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# DESIGN AND SIMULATION OF A LQG ROBUST CONTROLLER FOR AN ELECTRICAL POWER SYSTEM

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## *ABSTRACT*

*This paper describes a LQG robust controller for the load frequency control of an electrical power system. The controller is used in order to achieve robust stability and good dynamic performance against the variation of power system parameters and its load. The application of the proposed LQG robust control scheme is implemented through the simulation of a single area power system model. The proposed robust controller for power systems stability is designed using Matlab/Simulink program. Simulation results confirm the performance of the proposed controller for the electrical power system.*

**Keywords:** *LQG robust controller, electrical power system, modeling, Matlab/Simulink.*

## 1. INTRODUCTION

The dynamic behavior of electric power systems is heavily affected by disturbances and changes in the operating points. In electric power generation system, load frequency control is a very important component in power system operation and control for supplying and reliable electric power with good quality. The aim of load frequency control is to maintain zero steady state errors in power system [1-2]. Many investigations have been reported in the past pertaining to load frequency control of electric power system. In the literature, some control strategies have been suggested based on conventional linear control theory [3]. To some authors, a variable structure system control maintains stability of the system frequency. However, because of the inherent characteristics of the changing loads, the operating point of a power system changes continuously during daily cycle. Thus, a fixed controller may no longer be suitable in all operating conditions. There are some authors who have applied variable structure control to make the controller insensitive to change of system parameters [3, 4].

In many control applications, it is expected that the behavior of the designed system will be insensitive (robust) to external disturbance and parameter variations. It is known that feedback in conventional control systems has the inherent ability of reducing the effects of external disturbances and parameter variations. Unfortunately, robustness with the conventional feedback configuration is achieved only with high loop gain, which is normally detrimental for stability [5,6,7]. The reasons given above may affect the stability of system. A closed loop control system should be stable and have an acceptable performance.

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In the model application, the Linear Quadratic Gaussian (LQG) control, that is a kind of robust controller, is used. Also, the design of LQG controller in Matlab-Simulink is given.

In this paper, load frequency controller based on LQG robust controller is proposed for a single area power system. The target is to obtain robust stability and to improve the dynamic response of the power system against variations in the system parameters and loads. The problem formulation and the development of a LQG robust controller, based on 'Matching Conditions' and the Riccati-equation, approaches are given.

## 2. DESIGN OF LINEAR QUADRATIC GAUSSIAN (LQG) CONTROLLER

LQG controller is the modern state-space control technique for the design of optimal dynamic regulators [8]. It enables us to trade off regulation performance and control effort, and to take into account process disturbances and measurement noise. LQG design requires a state-space model of the plant [9, 10].

The main target in LQG control is to obtain a stable and reliable control. A block diagram of LQG control is given in Figure 1 [11].

