. Based on weight least square theory, allowing for control lag and the factors mentioned above, a real-time estimation method of AGC logic gains within each EDC cycle is presented in this paper. Its main objective is to eliminate the error between expected power and actual power of generating unit. The simulation results from a two-area power system demonstrate that it is feasible and effective.

Key-Words: - Logic gain; Real-time estimation; Automatic generation control; Control performance penalty; Weight least square

1 Introduction

AGC is an important component in electric power system operation and control for supplying reliable and economical electric power with good quality. One of the main requirements of interconnected electric power system is to assure satisfactory control of area frequency and inter-area tie line transfer, including interconnection frequency support obligation. Unpredictable mismatch between generator output and load demand will result in area control error (ACE). A control area serving rapid and widely varying loads would incur not only heavy penalty due to improper control performance, but also substantial costs in providing the necessary regulation.

Area's control performance is dependent on proper AGC control strategy, besides the responsiveness of the units, the frequency response characteristic, and the network condition. There are many papers on AGC control strategy. [1] described fundamental notion on AGC. [2] explained North American Electric Reliability Council's (NERC) control performance standards (CPS) and its technical foundations. [3] studied AGC parameter sensitivities. [4,5] dealt with highly varying load. Because of the limitation on the capability of computer and the robustness of algorithm, most of the above papers based their control strategy mainly on the accumulation of ACE, without consideration of the impact of AGC logic gains on area's control performance, which restrains the improvement of area's control performance to some extent.

In fact, it is an important component of AGC control strategy to estimate AGC logic gains on line. At least, control area's response to both ACE and the on-line modified AGC logic gains will be more prompt and effective than only response to the accumulation of ACE for the improvement of area's control performance. However, estimating the optimum values of AGC logic gains on a real-time basis is challenging. Not only the time-varying nature of the system operating condition, nonlinearities within the AGC and governor responses, and the uncertainty of load demand, but also electric power company's control performance penalty influences the setting of AGC logic gains greatly. There are some papers on the methods to estimate or design AGC logic gains, including weight least square methodology [6,7], robust control methodology [8,9], optimal control techniques [10], fuzzy control methodology [11], genetic algorithms [12], combination intelligent methods [13], etc. Most of them did not directly take into account control performance penalty. Some of them needed precise information of power system which is not always available in time with the growing of interconnected power system's capacity. In addition, their complex algorithms make them not easy to be implemented effectively.

With more and more attentions paid to control performance index by electric power company, based on weight least square theory, allowing for control performance penalty, control lag and error of the output of generating unit, a real-time estimation method of AGC logic gains within each economic dispatching control (EDC) cycle is presented in this paper. This method does not need an accurate model of generating unit. Case studies indicated its high effectiveness and robustness.

2 Simulation system

A simulation of the AGC dynamics of a real interconnected power system was implemented in C++ environment. The original test data are from Shanghai Municipal Electric Power Company, which adopts TBC (Tie-line load frequency bias control) and NERC's CPS. The tie-line control mode mostly used in interconnected electric power system is TBC. CPS is adopted in many countries, such as China, America, and Canada. Therefore, in this simulation, the tie-line control mode is TBC, and CPS is used to measure area control performance under the proposed new estimation method of AGC logic gains. As for other tie-line control mode and control performance index, the estimation method of AGC logic gains is similar.

The whole system (East China Grid Company Limited) is divided into two areas in the simulation. There are 4 generators in area A, and 4 tie-lines between area A and area B. The average value of the system capacity can be 1.2GW (area A, hydro) and 73GW (area B, 10GW hydro and 63GW fossil). In this paper, line losses and generator's regulation costs are neglected. Scheduled changes in generation from manual control or economic dispatch are not considered. The system condition and the loads are time-varying. There are constraints on the controller and equipment.

The load inside Area A is non-conforming, with temporal fluctuation up to 200 MW load change within a period of less than 1 min. The time characteristics of load fluctuation of area A in 9 hours are shown in Fig. 1.

