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Linear Quadratic Gaussian Regulator Based Frequency Control of Power System to Enhance the Continuity of Power Flow

Md. Alamgir Hossain
Department of Electrical and Electronic Engineering, Khulna University of Engineering & Technology, Khulna-9203, Bangladesh

ABSTRACT : *In power generation system, the change in load influence the frequency of the system. To keep the whole power system network stable and reliable it is mandatory to maintain a preset value of generator speed. In this paper a Kalman filter based linear quadratic Gaussian regulator is proposed to control the frequency variation due to change in load in an interconnected power system network. The conventional linear quadratic regulator is impractical for a practical power system network, because this method assumes that all the state information are accessible and can be used to feedback for controlling the system. But, the proposed method use partial state information of a state-space model and can control the frequency changes to optimize the system performance. To validate the performance of the proposed method, computer simulations were performed in MATLAB/Simulink software. The results shows that the proposed method perform well with reduced state information.*
KEYWORDS *Load-frequency control, Kalmna filter, linear quadratic gaussian regulator,*

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I. INTRODUCTION

Nowadays power system stability is considered as vital problem. The generator in an interconnected power network is independently well equipped with load frequency control (LFC) and automatic voltage regulator (AVR). LFC controls the change in frequency due to change in real power demand, and on the other hand AVR maintain the scheduled voltage magnitude and reactive power. These two controllers/regulators do not need to be cross-coupled, because the time constant of these to controller are different in large quantity [1].Therefore, the frequency and excitation voltage are investigated independently and separately. The demand of power is rapidly increasing with the growth of population and this arise the complexity of power network. The various component related to the power networks are sensitive to frequency and voltage to maintain the continuity and stability of the system and hence, power generator must preserve some international standard. For this reason, a robust control mechanism for power generation system is the key research focus.To keep the power system stable and in steady-state it is necessary to control active and reactive power. The main purpose of the control scheme is to generate and transmit power economically and reliably maintaining the voltage and frequency within a permissible range. The system frequency is sensitive to change in real power and not so much to reactive power that depend on magnitude of voltage [2]. Therefore, separate control mechanisms are needed for real and reactive power.

For an interconnected system, load frequency control (LFC) system controls the real power and frequency and automatic voltage regulator (AVR) on the other hand controls the reactive power as well. To maintain uniform frequency, generators' load sharing, and tie-line interchange scheduling, LFC plays a vital role. Since, the load frequency control issue of power system is important, various controlling method for LFC are reported in the literature [1]~[9]. Most of the researcher use classical PI and PID controller because of the simplicity [1], [3] and [5], but due to integration of various types of power to the network it is difficult to realize the practical case. To overcome this problem artificial algorithms are used in corporation with PID [1] and [9] that increases the calculation complexity and increase the response time. To optimize the control system, linear quadratic regulator (LQR) method is proposed in [11], but this method requires all the state of the state-space system accessible that is impractical. In this paper, by using partial state information, a Kalman filter based linear quadratic Gaussian (LQG) regulator is proposed. The organization of this paper is follows. First the system model will be explained in section II, and then proposed method will be clarified in section III. To demonstrate the performance of the proposed method some computer simulations were performed that will be illustrated with results in section IV. Finally, the overall system will be concluded in section V.

II. SYSTEM MODEL

A power generation system consists of mainly prime mover, generator and controlling mechanism. Figure 1 shows the basic schematic diagram for LFC where the tie-line real power and change in frequency are sensed and processed to generate command for prime mover to change the torque.

