PERFORMANCE ANALYSIS OF ROBUST CONTROL TECHNIQUES FOR LOAD FREQUENCY CONTROL OF MULTI AREA POWER SYSTEM

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Abstract

Robust control techniques are presented here for performance analysis of load frequency control in a five area interconnected power systems considering the impact of time delay and noise. The different controllers investigated in this paper are, fuzzy logic controller, station-to-grid supplementary controller and linear quadratic gaussian controller. The robust controllers are design to palliate the time delay response by using pade approximations and mitigate the measurement noise effects. Intelligent and supplementary controllers can perform better than the conventional controllers, proportional integral controller. When the impact of time delay is considered in area control error signal, fuzzy logic controller gives better dynamic response. When both time delay and noise are considered in area control error signal of system, LQG controller gives better dynamic performance.

Keywords: Load Frequency Control, Linear Quadratic Gaussian controller, Fuzzy Logic Controller, Station-to-Grid, Robust Controller.

I. Introduction

Load Frequency Control (LFC) is a part of the power system stability for controlling the frequency. The proper operation of interconnected power system maintains power balance among total generation and the total load demand with lesser system losses. However, with respect to the time for changing in load demand, the operating point of a power system also changes and produces fluctuations in both the frequency as well as a tie line power resulting in instability [1], [2]. The objective of the LFC is to maintain the system frequency within permissible limits when there is a change in real power load demand. The rotor angle changes with the small changes in real power which results in frequency deviation. In addition to this, LFC loop is also accountable for dividing the load between the generators and controlling the tie-line power [3].

In the past decades, the researchers have done lot of work on the LFC problems of power systems and various control strategies have been designed. The importance of control frequency or tie line power flow in the power system for stability is discussed in [4]. Various Control strategies like integral control [5], discrete time sliding mode control [6], optimal control [7], adaptive and auto-tuning control [8], conventional controller (PI/PID) [9], [20], robust control [10], [11], [12], [13], genetic algorithm [14], GWO algorithm [15], quasi-oppositional whale optimization algorithm (WOA) [25] have been implemented in the existing LFC solution. A fractional order fuzzy PID using biogeography based optimization in four-area system is discussed in [24].

In the present work, intelligent controller and supplementary controller are used to restore the frequency to its nominal value and their dynamic responses are compared for five area test system. Time delay and noise signal are considered in area control error signal of system. Fuzzy Logic Controller, Station-to-Grid, Linear Quadratic Gaussian Controller is compared with conventional controller. Further, it shows that implemented techniques are better than conventional technique for the test system. Fuzzy Logic Controller is not affected by the time delay response and LQG controller is not affected by the noisy signal.

II. Five Area Systems for Load Frequency Control

In this paper, five area systems are considered with a number of generators and loads as illustrated in Fig. 1. The transfer function for the plant model is given by eq. (1), when droop characteristics are neglecting,

$$G = G_g G_t G_p \tag{1}$$

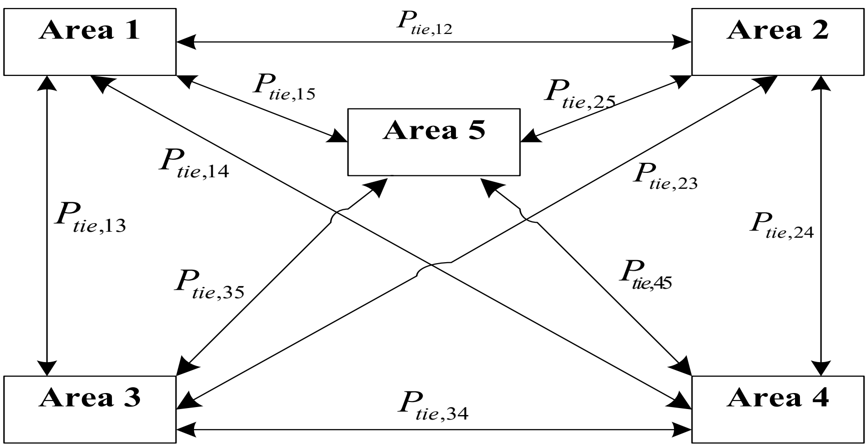

Figure 1: *Block diagram of five area interconnected system*

Where, $G_g = 1/(1+T_g s)$ is the transfer function of governor, $G_t = (1+K_r T_r s)/(1+T_t s)(1+T_r s)$ is the turbine transfer function, $Gp = K_p/(1+T_p s)$ is the power system transfer function which represents the load and machine dynamics. Since the reheat turbine used has different stages of low and high pressures of steam, it is modelled as a second-order unit. The transfer function for the plant model considering droop characteristics is given by eq. (2),

$$G = \frac{G_g G_t G_p}{1 + G_g G_t G_p \left(\frac{K_I}{s} + \frac{1}{R} \right)} \tag{2}$$

Power transported in ith area is given by eq. (3),

$$P_{tie,i} = \frac{|V_i| * |V_j| * \mathrm{Sin}(\delta_i - \delta_j)}{X_{ij}}, (i, j = 1, 2, ..., 5) \tag{3}$$

During normal condition, the active power of ith control areas,

$$ACE_i = B_i \Delta F_i + \Delta P_{tie,i}, (i = 1,2,...,5) \tag{4}$$

Where, B_i = biasing factor, ACE_i = area control error of i^{th} area and $\Delta P_{tie,i}$ = tie line power of i^{th} area. The control inputs for the five area systems is given by eq. (5),

$$u_i = -k_{ij} \int ACE_i dt = \Delta P_{ci}(S), (i, j = 1,2,...,5) \tag{5}$$

A. Impact of Noise

In the power systems, random fluctuations occur in the form of noise (energy) which is an unwanted signal and must reduce to a low level [16]. In this paper, Gaussian noise is used which effect on the controllers.