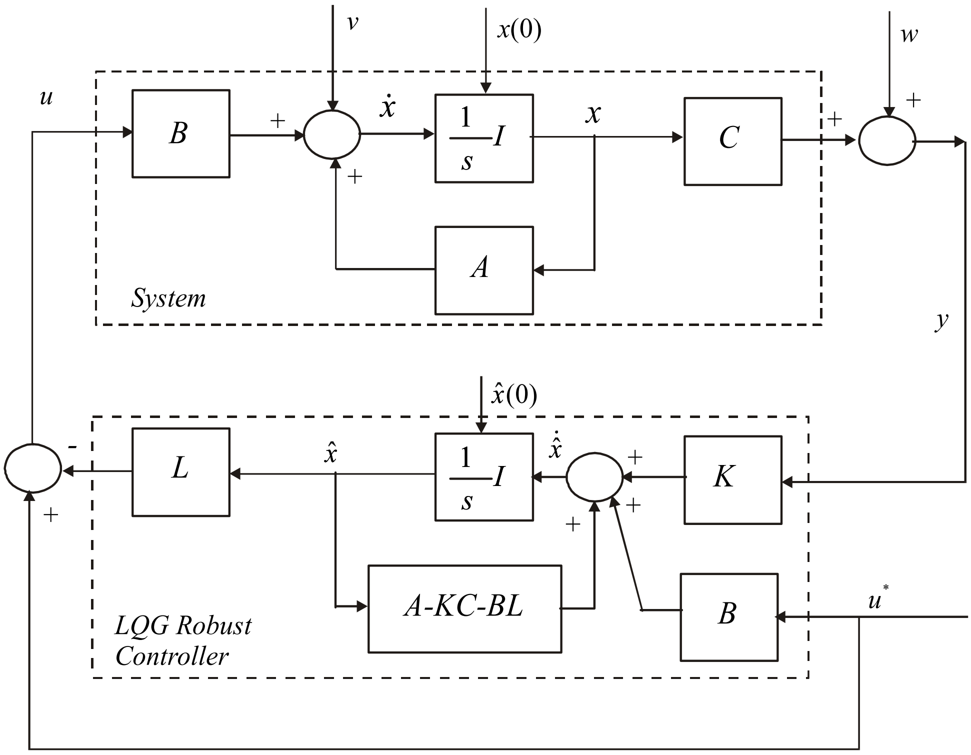


**Figure 1.** Feedback loop with system and LQG robust controller

In Figure 1, u is the control input, y is the measured control output, x is the state vector or state variables, A is the state matrix, B is the input matrix, C is the output matrix, v is the disturbance input and w is the measurement noise, L is the feedback matrix in form of state space and K is the Kalman gain. A state observer is obtained by producing a state estimate $\hat{x}$. It is now time to combine the controller and the state observer by simply putting [10].

$$u = -L\hat{x} + u^* \tag{1}$$

where u*; is called as the external input. To analysis the effect of any of L and K pairs, (2) and (3) equations are written [10].

$$|sI - A + BL| = 0 \tag{2}$$

$$|sI - A + KC| = 0 \tag{3}$$

By using (2) and (3) stable poles are obtained. The magnitudes directing the system are expressed with the equation sets below [10].

$$\dot{x} = Ax + Bu + v \tag{4}$$

$$y = Cx + w \tag{5}$$

$$u = -L\hat{x} + u^* \tag{6}$$

$$\hat{x} = A\hat{x} + Bu + K(y - C\hat{x}) \qquad (7)$$

Eliminating u and y by simple substitution, (8) is obtained.

$$\begin{pmatrix} \dot{x} \\ \hat{x} \end{pmatrix} = \begin{pmatrix} A & -BL \\ KC & A-KC-BL \end{pmatrix} \cdot \begin{pmatrix} x \\ \hat{x} \end{pmatrix} + \begin{pmatrix} I & 0 \\ 0 & K \end{pmatrix} \cdot \begin{pmatrix} v \\ w \end{pmatrix} + \begin{pmatrix} B \\ B \end{pmatrix} u^* \qquad (8)$$

In Figure 1, a more compact close loop control system is defined and the controller may be seen more clearly. The second state equations are rearranged according to Figure 1, and then equations are obtained as follows.

$$\hat{x} = (A - KC - BL)\hat{x} + K(Cx + w) + Bu^* \qquad (9)$$

$$(sI - A + KC + BL)\hat{x} = Ky + Bu^* \qquad (10)$$

$$\hat{x} = (sI - A + KC + BL)^{-1}(Ky + Bu^*) \qquad (11)$$

Because of $u = -L\hat{x} + u^*$ the feedback controller is given by (12).

$$C(s) = L(sI - A + KC + BL)^{-1}K \qquad (12)$$

The poles of controller are given by the eigenvalues of A-KC-BL. Note that these poles can be unstable. Some systems can only be stabilized by unstable controllers. In fact, these systems have intermittently poles and zeros on the real positive axis.