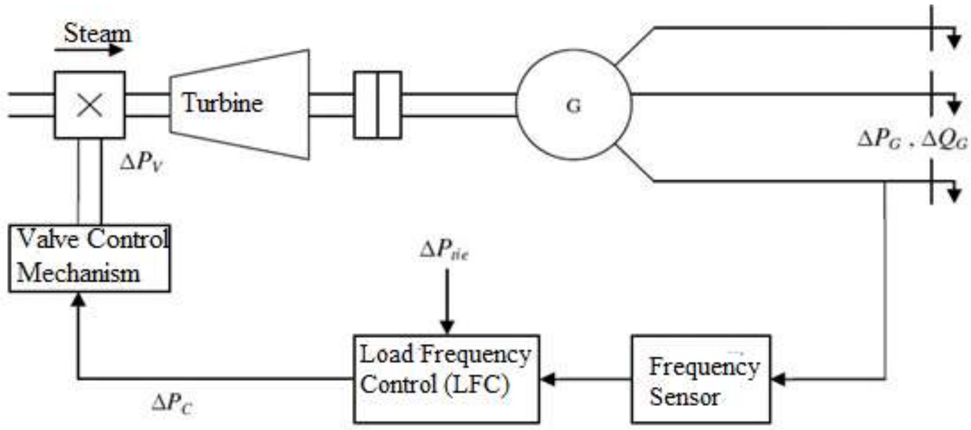

Figure 1: Load frequency control schematic diagram

Generator model:

The swing equation of a synchronous generator including small disturbances is given by [12]

$$\frac{2H}{\omega_s}\frac{d\Delta\Omega}{dt} = \Delta P_m - \Delta P_e \quad (1)$$

Where, ΔP_m is change in mechanical power, ΔP is that of electrical power, and $\Delta\Omega$ is change in angular speed of the generator. Applying Laplace transform on the above equation results

$$\Delta\Omega(s) = \frac{1}{2Hs}[\Delta P_m(s) - \Delta P_e(s)] \quad (2)$$

The equation (2) can be represented in the form of block diagram as

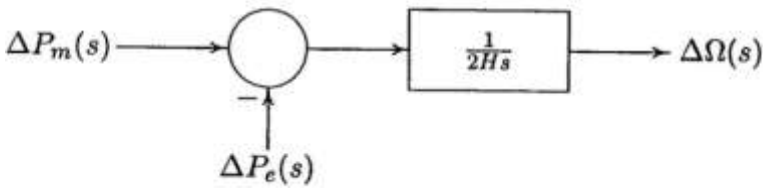

Figure 2: Generator block diagram

The speed-load characteristics of composite load is approximated as, $\Delta P_e = \Delta P_L + D\Delta\omega$, where, D is expressed in percent change in load to percent change in frequency.

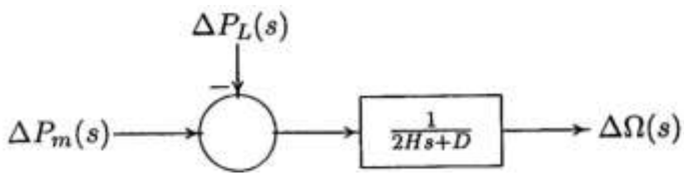

Figure 3: Generator and load block diagram

Prime mover:

Mechanical power output of a prime mover ΔP_m depends on the steam valve setting, for steam turbine and can be modeled by using the following transfer function

$$G_T(s) = \frac{\Delta P_m(s)}{\Delta P_V(s)} = \frac{1}{1+\tau_T s} \quad (3)$$

The function of the governor in power generation system is to sense the change in speed of the turbine and to adjust the valve position for steady-state operation. The speed governing system for steam turbine is presented in the following Figure 4. Assuming a linear relationship with simple time constant τ_g, input-output relation of governor can be obtained as follows,

$$\Delta P_V(s) = \frac{1}{1+\tau_g} \Delta P_g(s) \qquad (4)$$

Considering governor, turbine, and generator the LFC block diagram is drawn as shown in Figure 5.