B. Impact of Time Delay (Pade Approximations)

This system model is modified to include the time delay into the control loop for multi-area interconnected load frequency control [17]. Second order Pade approximations of is given by eq. (6), for a delay of 0.25 s,

$$TF_{\text{Pade}} \approx \frac{-\frac{1}{120}s^3T^3 + \frac{1}{12}s^2T^2 - \frac{1}{2}sT + 1}{\frac{1}{120}s^3T^3 + \frac{1}{12}s^2T^2 + \frac{1}{2}sT + 1} \tag{6}$$

III. CONTROL STRATEGIES

In this section following control strategies such as Fuzzy Logic Controller, Station-to-Grid (S2G) control technique, Linear Quadratic Gaussian (LQG) controller proposed for investigation of 5-area LFC system.

A. Fuzzy Logic Controller

The fuzzy logic is developed by Zadeh in 1965, today implemented in all industrial systems all over the world [18]. The control vector for the controller can be given by the eq. (7) and eq. (8) when ACE as the system response,

$$u_i(t) = -k_p(ACE_i) - \int k_i(ACE_i)dt$$

(7)

$$u_i(t) = -k_p(B_i \Delta F_i + \Delta P_{tie,i}) - \int k_i(B_i \Delta F_i + \Delta P_{tie,i})dt$$

(8)

B. Station-to-Grid (S2G) Control Technique

Station-to-Grid is termed as the, interconnection between the battery swapping station (BSS) and power grid. The BSS is a concept which introduced in EV industry for getting a rapid swap between an empty or a near empty battery from a fully-charged battery within a short period of time. Implementing this concept in load frequency control strategy, BSS will store the onset point of frequency and whenever deviation in frequency and power occur. In this scheme Monte-Carlo stochastic simulation method is used to estimate controllable capacity of BSS storage, and then a lumped equivalent model of S2G subjected to state of charge limit and CC constraints are presented in multi-area interconnected load frequency control for managing the speed deviation [19], [23]. BSSs energy storage is an emerging from of storage which having battery swapping of Electrical vehicles and the batteries are in charging mode. The scheme from which all the power of BSSs is adjusted when it is required in power grid, this scheme is called the S2G power. The storage capacity of the system is not always constant; it varies continuously with the number of controllable batteries (CBs) in BSSs of the control area [20].

C. Linear Quadratic Gaussian (LQG) controller

Linear Quadratic Gaussian (LQG) [21], [22] scheme is a robust control technique for controlling the random noise signal in state and output equation. The quantitative information about the noise is used in this controlling strategy. A Kalman filter [30] is used as an observer for getting the optimal solution. Firstly, it finds an optimal state estimation signal $\hat{x}(t)$ which minimize the covariance $E[(x-\hat{x})(x-\hat{x})^T]$, and further it is used to estimate the to replace the actual state variables [19], [20]. the gain K_f is given by,

$$K_f = P_f C^T \Theta^{-1} \tag{9}$$

Where, P_f = algebraic Riccati equation (ARE) i.e. a symmetrical semi positive-definite matrix, K_f = gain.

$$P_f = P_f^T \geq 0 \tag{10}$$

$$P_f A^T + A P_f - P_f C^T \Theta^{-1} C P_f + \mathbb{F} \Xi \mathbb{F}^T = 0 \tag{11}$$

The syntax for Kalman matrix is,

$$\left[G_k, K_f, P_f\right] = kalman\left(G, \Xi, \Theta\right) \tag{12}$$

IV. RESULTS AND DISCUSSION

The five-area interconnected reheat thermal power system investigated in this paper is modelled and implemented in MATLAB/Simulink environment.

A. Performance analysis of Fuzzy Logic Controller

The frequency deviation step responses of generator 1 and generator 3 with fuzzy logic controller are shown in fig. 2, and fig. 3 respectively. It is illustrated in fig. 2 and fig. 3, that when the system was operated with fuzzy logic controller, the dynamic performance of the system is significantly improved with comparison to conventional PI controller. Fig. 4 shows the power deviation step responses of generator 1 with fuzzy logic controller and PI controller.

