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Simulation Research of Frequency Modulation Control Based on PID

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Abstract. When the balance of power system is broken, the frequency of power system will be deviated. Induction motors are mostly used in industry. Frequency is closely related to the change of speed and output power. Firstly, this paper focuses on the analysis of the mathematical model of the inter-regional tie-line and deduces the Laplace transform of the power variation of the tie-line. The physical model is established to analyse. The fluctuation of the two regions and the interconnected power grid is obtained. The operating point will change in the case of disturbance. The relationship between the switching power deviation of tie-line and the disturbance position point. Through the simulation of the classical two-zone model, the simulation effect of the PID controller is better than that of the conventional controller. The control effect is remarkable, which provides a certain basis for later research. The ideal adjustment parameters of the PID controller are obtained by trial-and-error method. The dynamic and robust performances of the AGC system are further verified by simulation.

1. Introduction

There are different evaluation indexes for the operation state of power system. Frequency is one of the important indexes reflecting power system. The essence of power system operation is to ensure that the quality of electric energy is within the standard range. When the balance of power system is broken, the frequency of power system will be deviated. Induction motors are mostly used in industry. Frequency is closely related to the change of speed and output power. When the frequency increases or decreases, the speed and output power of the motor will change accordingly. It will seriously affect the operation of equipment, more and more precision instruments and electronic equipment will be affected by frequency. Whether the frequency is high or low, it will threaten the stable operation of the power system, and even lead to the whole system out of step.

Previous automatic generation control function is mainly through the frequency of the system by the automatic frequency modulator to adjust the frequency offset. The initial application is controlled by flywheel governor in synchronous motor, and the later control strategy of AGC, which is controlled by PI adjustment through deviation, is constant frequency control. Reference [1] presents a method of applying fractional order PID to AGC of interconnected power grid, and proves that this method can make AGC have better non-linear adaptability. In reference [2], a classical fuzzy controller based on output scaling factor is proposed. The sensitivity analysis proves that the method is robust to a wide range of changes in system parameters, step size and position of load disturbance. Literature [3] points out that the frequency fluctuation caused by AGC overshoot occurs many times after the asynchronous interconnection of Yunnan and South China Power Grid. It is pointed out that the system frequency fluctuation caused by AGC overshoot can be suppressed by adjusting the proportional gain. Document [4] combines genetic algorithm with deep learning algorithm in the AGC control strategy. The simulation results in three regions show that the method is good in the non-linear control. Literature [5] focuses on the strong robustness and non-linear adaptability of fractional-order PID. The simulation results of the application of fractional-order PID to the study of AGC interconnected power grid show that it is better than the traditional PID controller under the CPS evaluation criteria.

Frequency is one of the most important criteria to measure the operation status of power system. Rational and effective frequency control is an important research topic.

Firstly, this paper focuses on the analysis of the mathematical model of the inter-regional tie-line and the derivation of the Laplace transform of the power variation of the tie-line. The physical model is established to analyse the fluctuation of the two regions, and the operation point of the interconnected power grid will change when disturbance occurs. The relationship between the switching power deviation of tie-line and the disturbance position point. Through the simulation of classical two-zone model, the simulation result with PID controller is better than that with conventional controller. The control effect is remarkable, which provides a certain basis for later research.

2. Tie-Line model

The different areas of interconnected power grid realize power exchange through the interconnected lines. The effective use of the interconnected lines can give full play to the power supply capacity of the region. If the transmission power is analyzed under the condition that the tie-line length is long enough, each area can be equivalent to a line connected in series with a voltage source and an equivalent reactance. Its electrical equivalent is shown in Figure 1.Two-region interconnected system is the simplest multi-region system, so it is chosen as the research object.

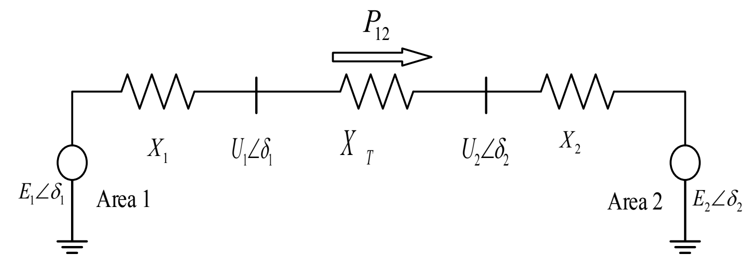

Figure 1. Electrical equivalence diagram of two interconnected areas

In Figure 1, X_1 is the equivalent reactance of region 1.X_2 is the equivalent reactance of zone 2. The equivalent reactance of the tie line is X_T. The voltages at the end and end of the tie-line are U_1 and U_2, respectively. The phase angles are δ_1 and δ_2, respectively. If the loss of tie-line is neglected, the mathematical expression of active power P_{12} of tie-line from area 1 to area 2 is as follows:

$$P_{12}=\frac{|U_1||U_2|}{X_T}\sin(\delta_1-\delta_2) \tag{1}$$

When small changes occur in δ_1 and δ_2, the power of the tie-line changes:

