An AGC Allocation Parameter Optimization Method Considering the Characteristics of Generator Valve Controllers

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Abstract—**Performances of AGC and generators' valve controllers, connected through AGC allocation strategy, both influence active power balance in power systems. In this paper, authors consider that when distributing the whole regulation demand, AGC should give consideration to the bottom-level generator valve controller' performance. Following this idea, an AGC allocation parameter optimization method is proposed considering valve controllers' characteristics. Area Control Error (ACE) is selected as optimization criterion and optimal distribution coefficients are calculated under associated constraints, thus improving control performance of power system frequency and tie-line transmission power. The simulation of two-area system with four generators shows the effectiveness of the proposed method.**

Keywords-automatic generation control; valve controller; allocation parameter; optimization method

I. INTRODUCTION

As an important part of Energy Management System (EMS), Automatic Generation Control (AGC) is one of the most fundamental and practical ways to guarantee safe and economic operation of power system [1]. From the perspective of control structure, AGC has typical hierarchical feature. The upper level, known as decision level, aims for area dispatching, while the bottom level operates the turbine governing process. The decision level comprises two main steps, the first is to generate the total regulation signals while the second is to dispatch allocated portion to corresponding turbine governor.

At present, much research has been made on how to generate total regulation demand [2-7] while seldom mentioning the allocation part. In [8], an AGC allocation method based on equal proportion of generator's adjustable capacity was presented, it utilized the generator's remaining capacity as allocation basis. In [9], a dynamic CPS dispatching rule was proposed according to the Q-learning algorithm. The author regarded CPS adjustment allocation as a stochastic optimal control problem. And the control performance was improved by defining reward functions. However, this method is theoretically complex and difficult for real-life practice. Fair and reasonable AGC allocation strategy is meaningful because it can effectively improve the power system dynamic performance, and make the balancing area control performance meet requirements under the condition of existing technology.

Besides the existing proposals on AGC regulation allocation. In this paper, we argue that control property of bottom-level generator should be considered for AGC adjustment allocation. Difference between generator valve controllers' performances should be taken into account when performing AGC distribution. Therefore, an optimal AGC parameter allocation strategy considering control performance of the bottom-level generators is proposed. Generators with good control performance are set to handle more adjusting responsibilities while poor-performing ones deal with less adjusting task. The philosophy behind is to make the best use of adjusting capacity of generators with good performance, thus improving the dynamic performance of the whole power system.

The paper is organized as follows. In section II, the overall idea of this paper is presented. In Section III, control performance of the bottom-level valve controllers is first analyzed. Then AGC allocation parameter optimization model considering valve controller's control performance is formulated in Section IV. Case studies and simulations are made in Section V. The conclusions are drawn in Section VI.

II. THE OVERALL IDEA

AGC controller comprises two main parts, namely calculation of the total regulation demand and regulation allocation part. The total AGC adjustment can be obtained by Area Control Error [10], which is calculated by deviations of system frequency and tie line transmission power. The total AGC regulation order is first obtained by ACE through a PID controller and filtering step. Then a set of distributing coefficients, which stands for the amount of regulation allocation, are utilized to calculate the allocation portions of corresponding generators through a dispatching block. The coefficients indicate adjusting amounts of corresponding generators. When there exist differences among control performances of the bottom-level controller, these differences should be considered in designing AGC allocation law, thus generators with good control performance can be fully utilized to improve the balancing area dynamic control performance.

The control diagram is shown in Fig. 1, the differences of controller performance are considered to adjust allocation coefficients in the Regulation Allocation block, such that

generators with good control performance take more responsibility in AGC adjusting. In this way, the overall control performance of power system frequency and tie-lie transmission line will be improved.
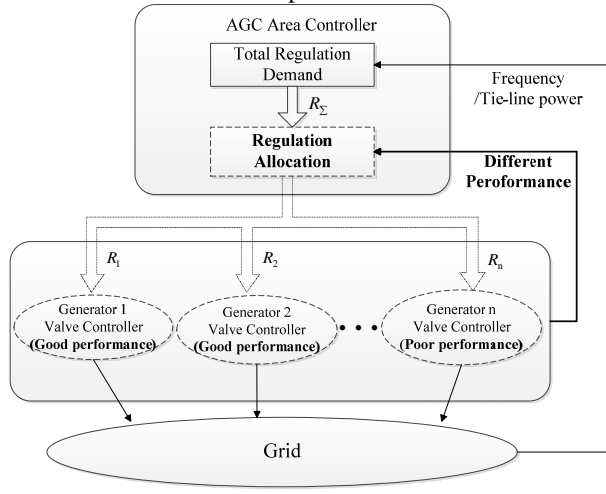

Figure 1.   The overall idea.