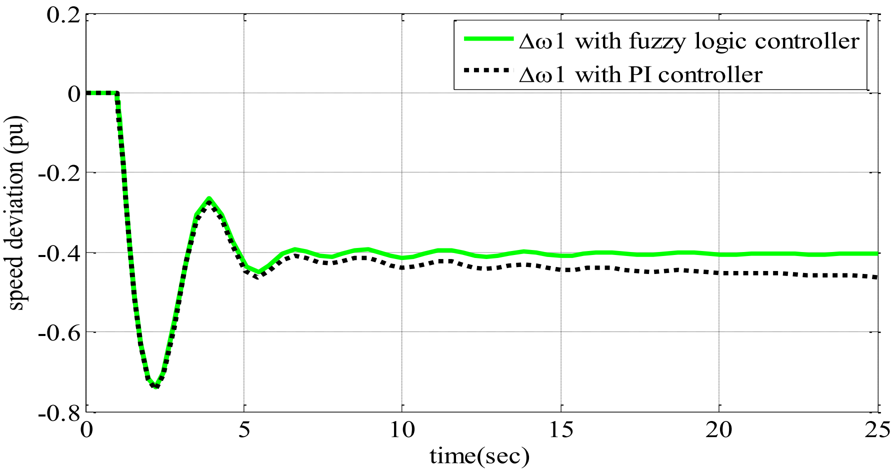

Figure 2: *Comparison between frequency deviation step responses of area 1 with fuzzy logic controller and PI controller*

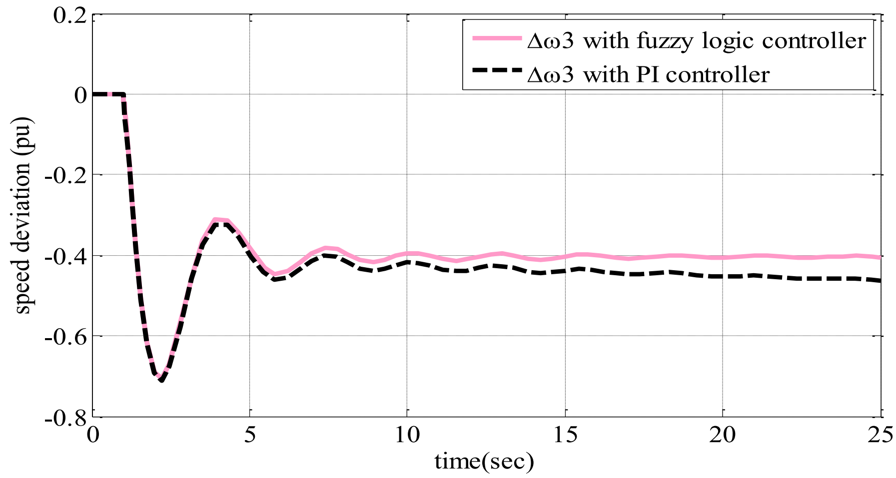

Figure 3: *Comparison between frequency deviation step responses of area 3 with fuzzy logic controller and PI controller*

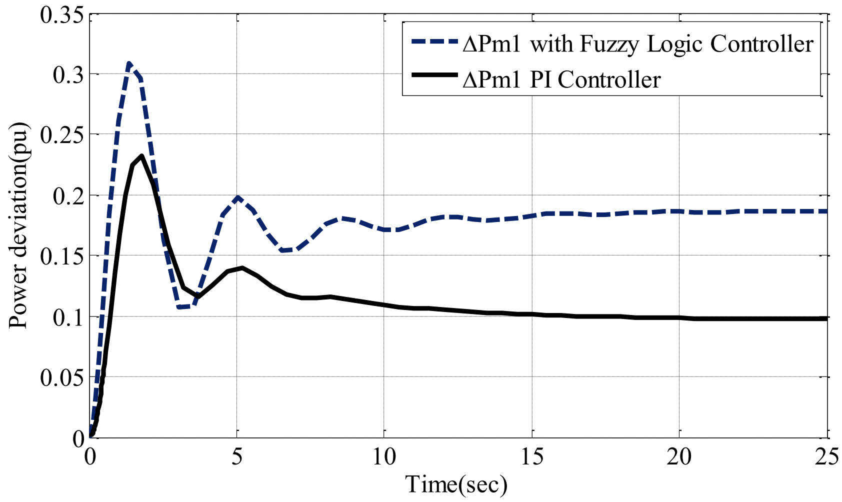

Figure 4: *Comparison between power deviation step responses of area 1 with fuzzy logic controller and PI controller*

B. Station-to-Grid Supplementary Controller

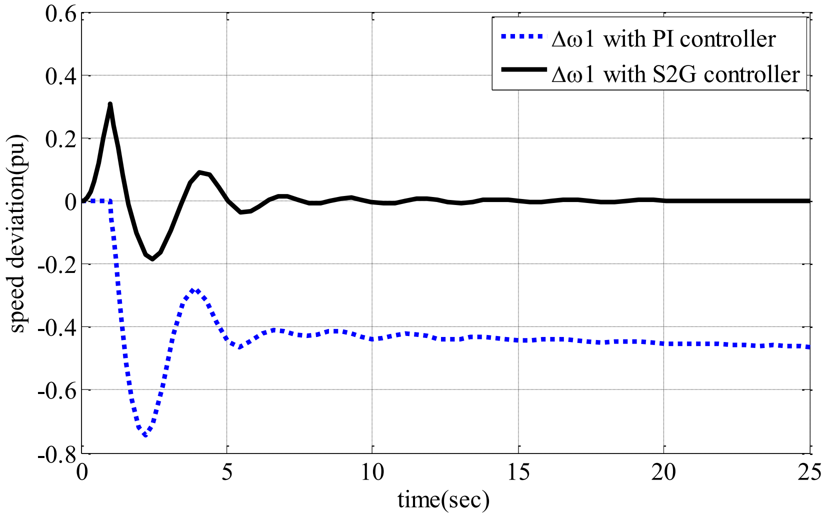

Figure 5: *Comparison between frequency deviation step responses of area 1 with s2g controller and PI controller*

