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Operating Performance of LQR Based Power System Stabilizer for Single Machine Infinite Bus System

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Abstract**:** In power system, the electromechanical modes of oscillations are considered as a vulnerable problem. It affects the dynamic stability of the system for the oscillation frequency range of 0.2 to 3Hz. Normally the power system stabilizer (PSS) is used to damp this oscillation and to keep up the system stability. In this paper, the PSS is designed based on the Quantitative feedback theory (QFT) and Linear Quadratic Regulator (LQR) methods to the effectiveness of damping the oscillation. QFT uses the system parametric insecurity, but LQR effectively tunes the gain of the controller in order to preserve the system function. Both these methods are improving the damping level of the system oscillations and the results are evaluated using MATLAB simulation for the optimum selection of controllers.

Index Terms: power system stabilizer (PSS), low frequency oscillation, Single machine infinite bus system (SMIB), quantitative feedback theory (QFT), linear quadratic regulator (LQR).

I. INTRODUCTION

Small signal stability is considered as an important part ofa power system, if the damping of low frequency oscillations is not controlled leads to unstable power system and causes power quality problems. There are two main reasons for losing this stability, namely i. increasedrotor angle due to insufficient synchronizing torque, ii. Increasedoscillation due to insufficient damping torque [1]. In order to maintain the system at stable condition, the two types of torque are important and it maintained at positive.

The function of the excitation systems is to provide proper excitation to the synchronous generator, due to introducing automatic voltage regulator the damping torque is going negative so the system loses the stability and it make the generator to oscillate [2,3]. The PSS is mainly used to provide positive damping torque to the system than it regains the stability. The low frequency modes of oscillation are divided into two types, namely interarea mode and local area mode. Both these types of modes of disturbance are handled by the power system stabilizer. The PSS controls the oscillation and retain the sufficient damping torque.There are three components used to design the power system stabilizer. Namely, stabilizer gain, lead lagcompensator and washout filter. The stabilizer gain is damp the oscillation, if the gain value is increased then the damping level is also increased upto the certain limit, beyond the limit, the damping level is decreases therefore maintain the stabilizer gain at a particular level.The washout filter is used for two purposes [4], (i) It removes the DC offset present in the output signal of the PSS. (ii) It avoids the steady state deviation and it smoothen the input signal of AVR.The lead lag compensator is used for controlling the phase angle of the motor and it produces the electromechanical torque in phase with the speed deviation, so it compensates the lag between the PSS output signal and excitation input signal [5].

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Normally the PSS gives the proper input to the system that decrease the speed deviation presence in the power system and the parameters of the PSS is tuned based on the generator design, AVR condition and system working characteristic [6]. Here the two methods are used to design the PSS, Quantitative feedback theory and another one is linear quadratic regulator [7, 8]. The LQR based PSS yields better damping performance for continuous- time systems [14].Eventually, both methods are providing the best result. TheQFT follows the uncertainty condition, but the LQR method [15, 16] provide faster response when compare to QFT.

In this paper, the SMIB system designed by Heffron Phillps is modelled using MATLAB/ SIMULINK block set. The low frequency oscillation damping capability of the SMIB system is demonstrated with and without the PSS. The PSS performance is evaluated with robust QFT and LQR technique. The desired damping of oscillations can be achieved from the LQR based PSS on the simulation results. The organization of the paper is as follows. Section I describes the importance of PSS and its characteristic performance. Section II describes the operating principle of the PSS. In section III, the linearized SMIB system design parameters, voltage regulator and exciter are explained. The implementation of the QFT based PSS design is explained in Section IV. The proposed LQR based PSS design is explained in section V. The illustrative simulation results of both QFT and LQR are discussed in section VI.