The main feature of this paper is to take the bottom-level controller differences when designing AGC allocation rule. To achieve it, the work in this paper is organized as the following two steps:

(1) Analyze the generator valve controller's control property, i.e. study traditional PID-based valve controller and inverse-system-based nonlinear controller. Since there exists control performance difference between these two types of controllers, AGC allocation design then should give consideration to them.

(2) Formulate AGC allocation parameter optimization model by setting area ACE as optimization target function under the constraints of electric connections, coefficients relation, control performance standard [11-12], etc. The optimization goal is to find the optimal allocation coefficients such that area performance index is optimized.

III. PERFORMANCE ANALYSIS OF THE GENERATOR'S VALVE CONTROLLER FROM BOTTOM LEVEL

Fig. 1 shows that AGC regulation allocation scheme should consider control performance difference. The overall area control performance can be improved by making full use of generators with good control performance. Therefore, analysis of bottom-level turbine governor is first made in order to explain this control performance difference. In this paper, PID-based traditional controller and inverse-system-based nonlinear one are discussed.

The diagram of PID-based traditional valve controller is as shown in Fig. 2. The controller adopts simple proportional controller, and valve control signal is generated through a first-order inertial and servo link.
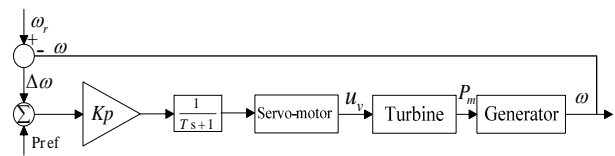

Figure 2.   Traditional PID-based steam turbine governor

ω_r is the reference value of rotor speed, ω is the actual velocity, Pref is reference active power. Kp is proportion coefficient, T is inertia time constant, u_v is valve control signal, P_m is mechanical power input.

Detailed design steps of nonlinear turbine controller based on inverse system theory can be found in [13-14]. The classic 4-order model considering speed governor is utilized for the generator [15]. The design procedure of nonlinear controller is organized as the following three steps:

(1) Select variable ω to be controlled, design inverse-system-based compensator, construct pseudo linear system by connecting the compensator with controlled variable in series;

(2) Adopt proportional controller for the pseudo linear system, in this paper, the closed-loop controller is formulated as $u = -k_1(\omega - \omega_r) - k_2\dot{\omega}$, k_1, k_2 are the proportional coefficients;

(3) Design interface between the nonlinear valve controller and AGC controller.

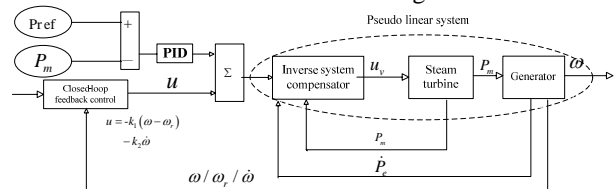The complete diagram of this inverse-system-based nonlinear valve controller is shown in Fig. 3.

Figure 3.   Diagram of the inverse-system-based nonlinear turbine controller

In Fig. 3, $\dot{\omega}$ is the derivate of rotor speed, $\dot{P}_e$ is the derivate of electromagnetic power,

The traditional PID-based valve controller in Fig. 2 is liable to generate overshoot and the dynamic control performance is not good. Compared with the traditional controller, nonlinear one in Fig. 3 gives consideration to nonlinearities of controlled object. Thus, the resulting turbine governor is more suitable to the object's characteristics and has better control performance.

IV. AGC ALLOCATION PARAMETER OPTIMIZATION MODEL CONSIDERING VALVE CONTROLLERS' FEATURES

AGC allocation rules should be optimized to improve overall AGC adjusting performance when part of the bottom-level turbines adopt nonlinear controllers while others utilizing traditional ones. To achieve this, an AGC optimization model considering valve controllers' property is proposed in the paper.

Integration of area control error from respective balancing areas is chosen as optimization object function. Optimization constraints include power system electrical connection relationship, unit parameters restriction, quantity limits of AGC allocating coefficients and control performance standard. By selecting the integration term as optimal function, the shortest adjusting time and best dynamic control performance can be achieved.

A two-area interconnected system is considered in this paper. The AGC allocation parameter optimization object function is defined as (1)

$$MIN \left(\int_0^{Ts} t\left(|ACE_1| + |ACE_2| \right) dt \right) \quad (1)$$

MIN denotes minimization of the object function. *Ts* means the optimization time range, ACE_1 is area control error from area 1 while ACE_2 is that from area 2.