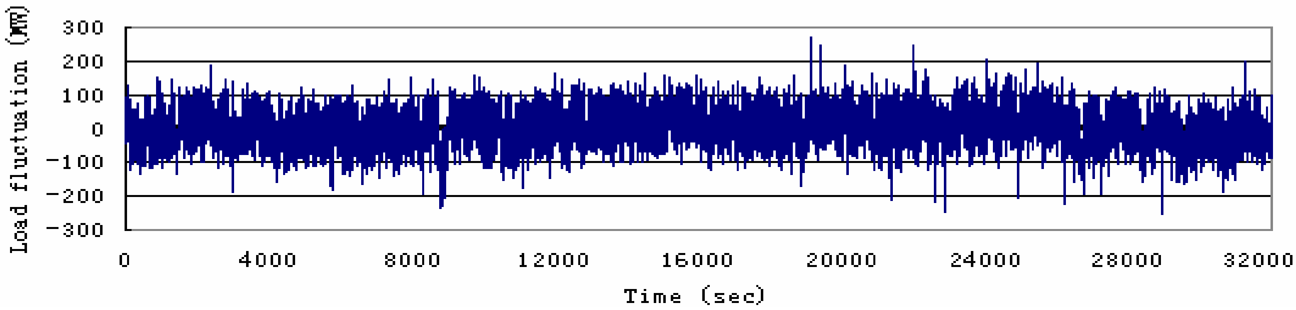

Fig. 1. Load fluctuation of area A.

A simplified AGC-plant model is shown in Fig. 2. The plant output is determined by AGC pulse, the set point of EDC, the generation plant's power distribution coefficient and its governor. AGC pulse is determined by the ACE, its integral and their gains whose estimation method is the focus of this paper. Although the plant in the simulation area A is made up of hydro generators, the conclusion of this paper is still the same with other types of plants, such as fossil plants, for the characteristics of various plants can be represented by changing the capacity, ramping rate, deadband and delay time of AGC logic and the governor capability, respectively.

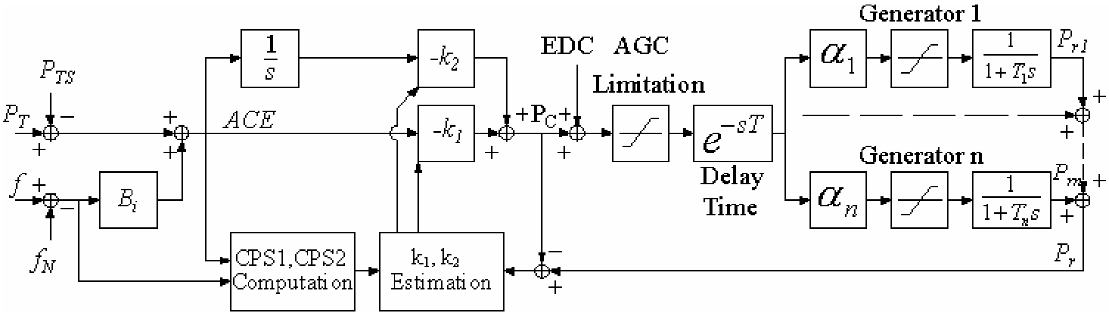

Fig. 2. Plant and AGC model.

The effect of the frequency control system for about 9 hours on each simulation case was simulated. The simulation parameters used to evaluate the new method are shown in Table 1 and 2. The frequency response characteristic of each area is set to agree with its frequency bias coefficient.

Table 1 Configuration of AGC parameters.

Area	Capacity (MW)	Ramping rate (%MW/min)	Deadband (MW)	Delay time (s)
A	500	30	35	2
B	1500	3	150	9

Table 2 Configuration of CPS parameters.