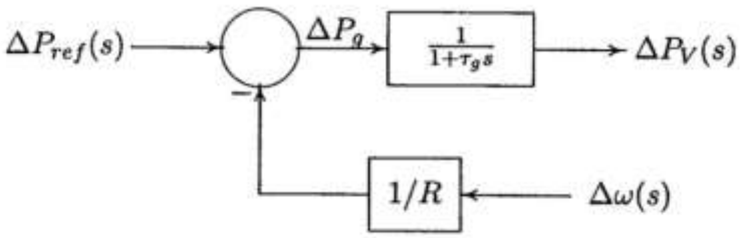

Figure 4: Speed governing system for steam turbine

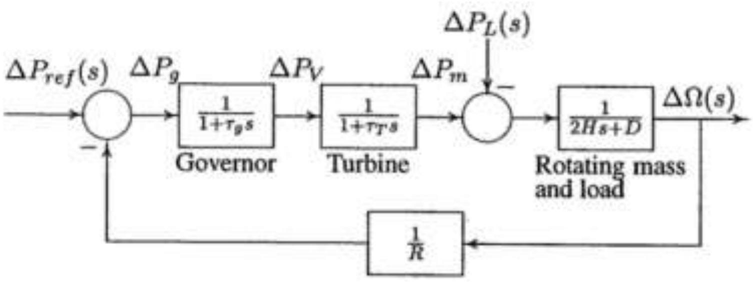

Figure 5: Load frequency block diagram for an isolated power system

The outputs of governor, turbine, and generator can be written in s-domain as follows

$$(1+\tau_g)\Delta P_V(s) = \Delta P_{ref}(s) - -\frac{1}{R}\Delta\Omega(s) \qquad (5)$$

$$(1+\tau_T s)\Delta P_m(s) = \Delta P_V \qquad (6)$$

$$(2H_s + D)\Delta\Omega(s) = \Delta P_m - \Delta P_L \qquad (7)$$

Solving for first derivative term of above equations results

$$s\Delta P_V(s) = -\frac{1}{\tau_g}\Delta P_V - \frac{1}{\tau_g}\Delta\Omega(s) + \frac{1}{R\tau_g}\Delta P_{ref}(s) \qquad (8)$$

$$s\Delta P_m(s) = \frac{1}{\tau_T}\Delta P_V - \frac{1}{\tau_T}\Delta P_m \qquad (9)$$

$$s\Delta\Omega(s) = \frac{1}{2H}\Delta P_m - \frac{D}{2H}\Delta\Omega(s) - \frac{1}{2H}\Delta P_L \qquad (10)$$

In matrix form,

$$\begin{bmatrix} \Delta\dot{P}_V \\ \Delta\dot{P}_m \\ \Delta\dot{\omega} \end{bmatrix} = \begin{bmatrix} -\frac{1}{\tau_g} & 0 & -\frac{1}{R\tau_g} \\ \frac{1}{\tau_T} & -\frac{1}{\tau_T} & 0 \\ 0 & \frac{1}{2H} & -\frac{D}{2H} \end{bmatrix} \begin{bmatrix} \Delta P_V \\ \Delta P_m \\ \Delta\omega \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ -\frac{1}{2H} \end{bmatrix} \Delta P_L + \begin{bmatrix} \frac{1}{\tau_g} \\ 0 \\ 0 \end{bmatrix} \Delta P_{ref} \qquad (11)$$

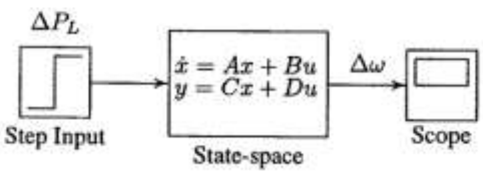

Figure 6: State space representation without feedback

III. PROPOSED CONTROLLER

For controlling power generation system due to change in load, the linear quadratic regulator can be efficiently used because of very high gain and near infinite phase margin. However, this regulator requires to access all the state variables to measure and to use in feedback. For any real life problem, it is impossible to access all the state variables. So, LQR is impractical as a load frequency controller. To overcome this constraint, Kalman filter can be a suitable candidate that uses the partially measurable state variable and avoiding the control law for LQR, the meaningful controller can be implemented by using linear quadratic Gaussian regulator (LQG) in addition with Kalman filter as shown in Figure 7.

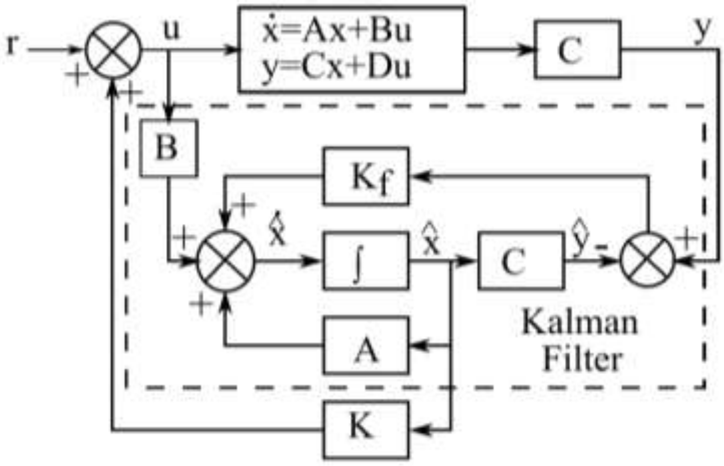

Figure 7: Simulated system with proposed controller

Consider a plant characterized by the following state space equations without feedback and assuming the reference input r is equal to zero.