2. PSS DESIGN

The Power System Stabilizer (PSS) is used to produce the desired positive damping to the rotor oscillations of the synchronous machine by controlling its excitation. Electromechanical oscillations in the electric generators are due to the disturbances in a power system. Tomaintain the system stability, these oscillations needs to damp out. The PSS output signal is used as an additional input (V_{PSS}) to the exciter of the generator. The generic PSS diagram is given in Figure(1). The model consists of a gain, a washout filter, a phase-compensator, and a limiter [2].

2.1. Gain

The power system stabilizer overall gain is taken as *K*. The amount of damping produced by the stabilizer is determinedby the gain *K*. Generally, the Gain *K* can be chosen in the range of 20 to 200.

2.2. Wash-out time constant

The low frequencies present in the speed deviation signal are eliminated by washout high-pass filter and allows the PSS torespond only to speed changes. The Time constant Tw can bechosen in the range of 1 to 2 for local modes of oscillation.However, if inter area modes are also to be damped, then Twmust be chosen in the range of 10 to 20.

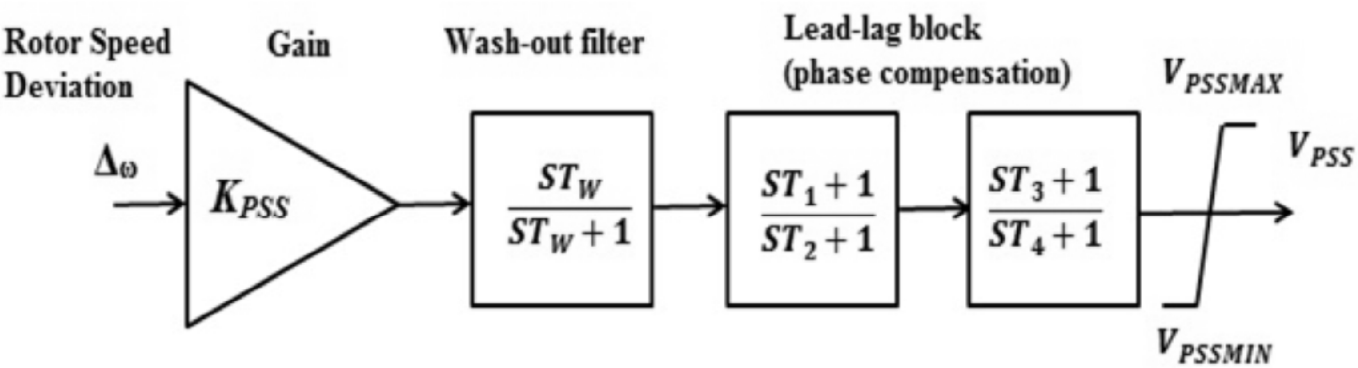

Figure 1: Block diagram of PSS [2]

2.3. Lead-lag time constants: (Phase Compensation System)

The phase-compensation system isrepresented by a cascade of two first-order lead-lag transferfunctions used to compensate the phase lag between theexcitation voltage and the electrical torque of the synchronousmachine.

3. SINGLE MACHINE INFINITE BUS (SMIB) SYSTEM

Figure (2) shows the linearized incremental model of the single machine infinite bus system. The dottedlines represent theexcitation system and synchronous machine coupled to the infinite bus [6]. In infinite bus system, the voltage and frequency is assumed to remain constant. Under the normal equilibrium form, the system maintains the stability, i.e. the angle between the arrangement of the rotor axis and resultant magnetic fields are fixed.During any disturbance is formed by a variation in generation and load pattern, the rotor will decelerate or accelerate with respect to the synchronously rotating air-gap mmf and a relative motion begins.