ACE is calculated by

$$ACE = \Delta P_{tie} + 10B \times \Delta f \quad (2)$$

Where ΔP_{tie} is the deviation between scheduled tie-line transmission power and actual one, B is response coefficient, which is negative (MW/0.1Hz), Δf is deviation between nominal and actual frequency.

After integrating unit's output limits, power flow constraints, AGC dispatching rule restriction and CPS, the complete optimization model of this two-area system is defined as (3)

$$\min \left(\int_0^{Ts} t\left(|ACE_1| + |ACE_2| \right) dt \right)$$
$$s.t. \quad f(\Delta f, \Delta P_{tie}, a, b) = 0$$
$$a + b = 1$$
$$0 < a、 b \quad (3)$$
$$P_{i\min} < P_i < P_{i\max} \quad (i <= n)$$
$$\Delta v_{i\min} < \Delta P_i < \Delta v_{i\max}$$
$$CPS1_j > 110\% \quad (j = 1,2)$$

Where $f(\Delta f, \Delta P_{tie}, a, b) = 0$ is the electric connection relation, Δf is the deviation between real and nominal frequency. ΔP_{tie} is deviation between real and nominal tie-lie transmission power. a, b are the allocation coefficients as decision variables in this model. $P_i, P_{i\min}, P_{i\max}$ are the actual active power output, the minimal and maximum generation of unit i respectively. n is the unit numbers, $\Delta P_i, \Delta v_{i\min}, \Delta v_{i\max}$ are power regulation speed, the minimum and maximum output changing rate respectively. $CPS1_j$ denotes Control Performance Standards 1 of area j, according to NERC standard, CPS1 should be larger than 100%, here a margin is reserved and it satisfies $CPS1_j > 110\%$. It is noted that CPS2

is neglected in this paper, because CPS2 is utilized for long period evaluation.

CPS1 is calculated by

$$CPS1 = \left(2 - AVG_{period} \left(\frac{ACE \times \Delta f}{-10B \times \varepsilon^2} \right) \right) \times 100\% \quad (4)$$

Where AVG_{period} is the average through a period time frame, ε is root-man-square of one- minute-average of deviations between standard and actual frequency annually.

In this paper, a PSO algorithm based on improved inertia weights method is utilized to solve the optimization problem and calculate the optimal coefficients. The algorithm flowchart is shown in Fig. 4.
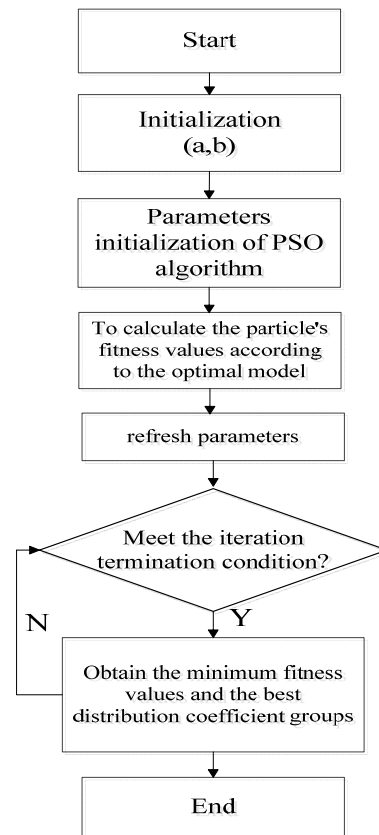