ε_1 (Hz)	ε_{10} (Hz)	B_A (MW/Hz)	B_B (MW/Hz)
0.030	0.018	150	7300

3 New estimation method of k_1 and k_2

Based on least square parameter estimation, the new estimation model which is applicable within EDC cycle can be described as follows:

$$P_{cj} = -k_1 \bullet ACE_j - k_2 \int_0^{t_{cj}} ACEdt \qquad (1)$$

$$P_{tri} = \sum_{j=1}^{N_p} \left\{ P_{cj} \sum_{l=1}^{N_g} \left\{ \alpha_l \left[1 - EXP\left(\frac{t_{cj} - t_{ri}}{T_l} \right) \right] \right\} \right\} \qquad (2)$$

$$P_{ri} = \Delta P_{tri} = \frac{\partial P_{tri}}{\partial t} \Delta t = \sum_{j=1}^{N_p} \left\{ P_{cj} \sum_{l=1}^{N_g} \left[\frac{\alpha_l \square T_{sp}}{T_l} EXP\left(\frac{t_{cj} - t_{ri}}{T_l} \right) \right] \right\} \qquad (3)$$

$$\Delta P_{ri} = P_{mri} - P_{ri} \qquad (4)$$

$$\Delta P_{ri} = \frac{\partial P_{ri}}{\partial k_1} \Delta k_1 + \frac{\partial P_{ri}}{\partial k_2} \Delta k_2 \qquad (5)$$

$$\frac{\partial P_{ri}}{\partial k_1} = \sum_{j=1}^{N_p} \left\{ -ACE_{t_{cj}} \square \sum_{l=1}^{N_g} \left[\frac{\alpha_l \square T_{sp}}{T_l} EXP\left(\frac{t_{cj} - t_{ri}}{T_l} \right) \right] \right\} \qquad (6)$$

$$\frac{\partial P_{ri}}{\partial k_2} = \sum_{j=1}^{N_p} \left\{ -\int_0^{t_{cj}} ACEdt \square \sum_{l=1}^{N_g} \left[\frac{\alpha_l \square T_{sp}}{T_l} EXP\left(\frac{t_{cj} - t_{ri}}{T_l} \right) \right] \right\} \qquad (7)$$

$$A^T A \square \Delta k = A^T \square \Delta P_r \qquad (8)$$

$$A = \begin{bmatrix} \frac{\partial P_{ri}}{\partial k_1} & \frac{\partial P_{ri}}{\partial k_2} \\ \vdots & \vdots \\ \frac{\partial P_{r(i-m+1)}}{\partial k_1} & \frac{\partial P_{r(i-m+1)}}{\partial k_2} \end{bmatrix}_{m \times 2} \qquad (9)$$

$$\Delta k = \begin{bmatrix} \Delta k_1 \\ \Delta k_2 \end{bmatrix}_{2 \times 1} \qquad (10)$$

$$\Delta P_r = \begin{bmatrix} \Delta P_{ri} \\ \vdots \\ \Delta P_{r(i-m+1)} \end{bmatrix}_{m \times 1} \qquad (11)$$

$$k^{(l+1)} = k^{(l)} - \left(\frac{1-\beta}{N_k} \sum_{j=l-N_k+1}^{l} \Delta k^{(j)} + \beta \cdot \Delta k^{(l)} \right) \qquad (12)$$

$$k = \begin{bmatrix} k_1 \\ k_2 \end{bmatrix}_{2\times1} \qquad (13)$$

Where P_{cj} is AGC pulse; *ACE* is area control error, in megawatts; k_1 is gain of *ACE*, dimensionless; k_2 is gain of *ACE*'s integral, in s^{-1}; N_p is total number of effective AGC pulses (= $\frac{5 \cdot \max\{T_l\}}{AGC\ cycle}$, approximately); N_g is total number of AGC generators; N_k is total number of Δk to be averaged; P_{tri} is computational total instantaneous power response to effective AGC pulses at the instant t_{ri}, in megawatts; P_{ri} is computational total power increment during sampling interval close to the instant t_{ri}, in megawatts; P_{mri} is actual total power increment during sampling interval close to the instant t_{ri}, in megawatts; T_l is equivalent time constant of generating unit *l* (mainly referring to governor), in second; T_{sp} is sampling period of P_{mri}, in second; t_{cj} is the instant when AGC pulse (P_{cj}) is sent to generating unit; α_l is power distribution factor of generating unit *l*; β is weight of the latest increment $\Delta k^{(l)}$; *m* is total number of sample P_{mri} within each AGC cycle.

