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Research article

Secondary frequency control for improved dynamic performance in interconnected power system

Farhad Mesrinejad[1], Somaye Yaghoubi[2,3*], Bahador Fani[4,5**]

[1]*Department of Electrical Engineering, Tiran Branch, Islamic Azad University, Tiran, Iran*
[2]*Department of Mechanical Engineering, Najafabad Branch, Islamic Azad University, Najafabad, Iran*
[3]*Modern Manufacturing Technologies Research Center, Najafabad Branch, Islamic Azad University, Najafabad, Iran*
[4]*Smart Microgrid Research Center, Najafabad Branch, Islamic Azad University, Najafabad, Iran*
[5]*Department of Electrical Engineering, Najafabad Branch, Islamic Azad University, Najafabad, Iran*

*s.yaghoubi@pmc.iaun.ac.ir, **bahadorfani@gmail.com

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Abstract

Load changes affect the frequency of electrical networks. Frequency stabilization is very important due to the increasing penetration of renewable energy sources in power systems. The main task of load frequency control is to keep the system frequency according to the specified nominal value and to maintain the correct amount of exchange power between the control areas. Load frequency control in two-area power system is studied and simulated in this paper. Each area has a steam generating unit with a reheat steam turbine. The system equations are expressed in the state space and the system model is determined based on the transfer function. The simulation results have been obtained using Matlab software. The simulation results show the effect of reheater on the transient dynamic behavior of the two-area power system.

Keywords: Load frequency control, Steam turbine, Reheater, Integral controller

1- Introduction

Nowadays, the increasing use of energy and its supply is one of the important issues [1,2]. Therefore, energy consumption management, in other words, optimizing and rationalizing energy consumption, has become very important. The impossibility of storing electricity on a large scale is one of the characteristics of electrical energy, and therefore the balance between production and consumption must be established instantly [3,4].

A power system is formed by many power plants consisting of synchronous generators connected together. Frequency and voltage, the two main parameters of the network, must be kept within permeable limits. The change in these variables determines the quality of the network [5,6]. Due to the change of active and reactive power and their almost independent from each other, two automatic load-frequency control systems and automatic voltage regulator are always needed to control transient and permanent responses of the system in power plants [7, 8].

The function of the secondary frequency control, or load frequency control (LFC), is to keep the frequency at the desired level after the disturbance [9, 10]. This system corrects the area control error based on the initial frequency and returns the frequency to the nominal value [11, 12].

Fig. 1 shows a typical frequency tuning scenario under a contingency event, where the rate of change of frequency is specified. The system frequency starts to deviate to a minimum set as a rare point [13].

Load frequency control (LFC) is a multi-area power system mechanism, which balances power generation and demand, regardless of load fluctuations, to maintain frequency deviations within acceptable limits [14, 15].

LFC or automatic generation control (AGC) is one of the main operations that is performed every day according to the performance in a modern power system [16, 17]. Load frequency control is necessary to create better control in order to achieve a lower effect on the frequency and power deviations of the connection line after load perturbation [18, 19]. Various studies have been conducted in the field of load frequency control [20,21].A survey on LFC mechanism is presented in [22], which reveals the investigation of soft computing based optimization technique and application of energy storage system and HVDC-link in LFC. Also, the different control techniques of LFC are mentioned, which includes all the recent application of FACTS devices. An overview of different types of deregulated power system structures, market models, contracts agreements and various control methodologies/techniques for mitigating the various LFC issues in a deregulated power system is provided in [23], which the detailed analysis of various control methodologies based on classical control, robust and self-tuning control and various soft computing control techniques are discussed.

The accurate modeling of HVDC links for the dynamic studies of automatic generation control/LFC) of the multi-area interconnected power system is presented in [24], which the comparative analysis has been performed to demonstrate error being accrued due to the use of the conventional model of HVDC links.

In this paper, the aim is to simulate the power system with a reheat steam turbine. The power system consists of two areas that are connected to each other through a tie line. The simulation results show the transient behavior of the power system in response to load demand changes in each area. The closed loop system of load frequency control tends to zero load frequency deviation changes. It also keeps the power transfer between the two areas constant at the specified value.