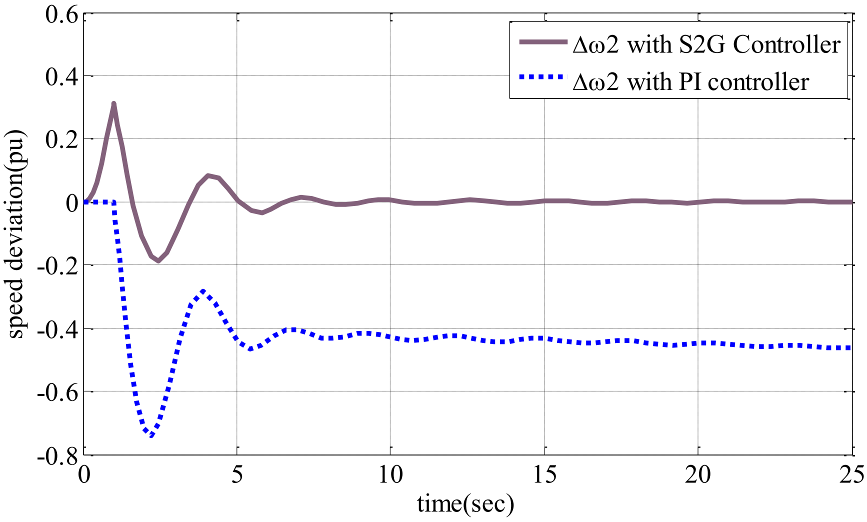

Figure 6: *Comparison between frequency deviation step responses of area 2 with s2g controller and PI controller*

The frequency deviation step responses of generator 1 and generator 2 with S2G are shown in fig. 5, and fig. 6 respectively. From the fig. 5 and fig. 6, it is observed that supplementary controller S2G has less damping oscillation compared to PI controller. It is a scheme that stored energy on BSS, and whenever speed deviation it occurs it pass the stored energy and further it gets the steady state position. Fast-cyclic component (less than 1 min) is followed by BSS storage and short-cyclic component (1-15 min) followed by thermal units of interconnected system. From this scheme the entailed capacity of BSS storage can be diminished and thermal units can be operated at undeviating state.

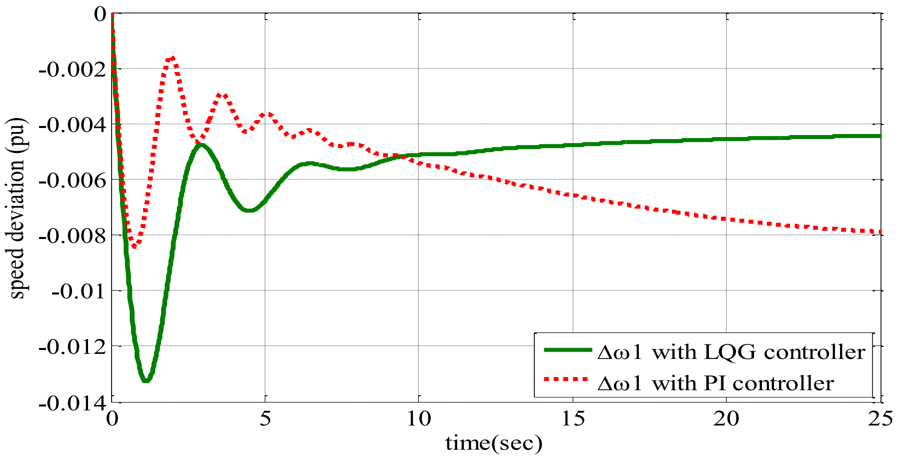

Figure 7: *Comparison between frequency deviation step responses of area 1 with LQG controller and PI controller*

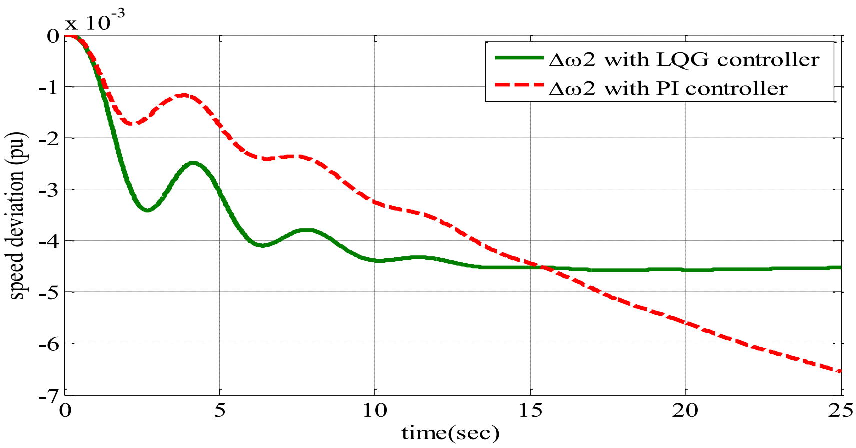

Figure 8: *Comparison between frequency deviation step responses of area 2 with LQG controller and PI controller*