Because P_{ri} is expected, the increment of *k* is $-\Delta k$, and *k* is updated as equation (12). The adoption of β is to mitigate the infection of noises, enhance the algorithm's robustness and provide smoothness of control. (4) is to eliminate error from generating unit and its control systems. Since electric power company pays more attention to control performance index, and control lag is not negligible, (4) is modified as

$$\Delta P_{ri} = \alpha_{eq} \left(P_{mri} - P_{ri} - \alpha_p \Delta P_{ci+1} \right) \qquad (14)$$

$$\Delta P_{ci+1} = \frac{\partial P_{ci}}{\partial t} \Delta t = -k_1 \left(ACE_{i+1} - ACE_i \right) - k_2 \frac{ACE_{i+1} + ACE_i}{2} T_{sp} \qquad (15)$$

$$\alpha_{eq} = \frac{|\operatorname{sgn}(ACE_i) + \operatorname{sgn}(\Delta f_i)|}{2} \cdot (1 + \lambda_{CF} \cdot e^{|CF_{1i}|}) \cdot (1 + \lambda_{ACE} \cdot e^{|ACE_i|}) \qquad (16)$$

where α_{eq} is weight of least square equation, allowing for CPS penalty; α_p is weight of the next AGC pulse increment (ΔP_{ci+1}); λ_{CF} and λ_{ACE} are weight of $CF1_i$ and ACE_i, respectively; sgn( ) denotes sign function.

The adoption of sign function is based on the fact that, if the sign of ACE_i is opposite to that of Δf_i, *CPS1*>200, and the control performance is satisfying, so there is no need to modify k_1 and k_2. $e^{|CF_{1i}|}$ and $e^{|ACE_i|}$ denote the influence of *CPS1* and *CPS2* respectively, for *CF1*[2] and *ACE* are the two main technical indices of CPS penalty. The introduction of ΔP_{ci+1} can compensate control lag to some extent. If the next AGC pulse increment $\Delta P_{ci+1} > 0$, the present positive difference between P_{mri} and P_{ri} is welcome to some extent. Therefore, ΔP_{ci+1} is subtracted from P_{mri} with weight.

In this paper, the actual total power increment during sampling interval is simulated by

$$P_{mri} = P_{ri} + w(t) \qquad (17)$$

where $w(t)$ is noise, which denotes a slight random variation characteristics of generating unit and its control systems. The noise of generating unit's active power is usually between 1MW and 5MW, which means smaller than $0.1P_{ri}$ in this simulation.

The optimal gains, k_1 and k_2, can be estimated using the developed models. The steps for the estimation within a given period of operation are as follows:

1) use (3) and (17) to compute P_{ri} and P_{mri} respectively. Note that in practice, P_{mri} can be obtained by summing the 2-s sampled power increments from all generating units;

2) use measured values of ACE_i and Δf_i to compute the rolling value of $CF1_i$ within each AGC cycle. The computation method of $CF1_i$ is similar to that of *CF1*, except that computation cycle is different;

3) use (14) ~ (16) to compute ΔP_{ri}. Use (6) and (7) to

form matrix A in (9);

4) if $|A^TA|<0.1$, then $\Delta k^{(l)}=0$;

5) compute $\Delta k^{(l)}$ by equation (8);

6) check the limit of $\Delta k^{(l)}$. If $\left|\Delta k^{(l)}\right|>0.2\left|k^{(l)}\right|$, then

$$\Delta k^{(l)}=0.2\Delta k^{(l)}\left|\frac{k^{(l)}}{\Delta k^{(l)}}\right|;$$

7) update k_1 and k_2 by equation (12).

4 Case studies

To validate the effectiveness of the new method, the types of noise are set as shown in Table 3, which represents the time-variation and nonlinearity within generating units. The uncertainty of load demand is shown in Fig. 1. Simulation cases are listed in Table 4. “No” in row 2 or 3 of Table 4 means that control lag or CPS penalty is not considered. “No” in row 4 means that k_1 and k_2 are not updated within each EDC cycle. Note that within each EDC cycle the initial value of k_1 and k_2 are calculated from data of previous EDC cycle. The method of penalty computation complies with East China Grid Company Limited’s document No. [2002] 086. Test results (*CPS1*, *CPS2*, standard deviation of frequency and CPS penalty) are shown in Fig. 3–5.

