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Frequency Response betterment By Using LQG Controller Via Bitumen Tank

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Abstract—Frequency deviation in power system is a major crisis in the present day scenario. It is very necessary to ensure frequency stability for the maintenance of power grid quality and security. This paper builds a better degree of frequency response by incorporating a LQG (Linear Quadratic Gaussian) controller. When the grid frequency varies from its operational value, it is very essential to bring back the system into its normal grid frequency nevertheless the load demand be. An approach to the comparison of LQG controller and LQR is done using MATLAB SIMULINK.As a result, LQG paves better result than an LQR controller by reducing the error.

Index Terms—LQR controller,LQG controller,Kalman filter

I. INTRODUCTION

Power system always experience random changes in load due to faults on the network, switching in or out a large load, loss of lines or generating units. These changes can be considered as the shifts of the power system from one stable state condition to another. In generation section, the generators convert the energy from various sources to electric power at a particular voltage. Power generator has a prime mover and an excitation system to control the output power as per the demand. With system load variation, the generator outputs are controlled to have changes according to their individual generation cost to meet the system demand. Generation frequency is an indication of this sudden load changes. A power system should maintain both its voltage and frequency at its desired value. Frequency is dependent on real power and voltage is dependent on reactive power. A large deviation of frequency occurs as a result to a sudden loss or change in generation, which will lead to the insufficiency to meet the load demand. In country like India, where the grid frequency tolerance deviates from over 2.5-5%, it is very essential to bring back the system to its normal operating frequency which is 50Hz.Once if it is not achieved then it can lead to shutting down of the plant, damage of turbine blades etc., since the speed of AC motors and the operation of transformers are directly related to the grid frequency. Therefore, grid frequency guarantees proper balance between the load demand and the power generation.

In our present day power system, the grid frequency control is provided by frequency-sensitive generation. Frequency sensitive generators are used conventionally nowadays to control grid frequency. They demand generation stations, power park modules and HVDC interconnectors to provide frequency response services. They systematically handle the load demand according to the generation by sharing the load and by load shedding. But this is not the effective way to control the grid frequency.

With a change in industrial heating loads, there is a larger change in frequency response. By connecting the tanks to the heating loads they can alter the power consumption in accordance with the grid frequency [1].The frequency response variation is for .5% and with the PI controller only 20% error was rectified. When the load demand does not match up with the generation then the frequency and power varies in an interconnected system. The grid frequency is dependent on real power and independent over reactive power [2].An alternative way to control grid frequency is demand control. When frequency falls below its grid value and if it continues to drop again then the industrial loads will be dispatched in order to maintain the grid operating frequency.

Another way to control grid frequency is by time-shifting the demand. This mainly focuses on the peak demand period. Involuntary rationing, if employed, would be accomplished via rolling blackouts during peak load periods [3]. Rolling blackouts generally result from two causes: insufficient generation capacity or inadequate transmission infrastructure to deliver sufficient power to the area where it is needed. In an interconnected power system when an electrical fault occurs, the frequency sensitive generators isolate that part of affected system to ensure system stability and proper functioning [4].

Demand-side management on a household level requires changes in the temporality of electricity-consuming practices in everyday life. One dominant approach to demand-side management is to influence the temporality of household’s consumption patterns by providing economic incentives through variable electricity prices [5].

The study for the frequency response was done by checking both the steady state and dynamic response of the domestic appliances [6].The heating loads were pre-set to a particular temperature in accordance with the frequency. And when the frequency drops these loads temperature increases and vice-versa.

The paper is organized as follows: Section 2 starts with a modeling of the tank and the system. Section 3 gives the structure of the controller and LQG controller design. Section 4 illustrates simulation and results including comparisons of the LQG controller with the LQR method. Section 5 concludes with the remarks.

