Fuzzy control strategy of interconnected power grid AGC system based on particle swarm optimization

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Abstract. Frequency is one of the key indicators of power quality. The power load is constantly changing and has uncontrollability. The change of load will affect the frequency of the system. The power system always hopes to keep the frequency as constant as possible, which leads to the problem of frequency control. The mechanism modeling of the multi-region interconnected power grid system is carried out, and the frequency response of the networked system is analyzed by building a simulation platform. Aiming at the shortcomings of "AGC controller" using fuzzy PID control, according to the particle swarm optimization algorithm, a fuzzy adaptive PID controller based on particle swarm algorithm is designed. The simulation results show that the fuzzy adaptive PID controller based on particle swarm algorithm can better improve the dynamic performance of the system.

1. Introduction

The grid frequency directly reflects the balance between the load in the power system and the active power of the generator set, and is one of the three important indicators for measuring power quality. At present, most of the new thermal power units in China are supercritical units. With the continuous expansion of the power grid capacity, the requirements for power supply quality are also continuously improved. The automatic generation control (AGC) of traditional thermal power units has been unable to meet the demand, so research on optimized control strategies for AGC systems has become a focus and a hot issue[1-3].

In this paper, a fuzzy adaptive PID controller based on particle swarm optimization is designed to improve the control performance of the system in view of the shortcomings of the online adjustment of the parameters of the fuzzy PID controller. Focusing on the research and analysis of the control mechanism of the CPS1 and CPS2 standard and its effect on the control quality of the power grid, it is pointed out that the evaluation of the AGC control performance according to the CPS standard is more suitable for the requirements of today's power grid control.

2. AGC principle and model establishment

The frequency modulation methods mainly include primary frequency modulation and secondary frequency modulation. Primary frequency modulation relies on the static characteristics of the generator set to adjust the active power of the generator. The adjustment is fast but with poor adjustment. When the unit is in standby, the primary frequency adjustment is invalid; secondary frequency adjustment means that the generator set provides sufficient adjustable capacity and a certain adjustment rate. Track the frequency in real time with the allowable adjustment deviation to meet the requirements of system frequency stability. The second frequency modulation is divided into manual
and automatic modes, the latter is the main content of AGC, which is realized by the power grid dispatch center through the control device of the generator set. When the power system load changes and the frequency of the system changes, the dispatch instruction is issued, so that the output power setting value of the generator set changes accordingly, and finally the generator set frequency is adjusted to run at the rated frequency to restore the balance of the active power and frequency of the generator set. In the power grid regulation, as shown in Figure 1, it mainly rely on ACE to achieve[4-7].

![AGC system overall structure](image)

Figure 1 AGC system overall structure

Among them: PR is the adjustment component of the unit; Pb is the base point value of the unit power; PG is the generator output power; P is the expected power generation; ACE is the regional control deviation; $\Delta f$ is the system frequency deviation.

Taking the interconnection of two regional power grids as an example for analysis, according to the AGC system composition and equivalence principle, its structural model can be constructed. The dynamic model of the AGC system of the two-region interconnected power grid is shown in Figure 2, and the parameters and variables in the model are shown in Table 1.

The steam turbine speed control system is the main part of steam turbine control and is the key to balance the output power and load of the steam turbine. Its dynamic performance not only affects the economy and reliability of the thermal power unit, but also is a key factor affecting the quality of power supply. In a stable state of the turbine generator set, after a disturbance, the speed of the unit will change. The speed control system receives the speed change signal, timely opens or closes the small steam turbine's control valve, changes the steam intake, and keeps the speed at the prescribed. Within the scope, this process is a frequency modulation.

In the actual operation of thermal power plants, primary frequency modulation and secondary frequency modulation are combined. The load command of the dispatch center is sent to the unit coordination controller. The controller calculates the control signal of the output of the generator set according to the deviation of the unit output power and the load command, and enters the coordination controller for calculation, thereby adjusting the valve opening of the steam turbine and changing the inlet. The steam volume makes the output power of the unit consistent with the load command. Obviously, this is a closed-loop control system.
Figure 2 Dynamic model of AGC system for two-region interconnected power generation

Table 1 Parameters and variables of the two-region interconnected AGC system

| parameter/variable | meaning | unit |
|--------------------|---------|------|
| $\Delta f_i(t)$ | frequency deviation of area i | Hz |
| $\Delta P_{ni}(t)$ | generator output power deviation | p.u.MW |
| $\Delta P_{Li}(t)$ | load disturbance deviation | p.u.MW |
| $\Delta P_{nij}(t)$ | tie line active power deviation | p.u.MW |
| $\Delta X_{gi}(t)$ | adjustment valve position deviation | p.u. |
| $\Delta P_{ci}$ | controller control quantity | p.u.MW |
| $ACE_i$ | regional control deviation | p.u.MW |
| $K_g$ | governor static gain coefficient | p.u./p.u.MW |
| $T_g$ | governor time constant | s |
| $K_r$ | steam turbine reheat coefficient | p.u. |
| $T_r$ | steam turbine reheat time constant | s |
| $K_{ij}$ | steam turbine gain coefficient | p.u.MW/p.u. |
| $T_T$ | steam capacity time constant | s |
| $K_p$ | gain coefficient of power generation system | Hz/p.u.MW |
| $T_p$ | time constant of power generation system | s |
| $K_{ij}$ | the connection line between | p.u.MW |
3. Fuzzy PID control design based on particle swarm optimization

Due to the characteristics of non-linearity, strong coupling, time-variation and parameter uncertainty of the AGC system of thermal power units, this paper uses a fuzzy PID control strategy based on particle swarm optimization.