2- Power System Model in State Space

There are many different types of electric power generating plants, such as hydroelectric power plants, wind power plants, solar power plants, nuclear power plants and steam power plants [25]. Usually, the power system of an area is connected to its neighboring areas through connecting lines [26, 27]. LFC is used in interconnected systems to reduce rotating storage and reduce frequency deviation changes in an area [28, 29]. The equations of the LFC for the two-area power system are expressed as follows by choosing 11 state variables in the state space:

$$\frac{d}{dt}x_1 = -\frac{1}{T_{P1}}x_1 + \frac{K_{P1}}{T_{P1}}x_2 - \frac{K_{P1}}{T_{P1}}x_{11} - \frac{K_{P1}}{T_{P1}}u_1 \quad (1)$$

$$\frac{d}{dt}x_2 = -\frac{1}{T_{T1}}x_2 + \frac{K_{T1}}{T_{T1}}x_3 \quad (2)$$

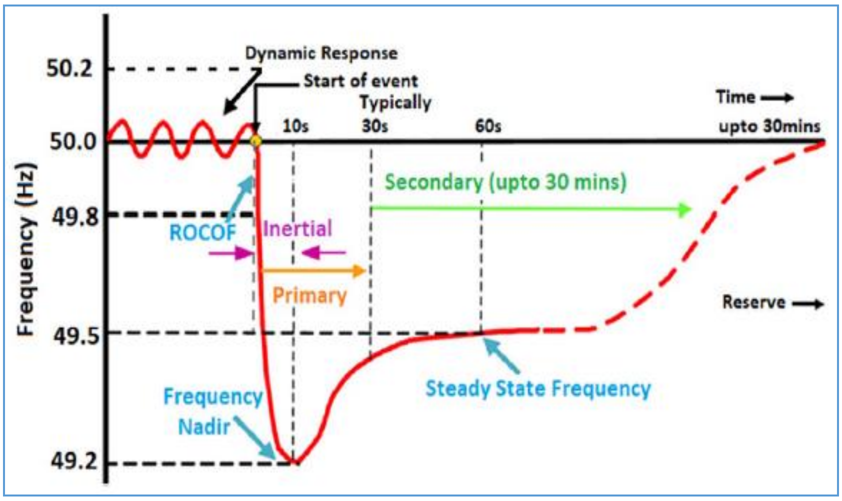

Fig. 1 Regulation services during frequency variation

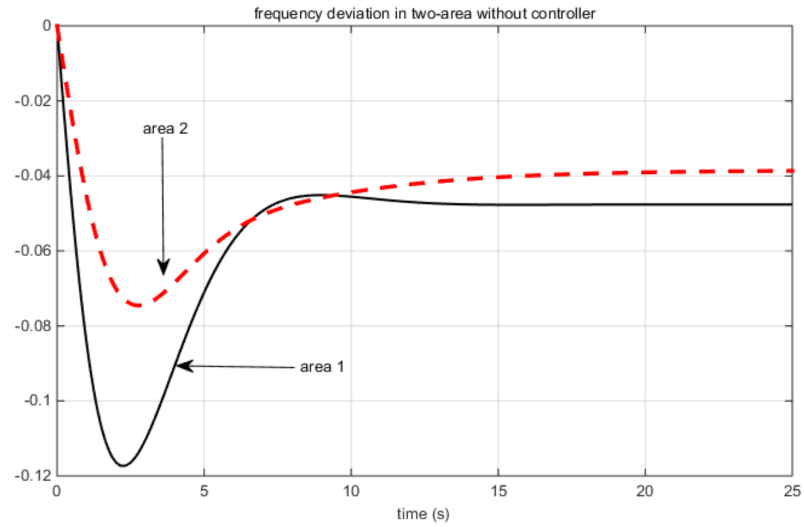

Fig. 2 Frequency deviation changes in single-area without controller (load changes in area 1)

$$\frac{d}{dt}x_3 = -\frac{K_{G1}F_{H1}}{T_{G1}R_{P1}}x_1 - \frac{1}{T_{R1}}x_3 + \left(\frac{1}{T_{R1}} - \frac{F_{H1}}{T_{G1}}\right)x_4 + \frac{K_{G1}F_{H1}}{T_{G1}}x_5 \quad (3)$$

$$\frac{d}{dt}x_4 = -\frac{K_{G1}}{T_{G1}R_{P1}}x_1 - \frac{1}{T_{G1}}x_4 + \frac{K_{G1}}{T_{G1}}x_5 \quad (4)$$

$$\frac{d}{dt}x_5 = -K_{I1}\beta_1 x_1 + K_{I1}x_{11} \quad (5)$$

$$\frac{d}{dt}x_6 = -\frac{1}{T_{P2}}x_6 + \frac{K_{P2}}{T_{P2}}x_7 - \frac{K_{P2}}{T_{P2}}x_{11} - \frac{K_{P2}}{T_{P2}}u_2 \quad (6)$$