$$\dot{x} = Ax + Bu + v(t) \tag{12}$$
$$y = Cx + w(t) \tag{13}$$

Where, $v(t)$ and $w(t)$ are input and measured zero mean white noise. For simplification, these noises can be excluded and the state-space form without feedback can be rewritten as follows

$$\dot{x} = Ax + Bu \tag{14}$$
$$y = Cx \tag{15}$$

The ultimate goal of an optimal control design is to obtain the control law so that a given performance index is minimized. The widely known and enormous used in optimal control design is the quadratic performance index based on minimum-error and minimum-energy is given by

$$J = \lim_{T\to\infty} \frac{1}{T} E\left[\int_0^T (x^T Q x + u^T R u) dt\right] \tag{16}$$

Where, $Q \geq 0, R > 0$. For the controller shown in Figure 7, the state space equations can be given by

$$\dot{\hat{x}} = A\hat{x} + Bu + K_f(y - \hat{y}) \tag{17}$$
$$\hat{y} = C\hat{x} \tag{18}$$

Where, $K_f = P_e C^T R^{-1}$ and P_e is the solution of the following Riccati equation

$$P_e A^T + AP_e - P_e C^T R^{-1} C P_e + Q = 0 \tag{19}$$

Assuming the reference input $r = 0$, the control law for LQG is given by

$$u = K\hat{x} \tag{20}$$

IV. SIMULATION AND RESULT

To demonstrate the performance of the proposed controller the model was simulated in MATLAB/Simulink environment. The parameters for the simulations are as follows. Turbine time constant, $\tau_T = 0.5$ sec, generator time constant $\tau_g = 0.2$ sec, generator inertia constant, $H = 5$ sec, change in load, $D = 0.8$, governor speed regulation, $R = 0.05$ per unit. The turbine rated output is 250 MW at nominal frequency of 60 Hz sudden load change of 50 MW (0.2 per unit) occurs. The overall simulation block diagram is shown in Figure 8. Considering the system parameter, the state space matrices will be as follows:

$$A = \begin{bmatrix} -5 & 0 & -100 \\ 2 & -2 & 0 \\ 0 & 0.1 & -0.08 \end{bmatrix}, B = \begin{bmatrix} 0 \\ 0 \\ -0.1 \end{bmatrix}, \text{and } C = \begin{bmatrix} 0 & 0 & 1 \end{bmatrix}$$