Table 3 Model of noise $w(t)$.

w_1 (MW)	w_2 (MW)	w_3 (MW)	w_4 (MW)
Sine disturbance	Sine disturbance	Gaussian noise	Gaussian noise
$0.05P_{ri}\sin\left(\frac{\pi t}{300}\right)$	$0.10P_{ri}\sin\left(\frac{\pi t}{600}\right)$	$N\left(0,0.02P_{ri}\right)$	$N\left(0,0.05P_{ri}\right)$

Table 4 Simulation cases.

Case	1	2	3	4	5	6	7	8	9	10	11	12
Control lag	No	No	Yes	No	No	Yes	No	No	Yes	No	No	Yes
CPS penalty	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
k_1, k_2 updated	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Noise	w_1	w_1	w_1	w_2	w_2	w_2	w_3	w_3	w_3	w_4	w_4	w_4

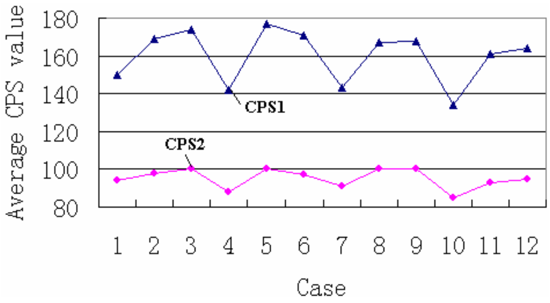

Fig. 3. CPS value in different cases.

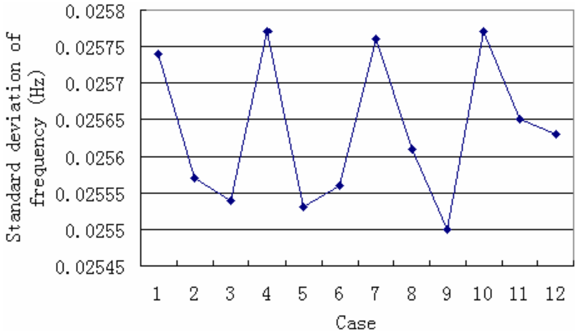

Fig. 4. Standard deviation of frequency in different cases.

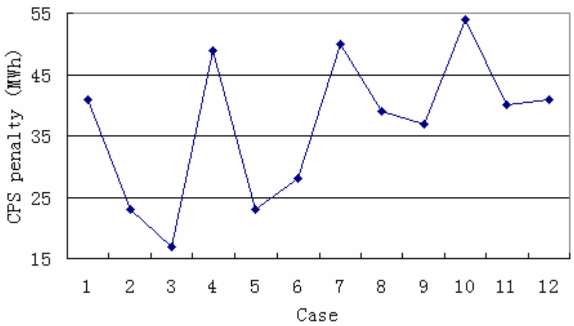

Fig. 5. CPS penalty in different cases.

The above figures show that, the new method improves CPS value and reduces the corresponding penalty of control area in all cases, whose mean value is about 0.36% of the total load demand. In addition, the new method reduces standard deviation of system frequency, improves quality of system frequency, which denotes that proper control area's AGC strategy is beneficial to both area and whole power system.

The average computation time for estimating AGC logic gains in each AGC cycle is about 0.3 ms on personal computer (CPU 1.5 GHz, memory 256 MB), which is feasible in current AGC system.

5 Conclusion

Because changes in AGC logic gains impact on area's control performance greatly, it is important to update AGC logic gains within each EDC cycle. A new dynamic increment model of AGC logic gains based on weight least square parameter estimation has been presented. Experiment demonstrates that the new method can improves CPS value, standard deviation of system frequency, and reduces total penalty of control area remarkably. The reason for this good performance is that, response to both ACE and the on-line modified AGC logic gains is more prompt and effective than only response to the accumulation of ACE. Its easy implementation and focus on CPS penalty make it especially suitable for area's control center. Nine-hour system operating simulation and short computation time under various noises show that, the new method is feasible, robust and effective to deal with nonlinearity, time-variation and uncertainty in generating unit without its precise model which is not always available in time.

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