II. MODELING OF THE SYSTEM

In a linear, time-invariant system, by using Swing equation,

$$\frac{2Hd^2\Delta\delta}{\omega dt^2} = \Delta P_m - \Delta P_e \tag{1}$$

where the inertia constant H is kinetic energy in MJ at rated speed to the machine rating in MVA.
For small change in speed, its Laplace transform gives,

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

Load model can be written as,

$$\Delta P_e = \Delta P_L + D\Delta\omega \tag{3}$$

where, ΔPL is the non-frequency sensitive load change, D Δω is the frequency sensitive load change and D is given by the ratio of percentage change in load to the percentage change in frequency.

$$\frac{\Delta\Omega(s)}{\Delta P_m - \Delta P_L} = \frac{1}{2Hs+D} \tag{4}$$

$$\frac{\Delta\Omega(s)}{\left(\Delta P_{ref} - \frac{\Delta\Omega(s)}{R}\right) - \Delta P_L} = \frac{1}{2Hs+D} \tag{5}$$

$$\Delta\Omega(s)[2Hs+D] + \frac{\Delta\Omega(s)}{R} = \Delta P_{ref} - \Delta P_L \tag{6}$$

$$\frac{\Delta\Omega(s)\left[2Hs+D+\frac{1}{R}\right]}{\Delta P_L} = \frac{\Delta P_{ref}}{\Delta P_L} \tag{7}$$

$\frac{\Delta P_{ref}}{\Delta P_L} \ll 1,$ inferred from the values based on the experimental results [7].

The transfer function of the system is obtained as

$$\frac{\Delta\Omega}{P_{ref}} = \frac{1}{\left[(2Hs+D)+\frac{1}{R}\right]} \tag{8}$$

III. CONTROLLER DESIGN

The state space equation of the above transfer function is given by,

$$\dot{x} = 2u - 2x_1 \tag{9}$$

$$y = x_1 \tag{10}$$

3.1 LQR Design

LQR (Linear Quadratic Regulator) is a feedback controller used to minimize the cost of a dynamic system. The LQR algorithm reduces the amount of work done by optimizing the controller in which the cost function parameters have to be specified. The LQR will compare the results with the specified goals.
Let us now consider the LQR problem for a linear time-variant system:

$$\dot{x} = Ax + Bu \tag{11}$$

Its cost function is given by,

$$J = \int_0^\infty (x^TQx + u^TRu)d\tau \tag{12}$$

where, Q and R are positive real symmetric matrices.Here,both the values are assumed to be unity.
Using Ricatti equation,

$$SA + A^TS + Q - SBR^{-1}B^TS = 0 \tag{13}$$

Optimal control is given by,

$$u^* = -R^{-1}B^TSx \tag{14}$$

$$K = R^{-1}B^TS \tag{15}$$

where, K= [.25 0] is the LQR gain.

3.2 LQG Design

The linear quadratic Gaussian (LQG) control is one of the most fundamental optimal control problems. It concerns uncertain linear systems disturbed by additive white Gaussian noise, having incomplete state information (i.e. not all the state variables are measured and available for feedback) and undergoing control subject to quadratic costs. Moreover, the solution is unique and constitutes a linear dynamic feedback control law that is easily computed and implemented.
The LQG controller is simply the combination of a Kalman filter, i.e. a linear–quadratic estimator (LQE), with a linear–quadratic regulator (LQR). The separation principle guarantees that these can be designed and computed independently. LQG control applies to both linear time-invariant systems as well as linear time-varying systems. The application to linear time-varying systems enables the design of linear feedback controllers for non-linear uncertain systems.

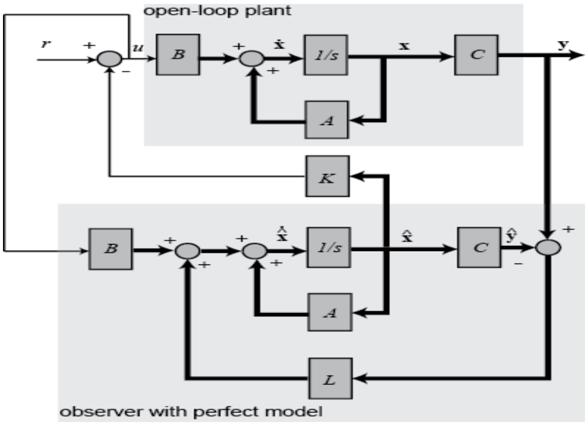

Fig.1 Block diagram of the system with the LQG controller

KF gain is obtained using the Ricatti Equation given by,

$$UA^T + AU + M - UC^T N^{-1} CU = 0 \qquad (16)$$

where, M and N are positive real symmetric matrices. Here, both the values are assumed to be unity.
And the Kalman gain L is given by,

$$L = -UC^T N^{-1} \qquad (17)$$

And L is obtained as,
L= [-.24; 1.87]

IV. SIMULATION RESULTS AND DISCUSSIONS

Different inputs were given to the system which includes the step, constant, sinusoidal and chirp inputs.