### 2.1 Preservation of Controller and Observer Poles

The equations are given above expressing that the poles of the close loop control system are complex functions of the observer gain K and the controller coefficient L. That is not the case by taking the state error ($\tilde{x}$) as a part of the state vector instead of the estimated state $\hat{x}$. The estimated state vector $\hat{x}$ is deducted from the state vector *x*, and the following equations are obtained.

$$\dot{x} = Ax - BL\hat{x} + v + Bu^* = (A - BL)x + BL(x - \hat{x}) + v + Bu^* \qquad (13)$$

$$\dot{\hat{x}} = (A - BL)\hat{x} + KC(x - \hat{x}) + Kw) + Bu^* \qquad (14)$$

$$\dot{x} - \dot{\hat{x}} = (A - BL)(x - \hat{x}) + BL(x - \hat{x}) - KC(x - \hat{x}) + v - Kw \qquad (15)$$

$$\dot{\tilde{x}} = (A - KC)\tilde{x} + v - Kw \qquad (16)$$

By using the equations above, the complete state description is expressed in the matrix form as follows.

$$\begin{bmatrix} \dot{x} \\ \dot{\tilde{x}} \end{bmatrix} = \begin{bmatrix} A-BL & BL \\ 0 & A-KC \end{bmatrix} \cdot \begin{bmatrix} x \\ \tilde{x} \end{bmatrix} + \begin{bmatrix} I & 0 \\ I & -K \end{bmatrix} \cdot \begin{bmatrix} v \\ w \end{bmatrix} + \begin{bmatrix} B \\ 0 \end{bmatrix} u^* \qquad (17)$$

Because of the zero blocks in the state matrix, the poles are obtained from (18).

$$\det \begin{pmatrix} sI - A + BL & -BL \\ 0 & sI - A + KC \end{pmatrix} = \det(sI - A + BL) \cdot \det(sI - A + KC) = 0 \qquad (18)$$

The poles of the closed loop systems are exactly the poles obtained before in the separate state control problem and the state observer problem. The state vector x changes depending on the external input u* and noise signal (v). The question arises whether the optimal designed controller (L) and the optimal observer (K) remain optimal designs in the LQG optimal controller [12].

### 2.2 Reference Input and Error in LQG Controller Design

The purpose of the LQG robust controller is to decrease the disturbances on a system. The disturbances are the state noise (v) and measurement noise (w). The sensor by its measurement noise and the actuator by its limited range introduce some constraints on the obtained performance. The LQG design must generate signals that ensure the least stable working of the system on a close loop system. If u* (exogenous input) is taken instead of r (t), that the output y (t) depends on the reference r = u* according to:

$$y(s) = C(sI - A + BL)^{-1}Bu^*(s) \qquad (19)$$

The expression of the feedback LQG controller in "s" domain given in equation (12) is as in Figure 2 as a block diagram.

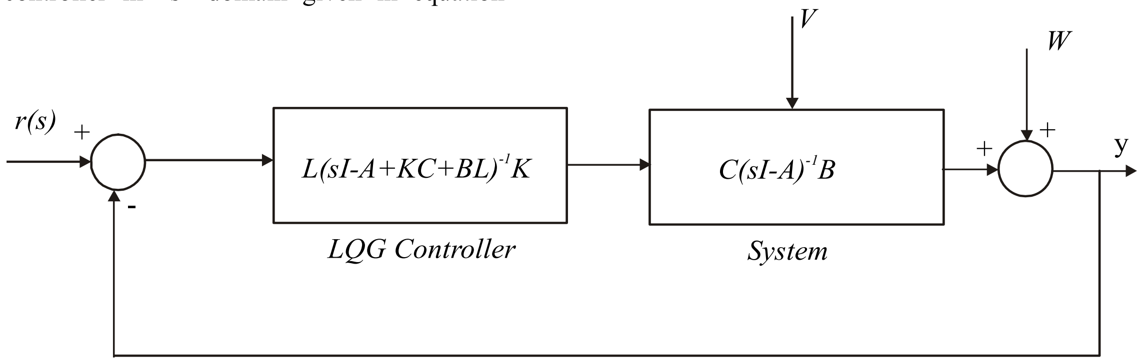


**Figure 2.** The block diagram of a system with LQG Controller

## 3. LOAD FREQUENCY CONTROL AND DESCRIPTION OF AN ELECTRIC POWER SYSTEM MODEL

As an application model with a LQG controller, the load frequency robust control of a power system against to load variations in a one-area power system is implemented. A block diagram of a one-area power system for the load frequency control is given in Figure 3.