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$$\Delta P_{12} = \frac{|U_1||U_2|}{X_T} cos(\delta_{10} - \delta_{20})\left(\Delta\delta_1 - \Delta\delta_2\right) \tag{2}$$

$$\begin{cases} \Delta\delta_1 = \delta_1 - \delta_{10} \\ \Delta\delta_2 = \delta_2 - \delta_{20} \\ \Delta\delta_{12} = \Delta\delta_1 - \Delta\delta_2 \end{cases} \tag{3}$$

In the formula, P_{12} is the change of active power of tie-line. δ_{10} and δ_{20} are the initial phase angles of the voltage at the end and end of the tie-line, i.e. the initial steady-state values. $\Delta\delta_1$ is the change of the phase angle at the end of the tie line. $\Delta\delta_2$ is the change of phase angle at the end of tie line. $\Delta\delta_{12}$ is the difference between the change of the phase angle at the head and the end of the tie line.

By substituting Formula (3) into Formula (2), the variation of active power of tie-line P12 can be simplified to:

$$\Delta P_{12} = \frac{U_1 U_2}{X_T}\cos(\delta_{10} - \delta_{20})\Delta\delta_{12} \tag{4}$$

Substitute $\Delta\delta = \int 2\pi\Delta f dt$ into the upper formula and get it by Laplace's change.

$$\Delta P_{12} = 2\pi\frac{U_1 U_2}{X_T}\cos(\delta_{10} - \delta_{20})\frac{1}{s}\Delta f\left(s\right) \tag{5}$$

Let the expression of synchronization coefficient T_{12} be:

$$T_{12} = 2\pi\frac{U_1 U_2}{X_T}\cos(\delta_{10} - \delta_{20}) \tag{6}$$

Then the tie-line power is transformed by Laplace transform:

$$\Delta P_{12}\left(s\right) = \frac{T_{12}}{s}\Delta f\left(s\right) \tag{7}$$

When $P_{12} > 0$ denotes that the area one transmits power to the area two through the tie line. $P_{12} < 0$ indicates that the power direction of tie-line is zone 2 to zone 1. T was defined as the contact line synchronization coefficient. The tie coefficient T_{ij} between tie lines i and j. If the expression is (7), the expression of tie-line switching power is (8).

$$T_{ij} = 2\pi\frac{U_i U_j}{X_T}\cos(\delta_{i0} - \delta_{j0}) \tag{8}$$

$$\Delta P_{ij} = \frac{T_{ij}}{s}\Delta f\left(s\right) \tag{9}$$

According to the above expression, the simplified model of tie line can be obtained:

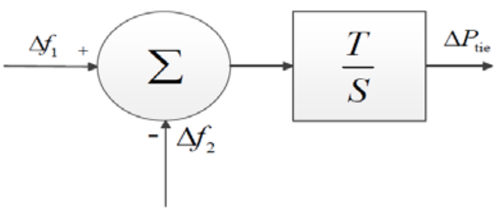

Figure 2. Mathematical model of the tie line

3. Principle analysis of frequency fluctuation in two regions

When the tie-line power fluctuates in the power system, the analysis is as follows:

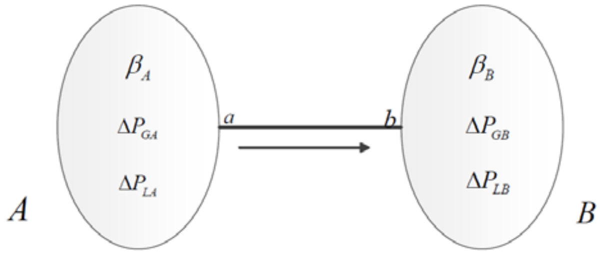

Figure 3. Two Regional tie-Line model

In the figure3, β_A represents the natural frequency characteristic coefficient of region A; β_B represents the natural frequency characteristic coefficient of B region; ΔP_{GA} represents the increment of active power output of regional A units; ΔP_{LA} represents the increment of active power output of area A load; ΔP_{GB} represents the increment of active power output of regional B load; ΔP_T represents the increment of switching power on area A and area B tie lines.