Figure 4.   The flowchart of PSO algorithm

V.   CASES AND SIMULATIONS

In order to test the efficiency of the proposed AGC allocation parameter optimization method, a four-generator two-area system is studied with the aid of MATLAB/ SimPowerSystems. The simulation diagram is shown in Fig. 5. The dotted line divides the system into two areas. Each area contains two generators and five bus lines. Transmission lines between bus 7 and 9 are the tie lines. Simulation model parameters are given in [16].
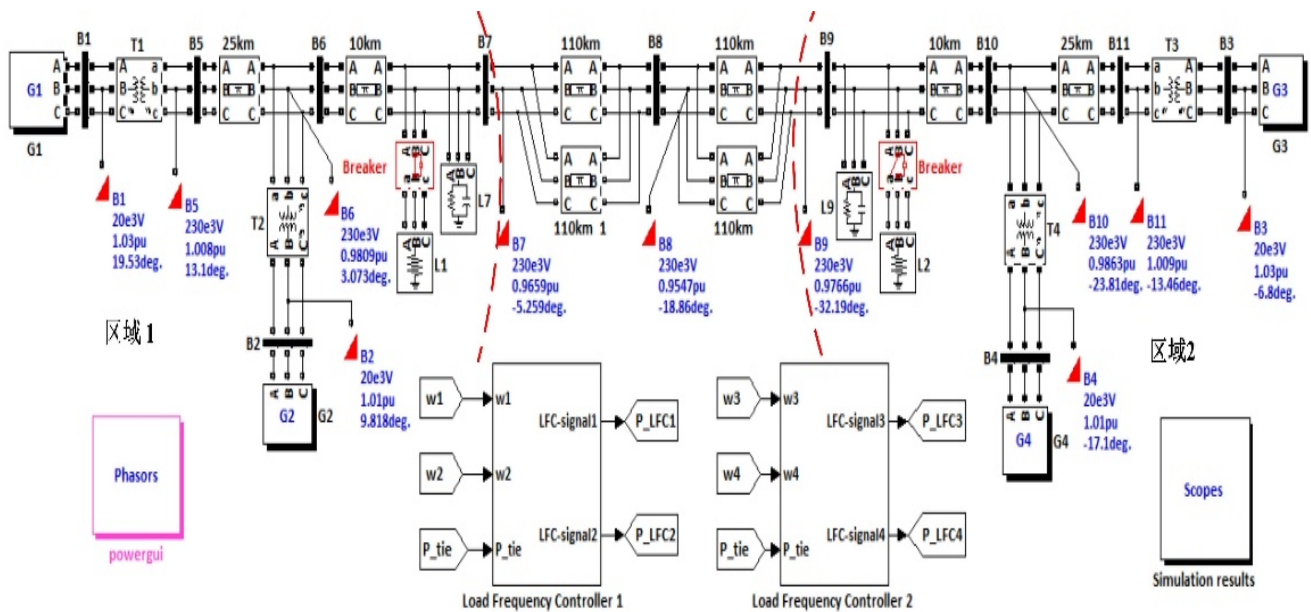
Figure 5.   Simulation model based on MATLAB/SimPowerSystems

In order to compare the control performances of inverse-system-based nonlinear valve controller and traditional one, generator G1 respectively adopts the two types of controllers while the remaining three units utilize traditional ones. The first disturbance is set in form of 400 MW load increase at t=5s between bus 6 and 7 in area 1. The second disturbance is set by increasing load of 200MW at t=25s between bus 9 and 10 in area 2. The simulation results are shown in Fig. 6. Fig. 6 shows the rotor velocities under two types of valve controllers. The control performances of these two types of valve controllers are proved to have some differences, so it should be considered in designing AGC allocation law.
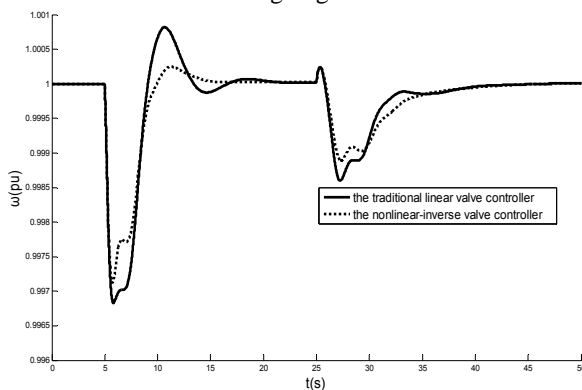

Figure 6.   Rotor speed of G1 under two types of valve controllers

The proposed AGC allocation optimization method is tested in area 1. Generator G1 adopts the nonlinear valve controller while generator G2 adopts the traditional one. Both generators of area 2 are adopted with traditional controllers. The disturbance series is set as follows: t=5s, 0.02p.u. adds to the mechanical power of G1; t=15s, load increase of 40MW between bus 6 and 7 in area 1. The

simulation time T is set as 50s. AGC total regulation order is obtained through traditional PI controller. After solving the optimization model as (3), AGC allocation coefficients are calculated as 0.65 (generator G1) and 0.35 (generator G2), and the optimal target is 4.632. Results can be explained through the fact the generator G1 valve controller has better control performance than generator G2. Under this coefficient group, generator G1 will be allocated with more adjustment, which is equivalent to bigger dispatching coefficient. When the allocation coefficients are equally set as 0.5 (generator G1) and 0.5 (generator G2) according to the AGC equal-allocation strategy, the target value is 5.999. The simulation results under these two allocation laws are shown in Fig. 7-10. Fig. 7 and Fig. 8 show trajectories of ACE1 and ACE2. Fig. 9 is system inertia center frequency curve. Fig. 10 shows tie-line power deviations between area 1 and area 2.
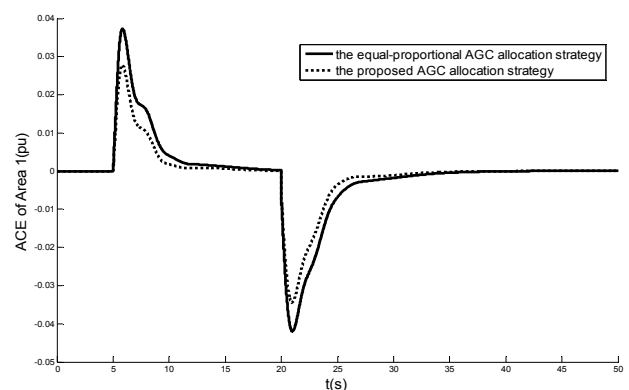