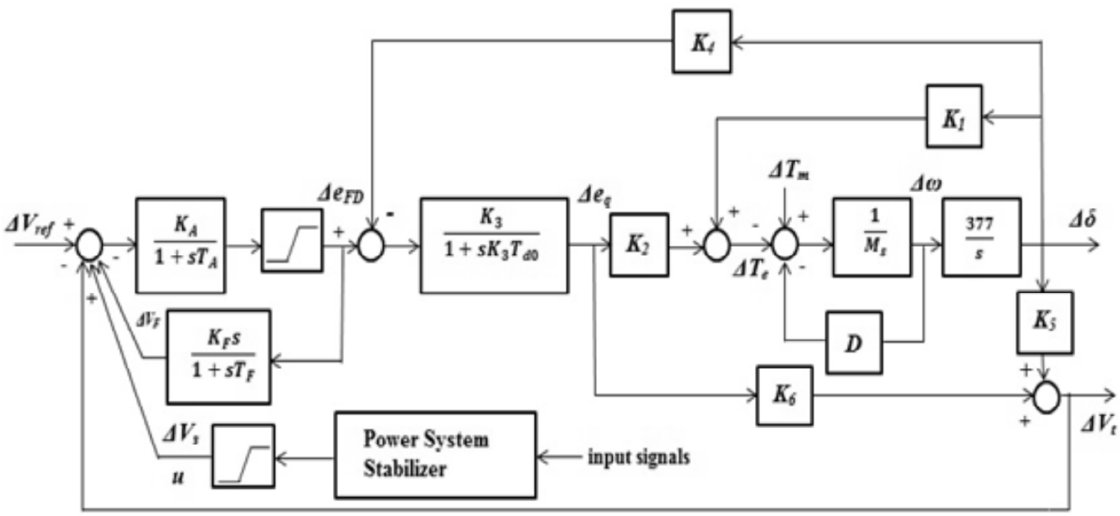

Figure 2: SMIB system designed by Heffron Phillps [12].

The parameters used in the system is given below [12],

$k_1 = 1.0755$, $k_2 = 1.2578$, $k_3 = 0.3072$, $k_4 = 1.7124$,

$k_5 = -0.0409$, $k_6 = 0.4971$, $k_A = 400$, $k_F = 0.025$, $T_A = 0.05$,

$T_{F1} = 1.0$, M = 4.74, $T'_{do} = 5.9$, $D = 0$, $e_{FD,max} = 7.3$,

$e_{FD,min} = -7.3$ $u_{max} = 0.12$, $u_{min} = -0.12$.

4. THE QUANTITATIVE FEEDBACK THEORY (QFT)

In this method, the closed loop transfer function is designed to satisfy a set of frequencies causes the oscillation. These conditions are shown as tolerance band contained by which the magnitude result of the closed loop transfer function should lie [9].

A compensator is selected by physically shaping the loop transmission such that it satisfies the limits at each of the frequency points. A Prefilter is then used to make sure that the closed-loop transfer function lies inside the individual bands [11, 12].The figure (2) shows the block diagram of the system with the controller in quantitative feedback design.

The QFT is used for single input single output and multi input multi output, linear and nonlinear, time varying and time invariant systems [10]. The advantages of QFT over other robust methods are,

- Enables the user to measure quantitatively the price of feedback.
- Controller design is transparency.
- Utilizes the phase information in the design procedure.