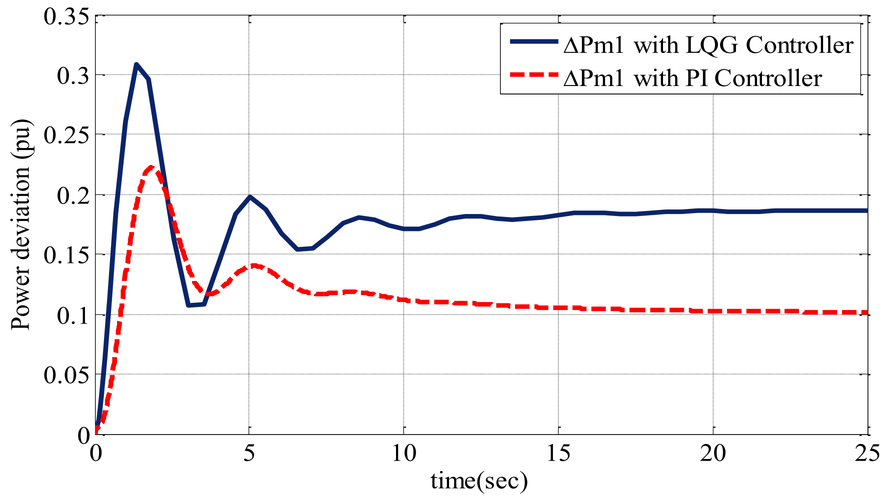

Figure 9: *Comparison between power deviation step responses of area 1 with LQG controller and PI controller*

C. Linear Quadratic Gaussian (LQG) Controller

The frequency deviation step responses of generator 1 and generator 2 with LQG controller are shown in fig. 7, and fig. 8 respectively. It is illustrated in fig. 7 and fig. 8, the optimal technique LQG has fewer damping oscillations as compared to the conventional PI controller. From the time domain response, obviously the settling time, oscillation magnitude, amplitude brings the system again into stable operation inside short span. Power deviation step responses of area 1 with LQG controller and PI controller is shown in fig. 9.

D. Impact of time delay on Fuzzy Logic Controller

Speed deviation of generator 2 having Fuzzy logic controller, with and without time delay is shown in fig. 10. The damping abilities of fuzzy logic controller, with and without time delay, nearly same damping capacities for frequency in all the areas. It is illustrated in fig. 10, that the delay margin is not affected the performance of fuzzy logic controller.

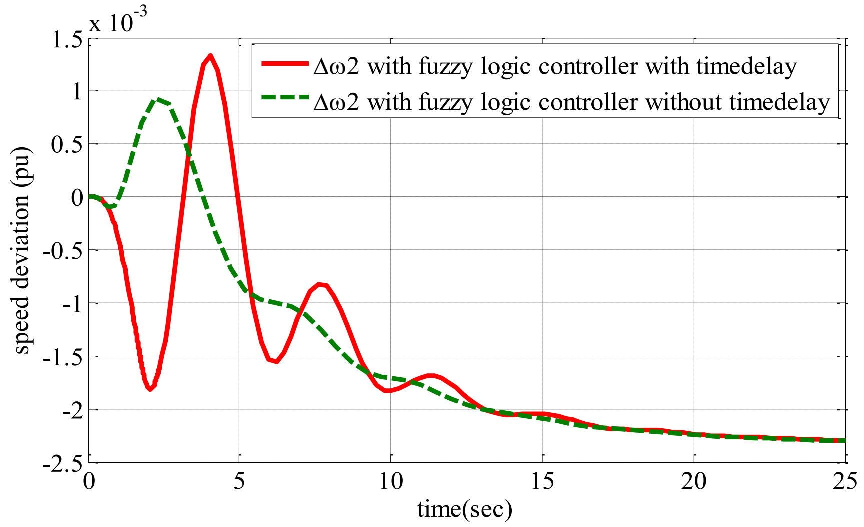

Figure 10: *Comparison of speed deviation of generator 2 having Fuzzy logic controller, with and without time delay*

E. Impact of time delay on Station-to-Grid Controller (S2G)

Speed deviation of generator 1 with and without time delay, having S2G Controller is shown in fig. 11 and fig. 12.

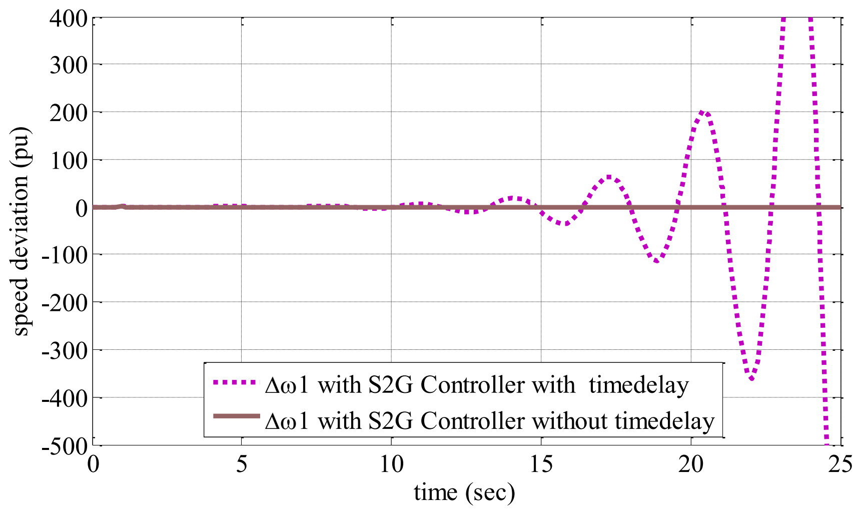

Figure 11: *Comparison of speed deviation in area1 with and without time delay with S2G*