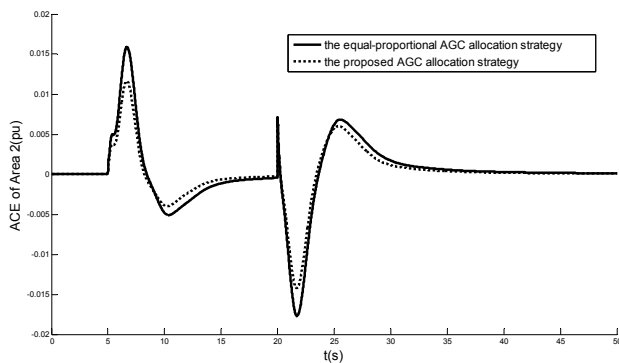Figure 7.   ACE comparison of area 1 under different AGC allocation strategy

Figure 8.   ACE comparison of area 2 under different AGC allocation strategy
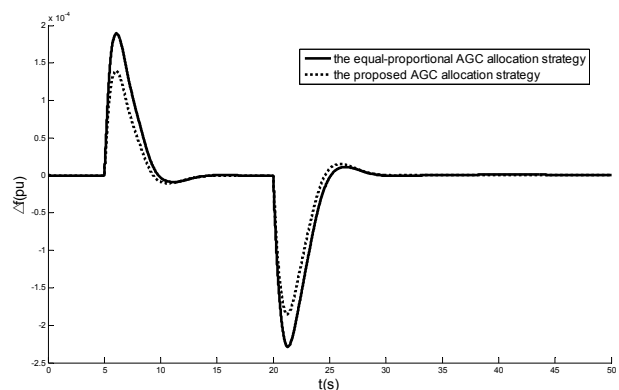

Figure 9.   Inertia center frequency comparison under different AGC allocation strategy
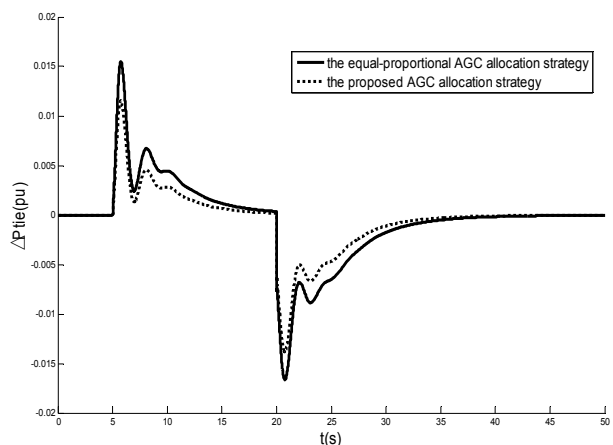

Figure 10. Tie-line power deviation comparison under different AGC allocation strategy

The area performance index, frequency and tie-line quality are shown as Table 1. The simulation time T is set as 50s.

TABLE I.   AREA PERFORMANCE COMPARISON UNDER TWO AGC ALLOCATION METHOD

AGC allocation method	Area Performance Comparison		
	The performance index	*Deviation integration of inertia center frequency (HZ)*	*Deviation integration of tie-line power (MW)*
The proposed method	4.632	0.0012	108.9
Equal-proportion method	5.999	0.0015	131.3

Fig. 6-9 and Table 1 illustrate that the proposed AGC allocation optimization method considering the features of valve controllers can improve area dynamic properties. It reduces deviations of frequency and tie-lie interchange under disturbances, which contributes to the safe and economic operation of power system.

VI.   CONCLUSIONS

In this paper, an AGC allocation parameter optimization method is proposed considering the generator valve controllers' properties. The optimization object is to minimize the area control error of the whole power systems. Allocation law is based on control performance of the bottom-level valve controllers. Optimal allocation scheme is obtained by solving AGC optimization model. Simulation results demonstrate the proposed method can improve area frequency and tie-line quality, thus the overall area dynamic control performance is upgraded.

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