$$\frac{d}{dt}x_7 = -\frac{1}{T_{T2}}x_7 + \frac{K_{T2}}{T_{T2}}x_8 \quad (7)$$

$$\frac{d}{dt}x_8 = -\frac{K_{G2}F_{H2}}{T_{G2}R_{P2}}x_6 - \frac{1}{T_{R2}}x_8 + \left(\frac{1}{T_{R2}} - \frac{F_{H2}}{T_{G2}}\right)x_9 + \frac{K_{G2}F_{H2}}{T_{G2}}x_{10} \quad (8)$$

$$\frac{d}{dt}x_9 = -\frac{K_{G2}}{T_{G2}R_{P2}}x_6 - \frac{1}{T_{G2}}x_9 + \frac{K_{G2}}{T_{G2}}x_9 \quad (9)$$

$$\frac{d}{dt}x_{10} = -K_{I2}\beta_2 x_6 + K_{I2}x_{11} \quad (10)$$

$$\frac{d}{dt}x_{11} = 2\pi T_S(x_1 - x_6) \quad (11)$$

where T_{P1} and T_{P2} are time constant, and K_{P1} and K_{P2} are gain of the power systems. T_{G1} and T_{G2} are time constant, and K_{G1} and K_{G2} are gain of governors. T_{T1} and T_{T2} are constant time and K_{T1} and K_{T2} are gain of turbines. F_{H1} and F_{H2} are compressive constant, T_{R1} and T_{R2} are constant time of reheater. Also, β_1 and β_2 are frequency response characteristic of areas 1 and 2, respectively.

where variables x_1 and x_6 show the frequency deviation changes in area 1 and 2, respectively. Also, the variable x_{11} shows the transmission power of the connecting line between the two areas. In these equations, the load changes in two areas are specified by $u_1=\Delta P_{D1}$ and $u_2=\Delta P_{D2}$, respectively.

3- Simulation Results

Unpredictable deviation of the load demand from the nominal value changes the operating point of the power system and therefore, deviations in the nominal frequency and planned power exchanges may be created in the system. The parameters of the studied two-area power system with reheat steam turbine are listed in Table 1.

Fig. 2 shows the frequency deviation changes for each area when they are independent from each other. As can be seen, after the load demand changes, the frequency deviation decreases in the steady state, which is higher in area 1 than area 2.

In addition, as can be seen, the amount of overshoot in area 2 is lower than in area 1.

Table 1: Parameters of the studied power system

Parameters	Area 1	Area 2
K_P	1	1
T_P	10	20
T_G	0.2	0.3
K_G	1	1
R_P	0.05	0.04
K_T	1	1
T_T	0.3	0.5
T_R	7	10
F_H	0.3	0.5
β	0.5	0.5
K_I	0.4	0.4

Fig. 3 shows the frequency deviation changes for each area when they are connected but still not controlled. As can be seen, in this case, the frequency deviation will reach a steady state, but due to the connection between the areas, the frequency droop has decreased. This frequency droop difference in steady state is shown for area 1 in Fig. 4.

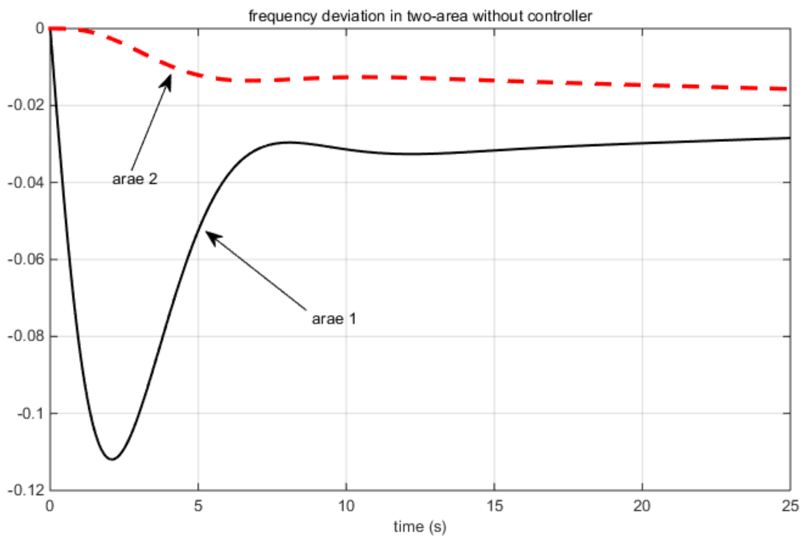

Fig. 3 Frequency deviation changes in two-area without controller (load changes in area 1)