Among them, Δf is the difference between the actual frequency and the rated frequency of the system.

$$\begin{cases} \Delta P_{GA} - \Delta P_{LA} - \Delta P_T = \beta_A \Delta f \\ \Delta P_{GB} - \Delta P_{LB} - \Delta P_T = \beta_B \Delta f \end{cases} \tag{10}$$

Let $\beta = \beta_A + \beta_B$ deduce that:

$$\Delta f = \frac{(\Delta P_{GA} - \Delta P_{LA}) + (\Delta P_{GB} - \Delta P_{LB})}{B} \tag{11}$$

$$\Delta P_T = \frac{\beta_A(\Delta P_{GB} - \Delta P_{LB}) + \beta_B(\Delta P_{GA} - \Delta P_{LA})}{B} \tag{12}$$

The operating point of two-area interconnected power grid will change when disturbance occurs. The relationship between the switching power deviation of tie-line and the disturbance location point is as follows: (1) Load disturbance or active power output change anywhere in the interconnected power grid will affect the tie line;(2) The same amount of active power disturbance in the same area has the same effect on the transmission power of tie-line.(3) When the same disturbance occurs in different regions, the larger area of beta has less influence on the transmission power of tie-line, and the smaller area of beta has greater influence on the transmission power of tie-line.(4) The fluctuation of tie-line power caused by any active disturbance has nothing to do with the voltage level of tie-line, the landing point of tie-line in two areas, the magnitude and direction of transmission power of tie-line before disturbance.

4. Two-region AGC model of classical control

The automatic control device used in the automatic control system of most production processes at present. Whether pneumatic, electro-hydraulic, programmable or micro-computer, although their structures are different, their control laws are proportional, integral and differential laws, so they are called PID controllers. It is the basic control device with the longest history and the strongest vitality. It has simple principle, convenient application, strong adaptability and robustness.

The dynamic equation of the PID controller is:

$$u(t) = K_p \left\{ e(k) + \frac{T}{T_i} \sum_{j=0}^{k} e(j) + \frac{T_d}{T} [e(k) - e(k-1)] \right\} \tag{13}$$

In the formula, Kp is the proportional coefficient; T_i is the integral time constant; T_d is a differential time constant; K_i=K_pT/Ti is the integral action coefficient; $K_d = K_pT_d\ /\ T$ is the differential coefficient of action; e (k) is the system deviation.

Two-machine and two-area simulation model is built by MATLAB/SIMULINK. Fig. 5, the regional control deviation is acted on the unit by the PID controller, and the unit action adjusts the output power of the unit.