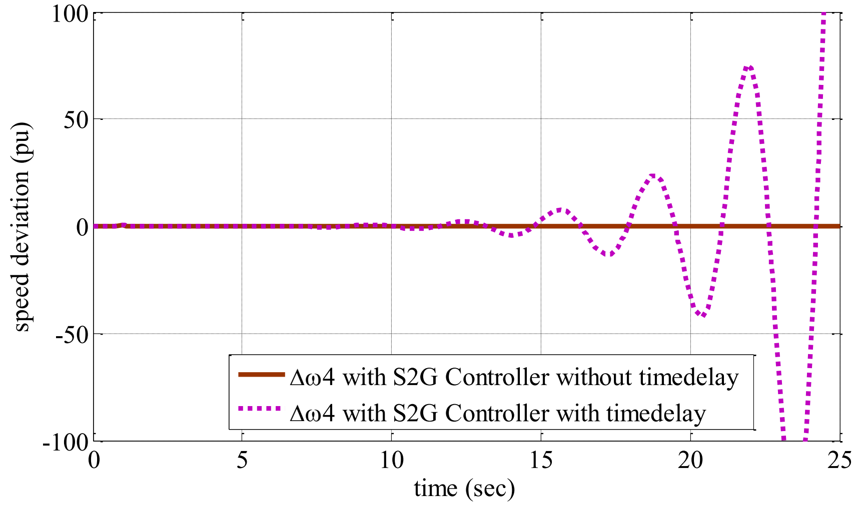

Figure 12: *Comparison of speed deviation in area 4 with and without timedelay with S2G*

F. Impact of time delay on Linear Quadratic Gaussian Controller (LQG)

The damping abilities of LQG controller with and without time delay are shown in figure 13. It can be seen from figure 13, that the system with or without time delay nearly same damping capacities for frequency in all the areas.

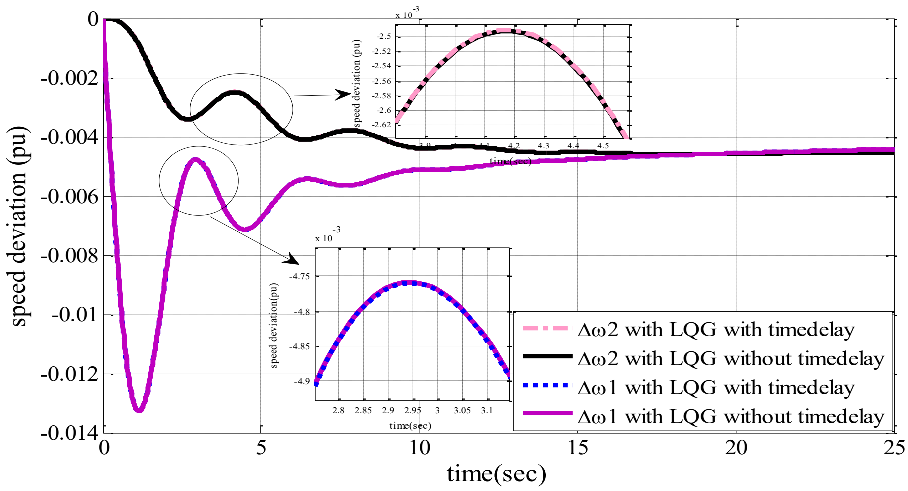

Figure 13: *Comparison of speed deviation in area1 and area 2 with and without time delay having LQG controller*

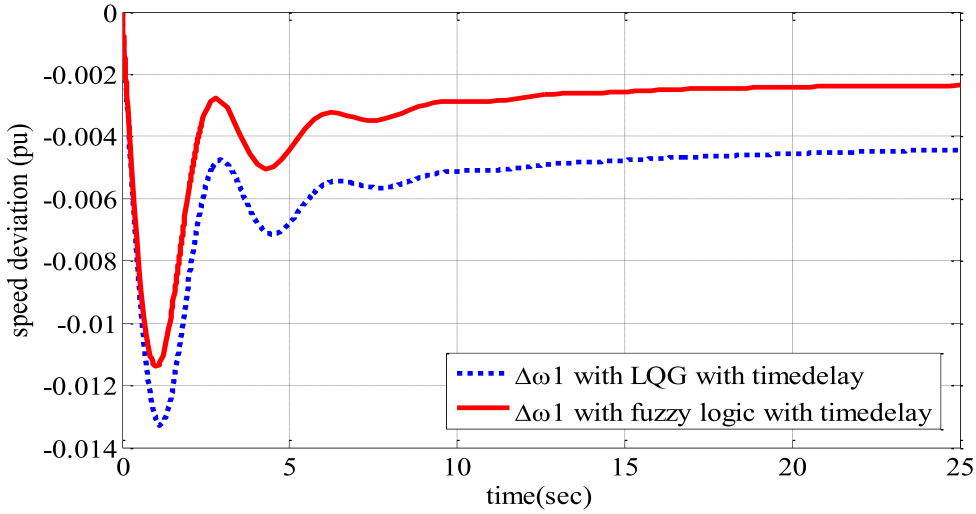

Figure 14: *Comparison results of fuzzy logic and LQG having time delay*

G. Comparison of Fuzzy Logic and LQG controller including time delay

It is illustrated in fig. 14 that the time domain response, obviously the settling time, oscillation magnitude and the impact of the delay margin is reduced by utilizing the Fuzzy controller. The designed Fuzzy appears to better than the others as it mitigates the delay margin and brings the system back into stable zone.