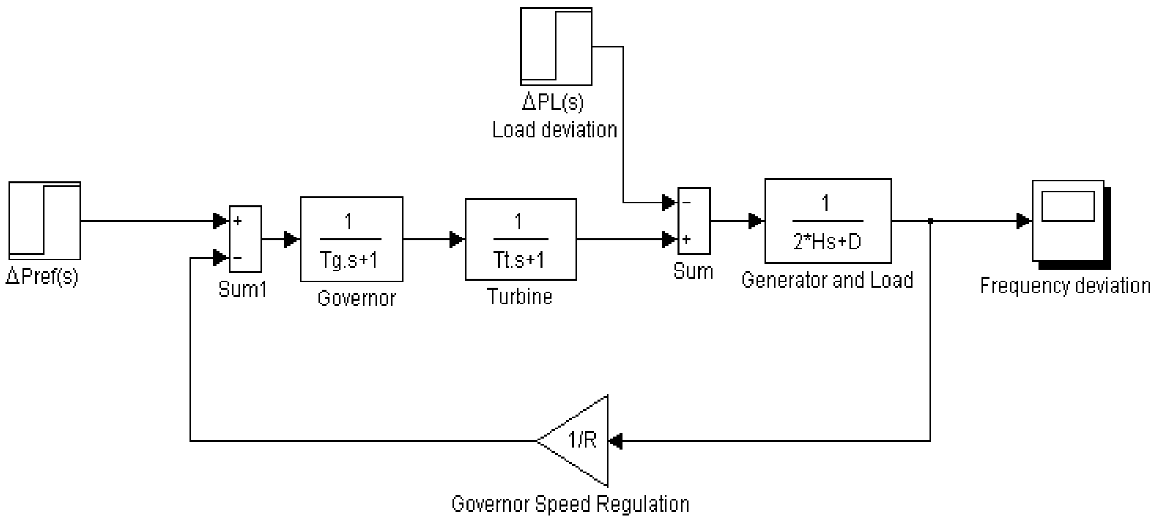


**Figure 3.** Load frequency control block diagram in Matlab-Simulink for the one-area power system

By means of the fixed- gaining regulators, the control procedure is realized by the feedback state variables. By using the block diagram of load frequency controller on the "s" plane, the following state equations are obtained.

$$(1+\tau_g s)\Delta P_V(s) = \Delta Pef - \frac{1}{R}\Delta f(s)$$

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

$$(2Hs + D)\Delta f(s) = \Delta P_m - \Delta P_L$$

(20)

Parameters that are used in the equation set (20);

$\tau_g$ : speed regulator time constant
$\Delta P_V$ : changing power in turbine valve position
$\Delta P_{ref}$ : reference power changing,
R : regulator gain,
$\tau_T$ : turbine time constant,
$\Delta P_m$ : changing on turbine mechanic output power
$\Delta f$ : changing in frequency
$\Delta P_L$ : load changing

### 3.1 Numerical Example

The parameters for the one-area power system are given as follows:

Turbine time constant ($\tau_T$)=0.5 sec.

Speed regulator time constant ($\tau_g$)=0.2 sec.

Generator inertia constant (H)= 5 sec.Speed regulation rate (R) =0.05 pu

The turbine output power is 250 MW at nominal frequency. In case a sudden 50 MW and 75 MW load increases occur, obtain the deviations of the frequency by using the state equations. Block diagram of the optimal LQG controller and the power system in Matlab-Simulink are shown in Figure 4.