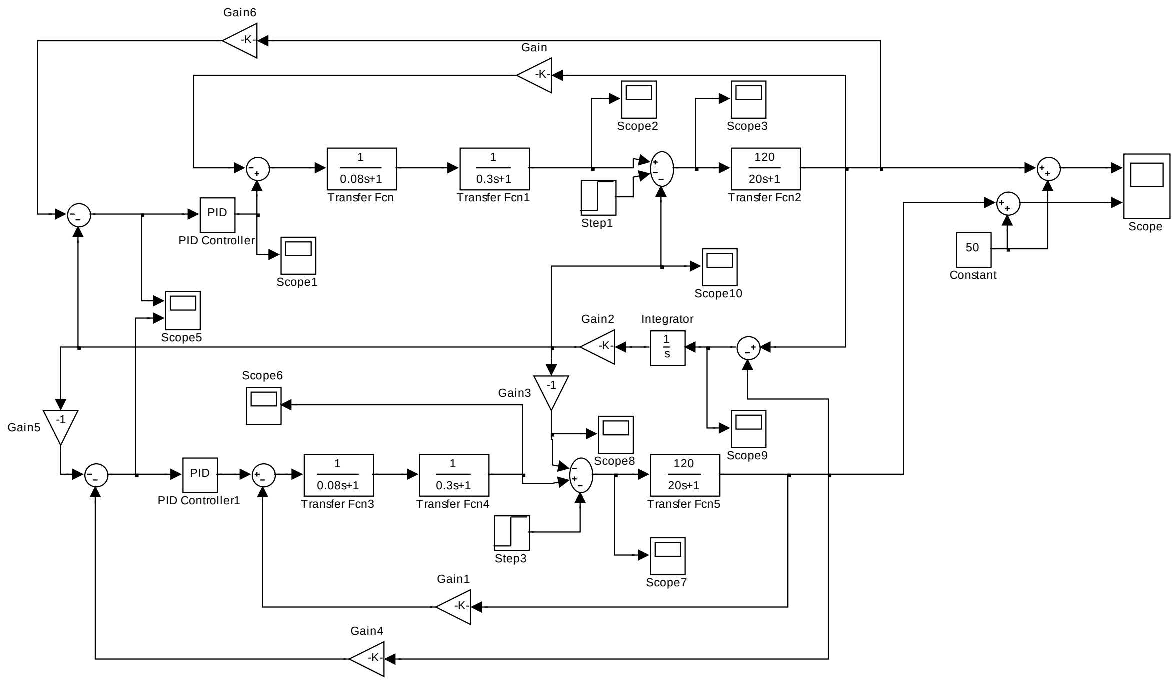

Figure 4. Two-area interconnection simulation model of PID control

Load disturbance of 0.02pu is applied in A region and 0.03pu is applied in B region when t=0s. The simulation results are as follows:

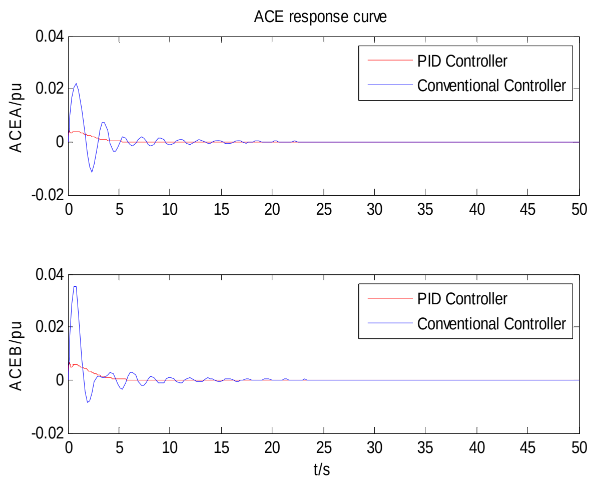

Figure 5. Frequency response curve

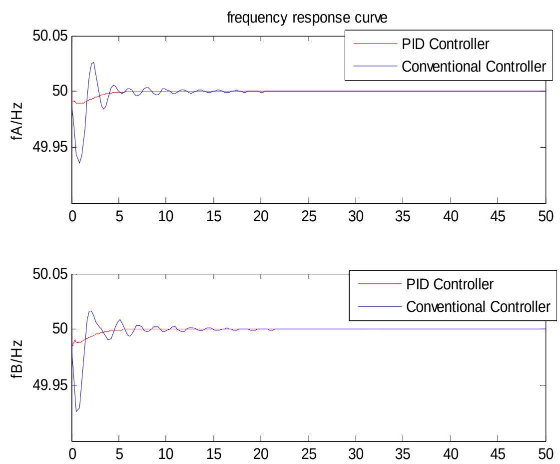

Figure 6. Tie-line switching power response curve

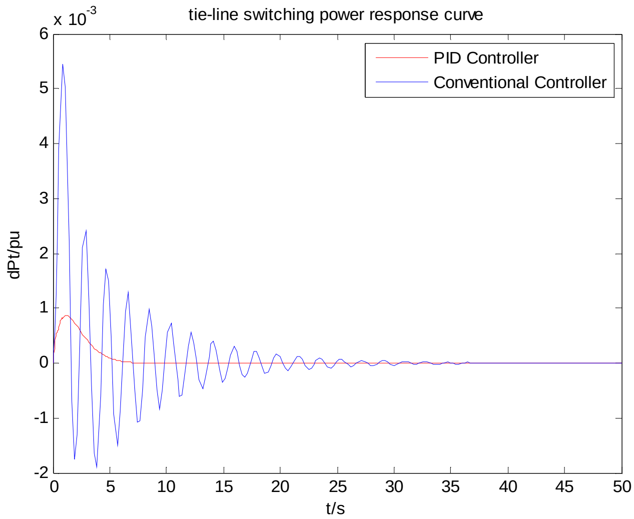

Figure 7. ACE response curve

A group of PID parameters with better control effect obtained after many times of trial and error are as follows. $k_p = 3,\ k_I = 2,\ k_d = 2$. When both interconnected regions are disturbed by load, the two regions are regulated by their respective closed-loop feedback control systems. The simulation waveform was observed and the frequency was restored to 50Hz at about 7s.That is to say, after about 7 seconds of simulation adjustment, the time-frequency deviation is 0, the power deviation of tie-line and the regional control deviation are all 0.