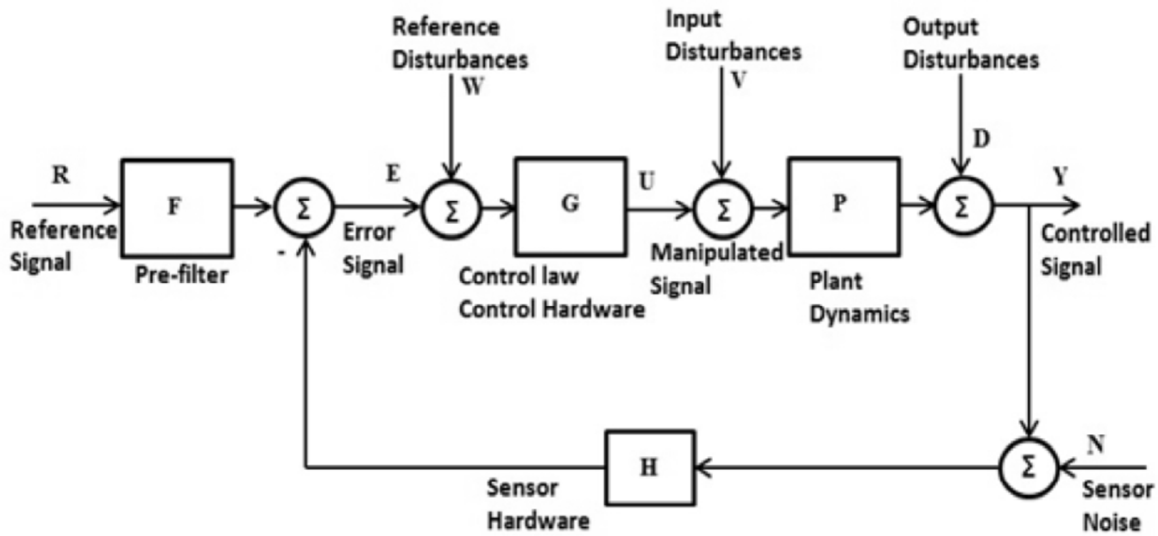

Figure 3: The controller design with QFT

5. LINEAR QUADRATIC REGULATOR (LQR)

In this method, the feedback controller is designed by solving the set of linear quadratic equation with choosing minimum performance index Q and R value [15, 16]. By adjusting the value of the gain K value, we get the best performance of the system when compares the previous method.

The above linearized model in Figure(1) of SMIB system can be represented by the matrix A and B given below [15],

$$A = \begin{bmatrix} 0 & \omega_0 & 0 \\ -\frac{K_1}{2H} & -\frac{D}{2H} & -\frac{K_2}{2H} \\ -\frac{K_3}{T_{do}} & 0 & \frac{1}{T_d} \end{bmatrix}; B = \begin{bmatrix} 0 \\ 0 \\ \frac{1}{T_{do}} \end{bmatrix} \tag{1}$$

Where

$$\Delta x = [\Delta\delta\ \Delta\omega\ \Delta E'q]^T \tag{2}$$

By using these two matrixes the LQR method is discussed below.

The state equation of the linear system is described by,

$$\dot{x} = Ax + Bu \tag{3}$$

Performance index with cost function is defined as J, by choosing aminimum value of performance index; the controller is designed [18].

$$J = \int_0^\infty \left(x^T Q x + u^T R u \right) dt \tag{4}$$

The feedback control law '*u*' is designed by using the gain value *K*,

$$u = -Kx \tag{5}$$

Where *K* is given below,

$$K = R^{-1} B^T P \tag{6}$$

The value of *P* matrix is found by solving the following Riccati equation,

$$A^T P + PA - PBR^{-1} B^T P + Q = 0 \tag{7}$$

In order to find out the matrix *P*, the weighting matrices *Q* and *R* are chosen as