H. Impact of Noise on Fuzzy Logic Controller

Gaussian noise [22] is associated to an unwanted electrical signal with a frequency generally lower than 200 kHz [4]. The damping abilities of generator 1 and 3 having fuzzy logic controller with and without noise signal are shown in fig. 15.

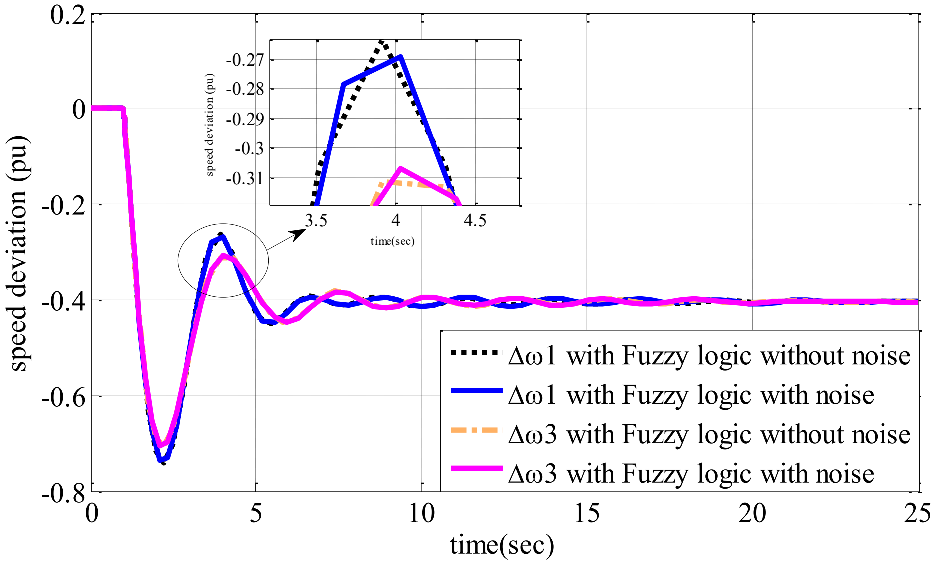

Figure 15: *Comparison of speed deviation with fuzzy logic controller, with and without noise*

I. Impact of Noise on Station-to-Grid Controller (S2G)

Figure 16 shows comparison result of speed deviation of generator 2 with or without noise signal. Critical analysis of plot providing delay margin in S2G controllers shows a higher damping oscillation, less dynamic performance.

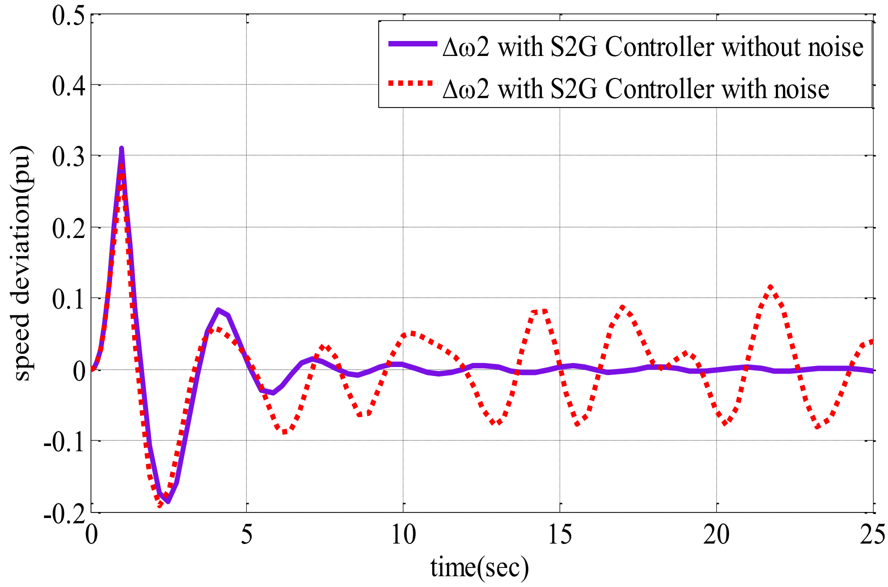

Figure 16: *Comparison of speed deviation having S2G with and without noise*

J. Impact of Noise on Linear Quadratic Gaussian (LQG) Controller

Speed deviation having LQG controller with and without noise of generator 1 and 2 is shown in fig. 17. Amplitude of noise signal is 0.01. It can be observed from result that the system with or without noise signal similarly damping capacities for frequency in corresponding areas. That shows the noise is not affected the performance of LQG controller.