The fuzzy adaptive PI controller takes the error e and the error conversion rate ec as inputs, and uses fuzzy control rules to modify the parameters of the conventional PI controller to meet the different requirements of different e and ec for the control parameters, so that the controlled object has better dynamic and static performance. The structure of fuzzy adaptive PI controller is shown in the figure:

![Figure 3 structure of fuzzy PID controller](insert image)

In view of the limited self-adaptation of the fuzzy PID controller, when the load disturbance is different, the self-tuning fuzzy PID controller cannot be further self-adjusted. In order to continue to improve the performance of the controller, further reduce the transient frequency oscillation and shorten the time to reach the steady state. In order to overcome the shortcomings of fuzzy adaptive PI control, before the fuzzy PID control, a particle swarm optimization algorithm was added to optimize PI parameters online.

Principle of particle swarm algorithm: Particle Swarm Optimizer (PSO) originates from the mimicry of migration and swarm behavior of birds in the process of foraging. It is an iterative algorithm, and its basic idea is as follows: The solution of the optimization problem is regarded as particles, each particle corresponds to a fitness value, and all particles form a swarm. In order to make the particles in the swarm "fly" towards the optimal solution (equivalent to birds flying towards food), PSO introduces velocity to update the particle swarm. Obviously, this speed needs to reflect the current bird's How far is the position from the food, and at the same time, the speed also determines the direction and distance of the birds flying. The value of velocity is determined by the following two points of information: the individual extremum and the global extremum are the optimal solution found by the particle itself and the optimal solution currently found by the entire particle swarm. These two points of information correspond to the bird’s own Flight experience and flight experience of companions, it is with these experiences that birds can find food, that is to say, PSO can find the optimal solution. Its speed and position are:
\[
\begin{align*}
 v_{t+1} &= wv_t + c_1r_1(P_t - x_t) + c_2r_2(G_t - x_t) \\
 x_{t+1} &= x_t + v_{t+1}
\end{align*}
\]

(1)

Performance indicators (also called objective functions) usually reflect the requirements for a comprehensive control system in terms of quality and performance. This article selects ITAE as the performance indicator. ITAE has good engineering practicality and selectivity, and can better suppress long-term errors. Its definition is as follows:

\[J_{ITAE} = \int_0^T |e(t)| dt\]

(2)

Determination of fitness function: For the interconnected power system under study, the system error is composed of regional control deviation (ACE). ACE is essentially composed of regional frequency deviation and tie line power deviation, and its calculation formula is as follows:

\[ACE = \Delta P_{ij} + k\Delta f_i\]

(3)

Where \(k\) is the frequency deviation coefficient (MW/Hz) of the control area, the frequency deviation of area \(i\), and the tie line power deviation between area \(i\) and area \(j\). Based on this, the fitness function determined in this paper is as follows:

\[J_{ITAE} = \int_0^T |ACE| dt + \int_0^T k\Delta f_i + \Delta P_{ij} dt\]

(4)

Evaluation criteria of CPS1/CPS2: According to the regulations of NRC, for any control area, the standards of CPS1 and CPS2 improve the control performance of regional AGC evaluation, and its control index requires CPS1≥100%, CPS2≥90%.

4. Simulation analysis

If there is a load disturbance of 0.1 in area 1, Figure 3 shows the fuzzy self-tuning PID and fuzzy self-tuning PID-based particle swarm algorithm load control simulation curve of the AGC system. According to Figure 3, it can be concluded that the AGC system under fuzzy self-tuning PID control has a longer adjustment time and a larger overshoot, which makes the power of the unit impossible to adjust quickly. At the same time, the system's anti-disturbance ability is poor, which is difficult to meet the actual demand in production; and after using fuzzy self-tuning PID control based on particle swarm algorithm to optimize the system, the system has made a rapid response and adjustment to the load, and the adjustment time under the disturbance state has been reduced by about 1/2.

![Figure 4 AGC frequency deviation curve](image)

Under the particle swarm optimization optimized fuzzy PID controller, we select the value when the 1s system frequency and tie line power deviate to verify whether the system still meets the CPS standard when the disturbance is most severe. After calculation, at this time value, the CPS1 of the
area 1 affected by the disturbance is about 165%>100%, and the CF1 is about 0.25<1. The CPS2 of the unaffected area 2 is about 190%>100%, and CF2 is about 0.1<1. And also meet the above requirements at other times. Therefore, a fuzzy PID controller based on particle swarm optimization is used to enhance the frequency control under the established interconnection model, which can meet the CPS standard.

From the above analysis, it can be seen that compared with fuzzy PID control, the fuzzy PID controller based on particle swarm optimization can realize online adjustment of a larger range of parameters, optimize the unit operation, the system tracks variable load more quickly. And whether it is in load response or frequency deviation adjustment, it can improve the system's adjustment time, overshoot, robustness and other important control indicators.

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