5. Dynamic Performance of AGC System

Generally, the occurrence of load disturbance is random. In order to verify the dynamic performance of PID, when t=0s is set, the load disturbance in Area A is 0.02pu.Load perturbation of 0.03pu is applied to B region when t=5s.That is to say, the dynamic characteristics of PID controllers with different disturbances in different areas of interconnected power grid in different time periods are validated by the time difference of 5S. The above values are still used for the model parameters of the two areas. The simulation results are as follows:

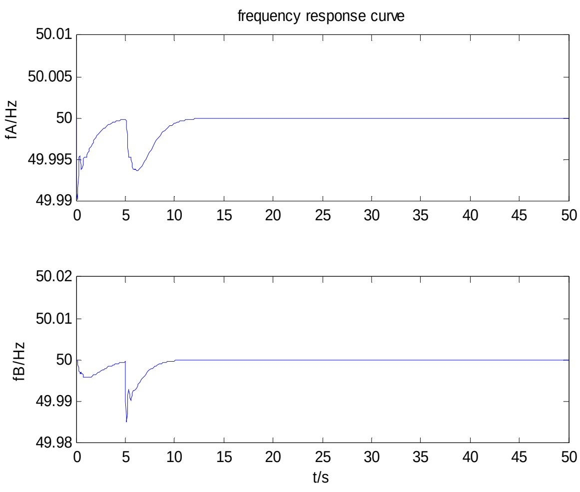

Figure 8. Frequency response curve

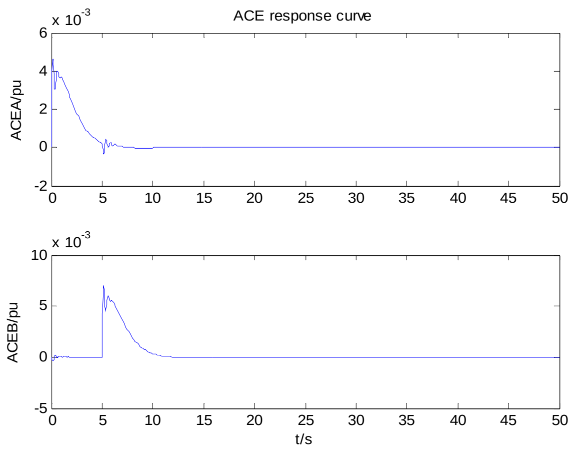

Figure 9. Tie-line switching power response curve

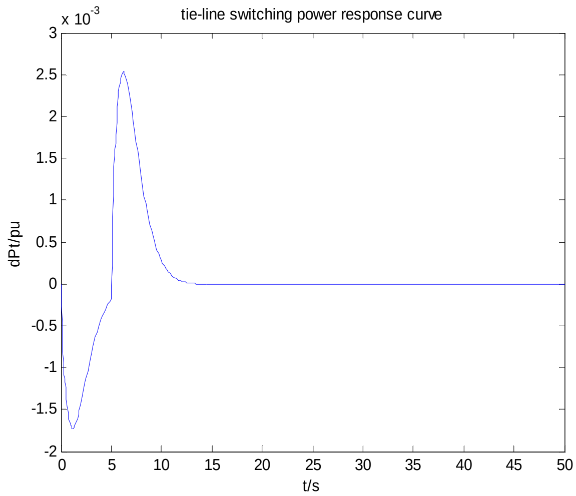

Figure 10. ACE response curve

From the above simulation results, it can be observed that the "inflection point" appears on the simulation waveform at 5S time when the load disturbance in the delayed B region occurs, which is obviously caused by the introduction of load disturbance in the B region. The frequency recovery time in the A and B regions is 12.4s and 9.9s respectively. The maximum transmission power on the tie-line is about 0.0025pu. The ACE curve also appears discontinuous when t = 5s, but in general, it can recover to 0.It shows the dynamic stability of PID control in restraining load disturbance.