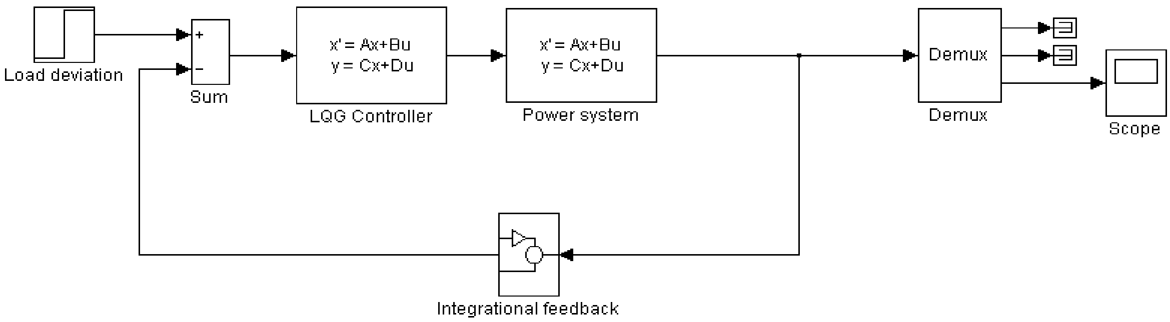


**Figure 4.** Block diagram of optimal LQG control and the power system in Matlab-Simulink

Figure 5 shows that, when LQG controller is used there is no deviation on frequency as the load increases to 50 MW and 75 MW. In the beginning there is a negligible variation (about -0.0003 pu) in frequency. After that there is no change and the steady-state error is nearly zero.

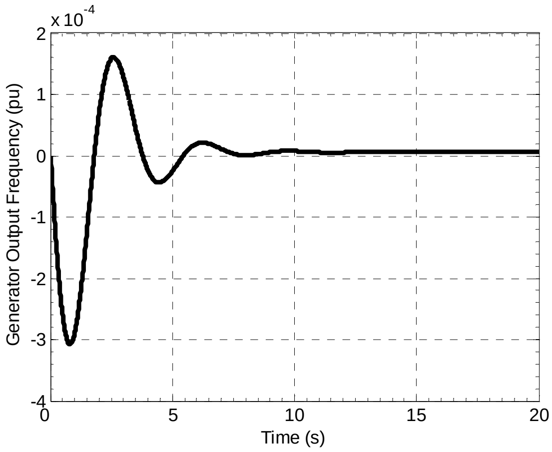


**Figure 5.** The response of generator output frequency in 50 MW and 75 MW load increase in controlled case

Figure 6 shows the comparison of the response curves of the frequency in controlled and uncontrolled case when load increases to 50 MW and 75 MW. The dynamic response has an excellent and robust performance with the proposed controller against variations of the power system parameters and external disturbances. It is also observed that when load increases, the variations of the frequency increases negatively on uncontrolled case.

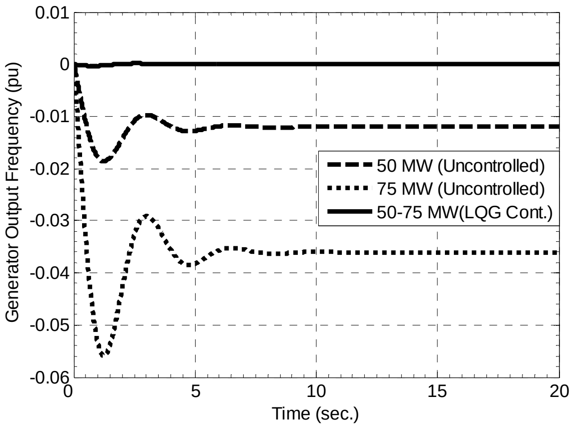


**Figure 6.** The comparison of the response curves of the frequency in LQG controlled and uncontrolled case.

## 4. CONCLUSION

In this study, an optimal LQG controller with integral feedback is designed in Matlab-Simulink to control the frequency of an electrical power system. The performance of the proposed optimal LQG controller has been tested by simulation an electrical power system model in the presence of parameter uncertainty. It may be noted that tuning parameters play an important role to stabilize the uncertain power system. Also, it may be noted that the inverse of the system matrix must exist. The results show that the dynamic response of the system by the proposed LQG controller ensures stability of the closed-loop system for all admissible structured uncertainties.

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