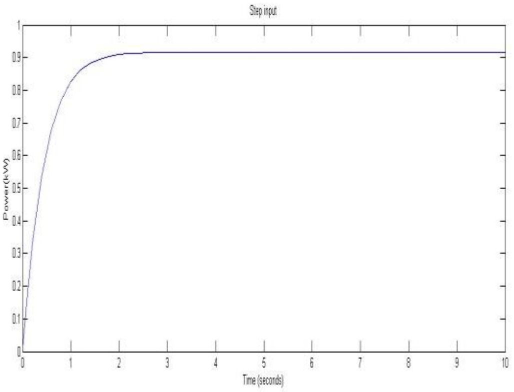

Fig.2 LQR controlled system with step input

When a step change in input was given to the system an error of 10% is been observed from fig.2.This is mainly because the noises and distortions were added up with the system and any use of filters or control was not provided to eliminate those errors.

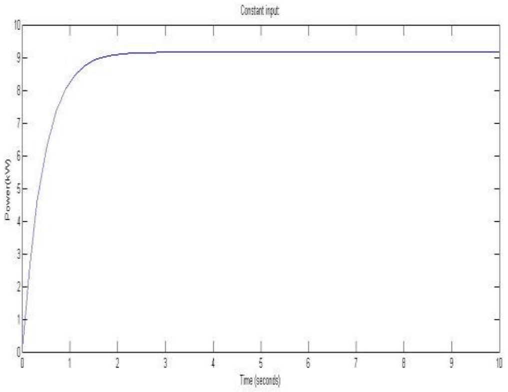

Fig.3 LQR controlled system with a constant input

A constant input was given to the LQR controlled system. The fig.3 shows the simulation result of the constant input. The constant input value given here is 10.And from the graph, it is clear that proper tracking was not obtained. An error of 10% was obtained here also.

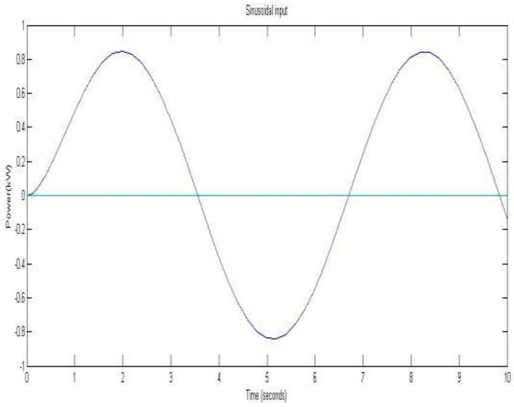

Fig.4 LQR controlled system with a sinusoidal input

A sinusoidal input was given to the LQR controlled system to analyze the steady state response of the system. It also shows an error of 10% is shown in fig.4.

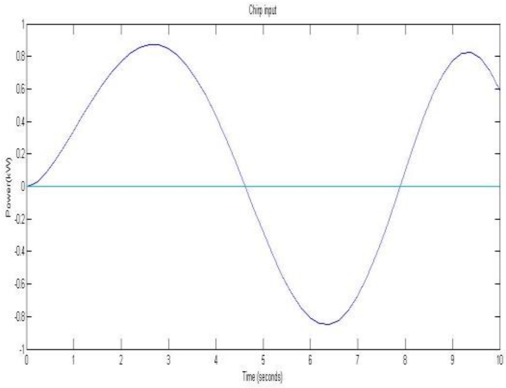

Fig.5 LQR controlled system with a chirp input

The last input given to the LQR controlled system was a chirp input. The chirp signal tracks its output but less effectively (fig.5)