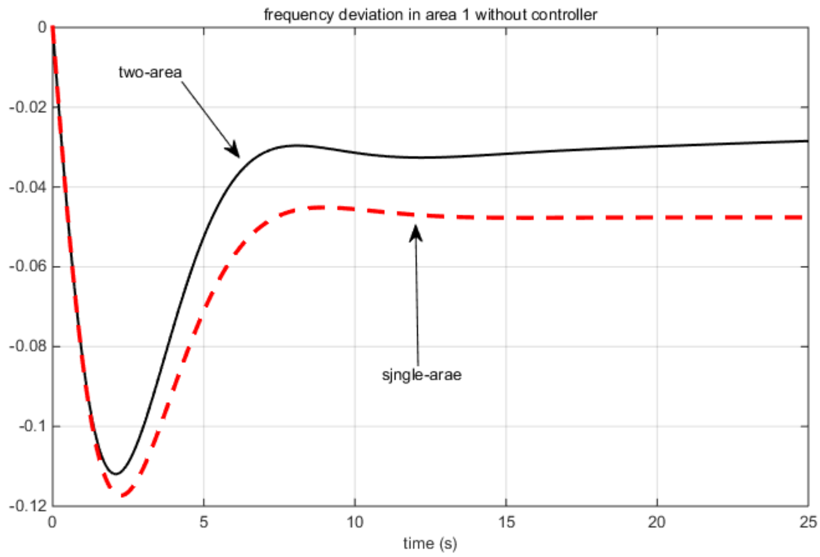

Fig. 4 Comparison of frequency deviation changes in two connection modes

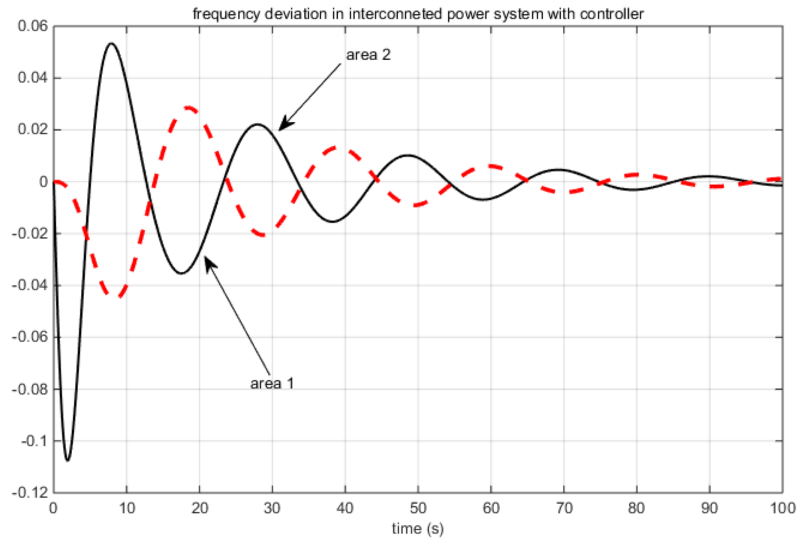

Fig. 5 Frequency deviation changes in area 1 (load changes in area 1)

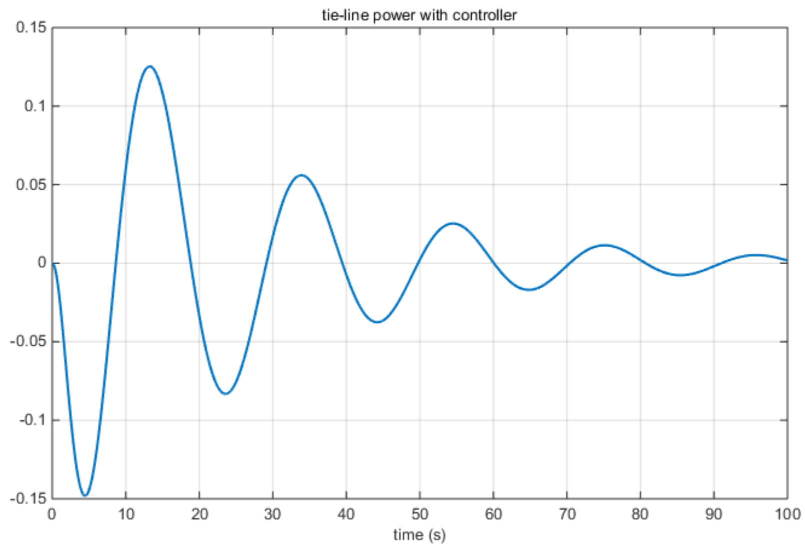

Fig. 6 Changes in power transmission between two-area (load changes in area 2)