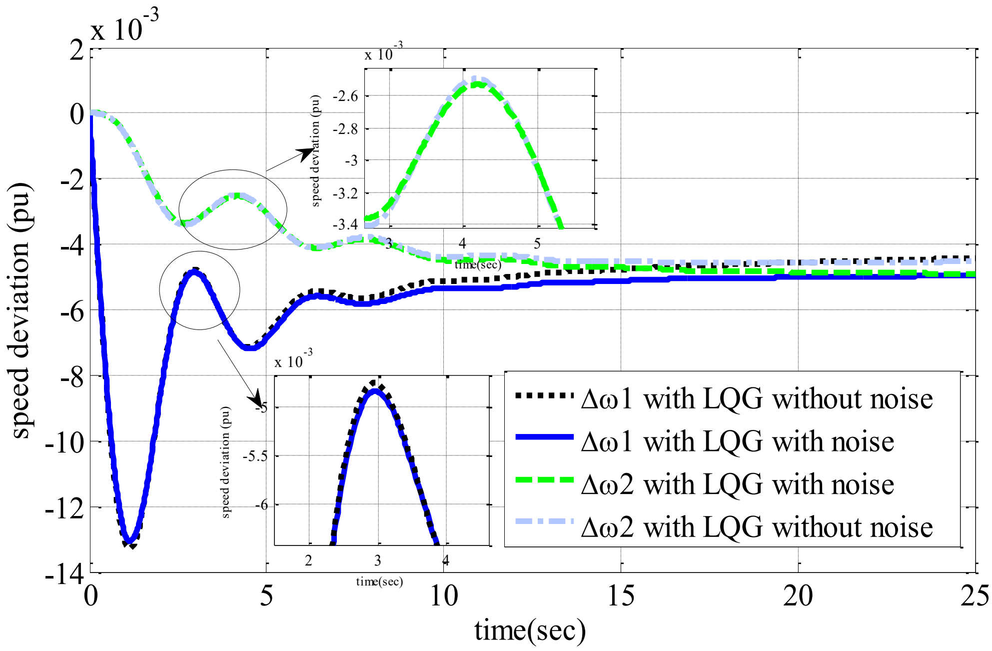

Figure 17: *Comparison of speed deviation having LQG controller with and without noise*

K. Comparison of Fuzzy Logic Controller and LQG controller including noise

Performance of linear quadratic gaussian controller and fuzzy logic controller with 0.01 amplitude of noise signal response is shown in fig. 18. It is illustrated in fig. 19 that LQG controller appears to be better than the fuzzy logic controller. From the time domain response, obviously the settling time, oscillation magnitude and effect of the noise signal is utilized by LQG and it mitigates the noise effect and brings the system back to set up point.

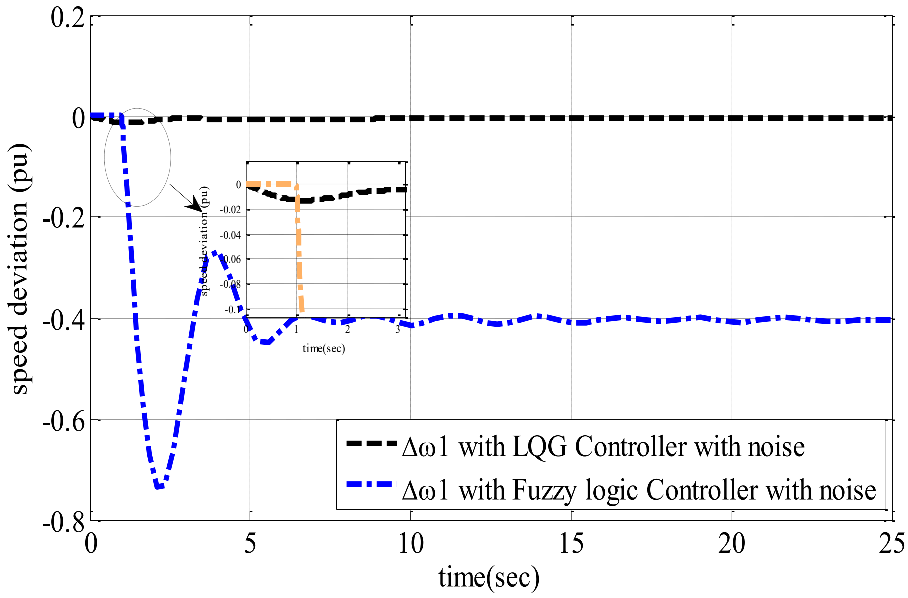

Figure 18: *Comparison of speed deviation having LQG controller and fuzzy logic controller with noise*

V. Conclusion

This study intended to assess the impact of time delay and noise in a robust LFC problem. Initially, three inference controllers are designed, including input and output rules based Fuzzy Logic Controller, Supplementary Controller Station-to-Grid which is based on Battery Swapping Concept and Linear Quadratic Gaussian technique designed through the Kalman filter. These all the techniques give better performance from conventional techniques (PI Controller). It should be pointed out that there are some disturbances occur in the multi-area LFC system. Station-to-Grid is not a robust controller but it has an advantage that it stores the system data as a back-up plan and further when deviation occurs it restores the system data. Further, time delay and noise are implemented in these control strategies. More remarkably, when time delay is implemented Fuzzy Logic approach resulted in more robust performance and when noise is implemented LQG approach result in more robust performance in LFC problem.

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