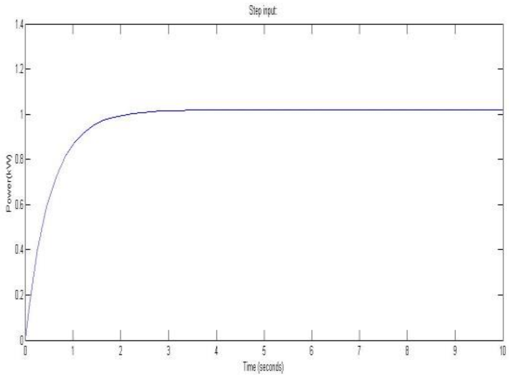

Fig.6 LQG controlled system with a step input

After designing the LQG controller it was simulated to obtain tracking for different inputs. At first, a step input was given to the system equipped with the LQG controller. The system was able to track its output completely which is shown in fig.6.

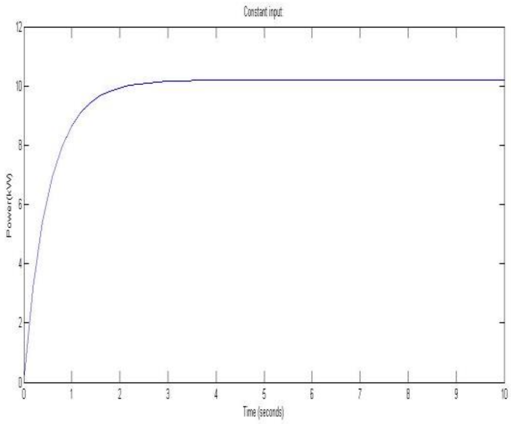

Fig.7 LQG controlled system with a constant input

A constant input was fed to the LQG controlled system (fig7). The result obtained proves effective tracking.

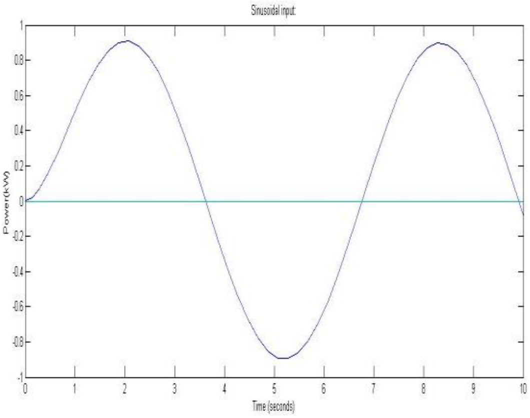

Fig.8 LQG controlled system with a sinusoidal input

The fig.8 shows the simulation result of an LQG controlled system with a sinusoidal input. It shows better tracking than the LQR controller.

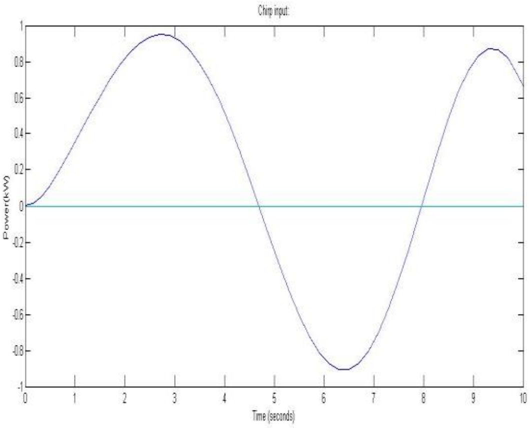

Fig.9 LQG controlled system with a chirp input

At last, a chirp input was given to the system with LQG controller and the simulation result is shown in fig.9.From the graph it is clear that the system performed better tracking than the LQR controller.

V. CONCLUSIONS

An approach to the comparison of an LQR and an LQG controller has been performed and the results were obtained using MATLAB Simulink. By investigating the simulation results it is evident that the Linear Quadratic Regulator functions well with the Kalman Filter than performing alone. As a result, the adaptation of LQG reduces the error which is obtained in the LQR control. Also the simulation results of LQG shows some error which can be overcome using an adaptive controller.

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