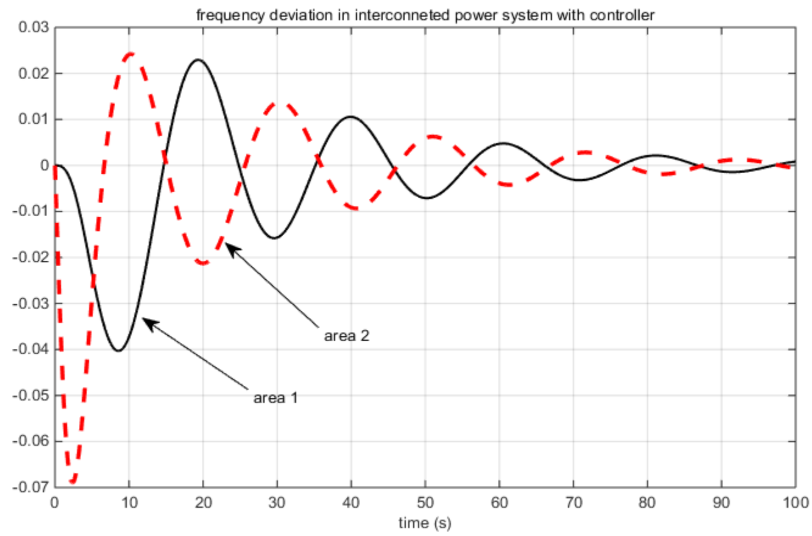

Fig. 7 Frequency deviation changes in area 1 (load changes in area 2)

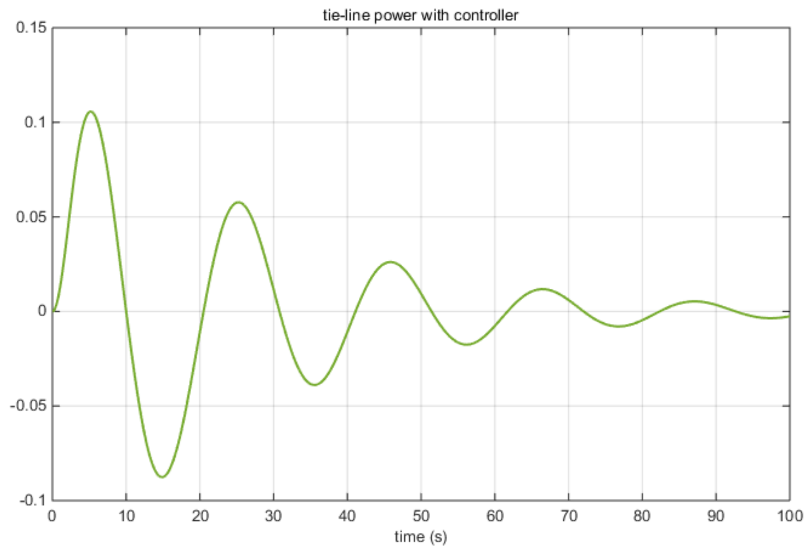

Fig. 8 Changes in power transmission between two-area (load changes in area 2)

The dynamic response of frequency deviation changes in areas 1 and 2, for step changes in load demand in area 1, are shown in Fig. 5. In addition, the changes in power transmission between two-area is shown in Fig. 6. As can be seen, the power changes tend to zero in the steady state.

As can be seen, the overshoot of the response for area 1 is higher than the overshoot in area 2. In addition, the changes in transmission power between the two areas reach zero in the steady state. For faster response, you can use PID controller.

In the same way, for step change of load demand in area 2, frequency deviation changes and power changes between two areas are shown in Figs. 7 and 8, respectively. In this case, the overshoot response of frequency deviation changes for area 2 is higher than area 1. This response is natural, because the area where the load demand changes have occurred is more inclined to respond to it. Therefore, in the relevant area, there are both higher fluctuations and higher overshoot.

4- Conclusion

Load frequency control is an important function in modern energy management systems. In this paper, the frequency deviation changes in the power system with reheat steam turbine were studied. Two areas were considered for the target system. The first order differential equations in the state space were expressed for two systems. Then, the simulation results were obtained using Matlab software. The simulation results were obtained for an independent area, two interconnected areas without a controller and for two interconnected areas with a controller, and the transient behavior of the system was shown.

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