6. Robust Performance of AGC Systems

Actual power grid operation is affected by various uncertainties, and there are some changes in the parameters. AGC control system puts forward certain requirements for robustness. In order to verify the robustness of the AGC system under PID control, the model parameters of the interconnected power grid in the above two regions are changed. The model parameters after the change are as follows:

Table 1. Two-area interconnected grid model parameters

Area A	T_{T1}/s	T_{G1}/s	k_{P1}/(Hz/pu)	T_{P1}/s	D_1(pu/Hz)	R_1(Hz/pu)	T_{12}(pu/Hz)
	0.32	0.76	120	120	0.00833	2.4	0.545
Area B	T_{T2}/s	T_{G2}/s	k_{P2}/(Hz/pu)	T_{P2}/s	D_2(pu/Hz)	R_2(Hz/pu)	T_{12}(pu/Hz)
	0.29	0.082	12	20	0.00866	2.6	0.545

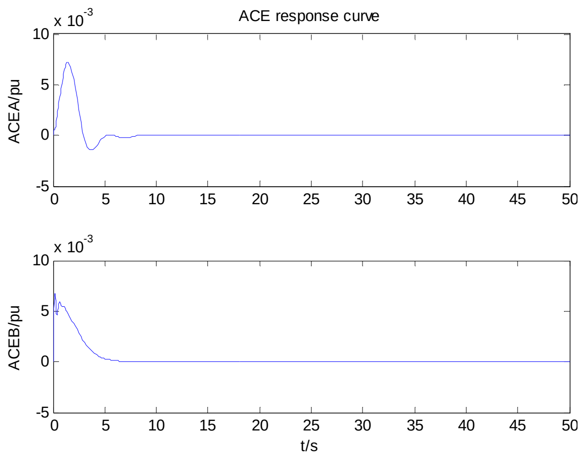

Figure 11. Frequency response curve

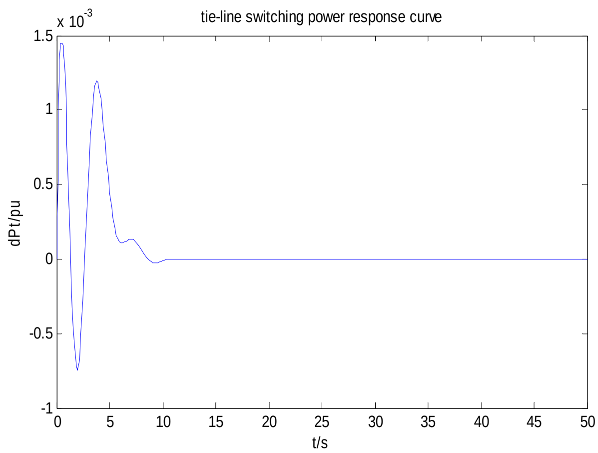

Figure 12. Tie-line switching power response curve

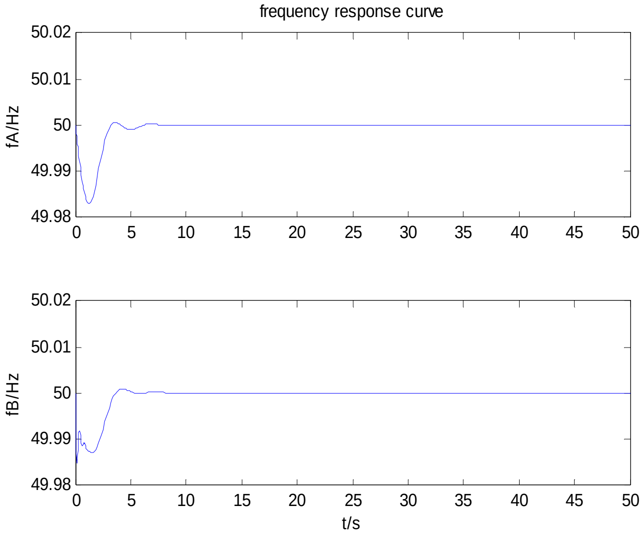

Figure13. ACE response curve

The simulation conditions are consistent with the previous section. Load disturbances of 0.02pu and 0.03pu are applied simultaneously in area A and area B at the beginning of the simulation. The simulation results are shown in figs. 11 and 13.

By observing the simulation waveform, it can be found that even if the parameters of the regional model change, the PID parameters of the tuned parameters can still restore the frequency to a stable value.The time for region A to reach stability is about 6.8 seconds, and that for region B is about 7 seconds. The regulation can be completed quickly and accurately within the prescribed time range.

7. Conclusion

Frequency is one of the important elements to measure the quality of power system.Through the simulation of classical two-zone model, the simulation effect of the PID controller is better than that of the conventional controller.It provides a certain basis for later research, and gets the ideal adjusting parameters of the PID controller by trial and error method.The dynamic and robust performances of the AGC system are further verified by simulation.

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