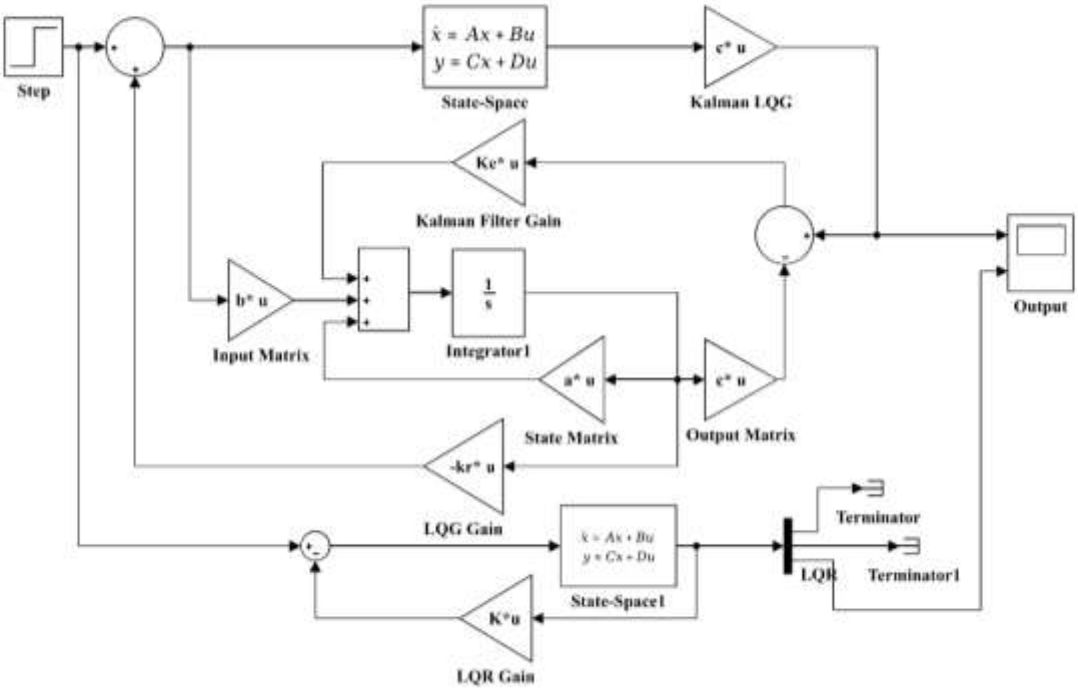

Figure 8: Simulink block diagram of proposed Kalman-LQGand conventional LQR controller

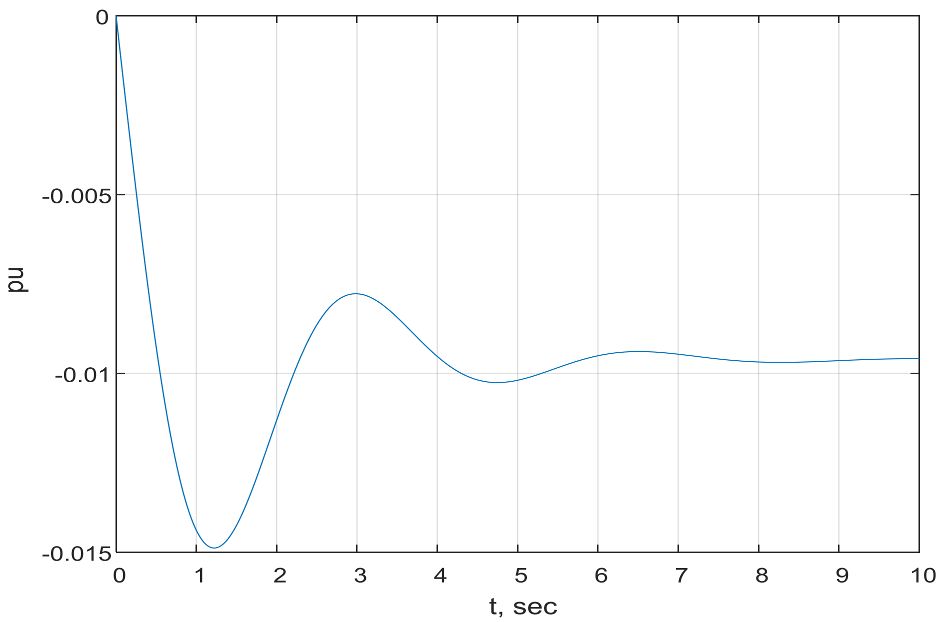

Figure 9: Uncompensated frequency deviation step response

The state-space model is simulated first without feedback to observe the performance and it is seen that without feedback the desired control of a system cannot be obtained as shown in Figure 9. From this figure it is observed that at time 4 sec, still there is system instability due to change in load or real power fluctuation. The change in load in per unit is oscillating for long time, almost 8 second in this case, compared to Figure 10 where feedback is used. For this case the system is simulated for 4 second and it is noticed that from near 2 second, the system is getting stable. The main objective of this paper is to investigate the performance comparison in terms of control of power system where frequent change in load occurs. In conventional linear quadratic regulator all the states must be accessible and usable for feedback. This is practically impossible for any real life physical system. This is vital and inherent problem of LQR.

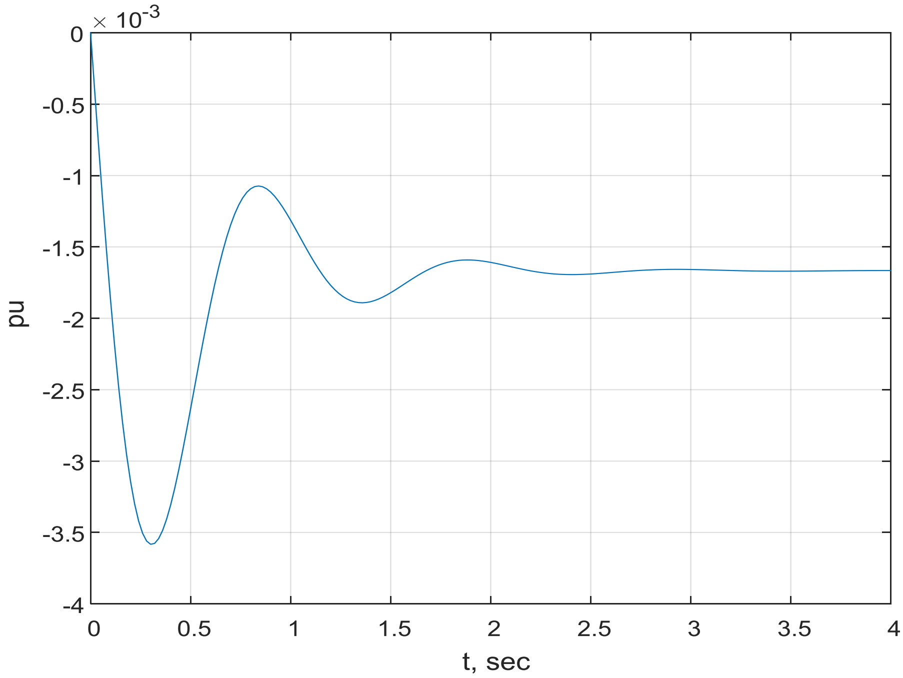

Figure 10: Compensated frequency deviation step response

The performance comparison curves, shown in Figure 11, shows that the nature of the controller toward stable system is almost identical with negligible difference in magnitude. The upper red marked curve is for proposed Kalman filter based LQG controller performance.

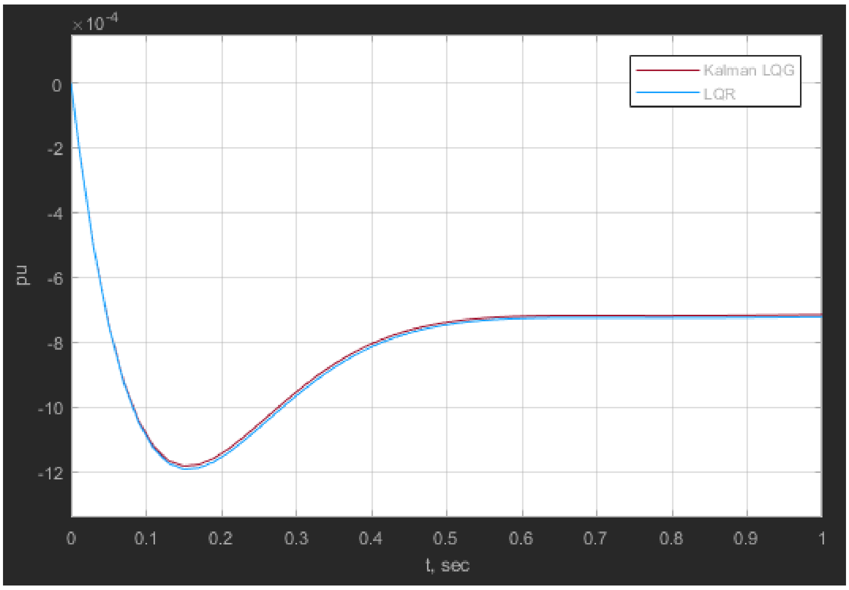

Figure 11: Comparison of step response for proposed and conventional controller

V. CONCLUSION

From the simulation it is obvious that the proposed method of load frequency control perform enough well with the reduced number of state information from a state-space model whereas conventional LQR method assumes that the all states from the system are measurable and able to use in feedback. The proposed method can also be used in another case of interconnected wind power and grid-tie power system network.

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