$$Q = C^T * C \; R = 1 \tag{8}$$

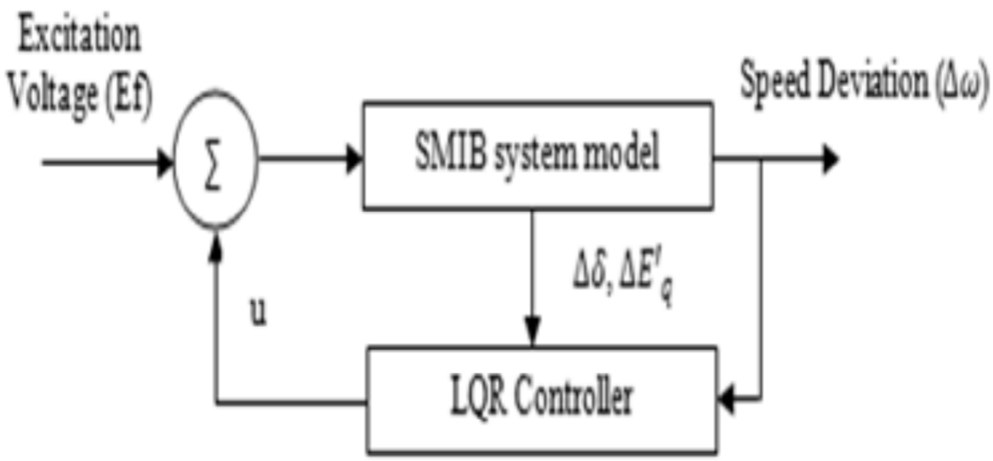

Figure 4: Power system connected by LQR controller

The controller designed by using LQR is connected to the power system [19] is shown in figure 4.

6. SIMULATION RESULTS AND DISCUSSION

The performance of SMIB system, with and without PSS was studied by using MATLAB/SIMULINK software. The PSS is designed with both QFT and LQR techniques. The results of the both techniques are compared to show their effectiveness.

Figure (5) shows the angular speed deviation (Δω) and figure (6) shows the torque angle deviation (Δδ), which are due to the results of disturbance occurs in the power system. Both speed deviation and torque angle deviation are taking much longer settling time greater than 10 sec. The SMIB system without the stabilizer produces more rotor oscillations and it needs to design a PSS for damping the low frequency oscillation.

Figure (7) shows the QFT-PSS result of angular speed deviation (Δω) settled at 2.5 sec and figure (8) shows the QFT-PSS result of torque angle deviation (Δδ) settled at 2.7 sec.

Figure (9) and (10) shows the results of the LQR-PSS, angular speed deviation (Δω) settles at 1.8 sec and torque angle deviation (Δδ) settles at 2.6 respectively.

The settling time of (Δω) is 1.8 sec in LQR-PSS seems much quicker than the QFT-PSS, which settles at 2.5 sec. The settling time of (Δδ) is 2.6 sec in LQR-PSS seems much quicker than the QFT-PSS, which settles at 2.7 sec.

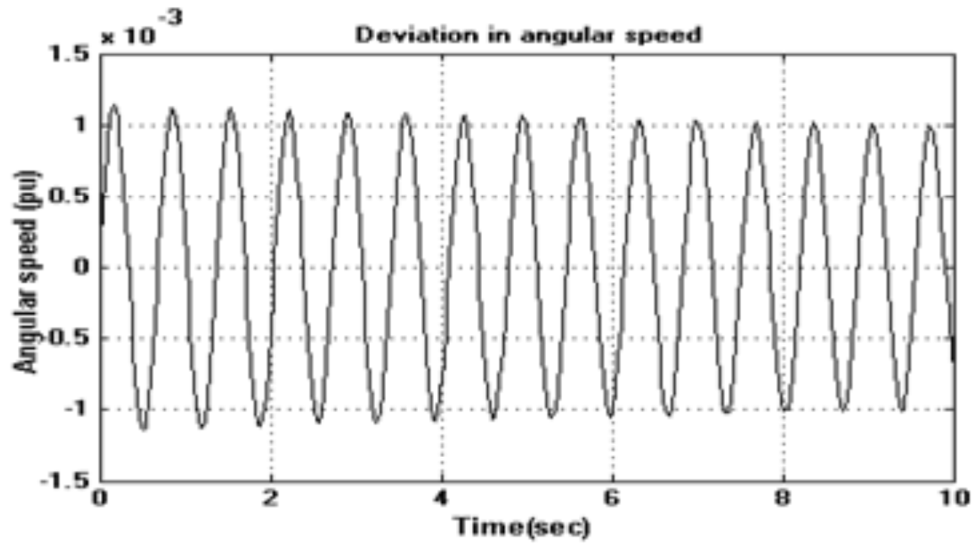

Figure 5: Deviation in angular speed (Δω) without using PSS.

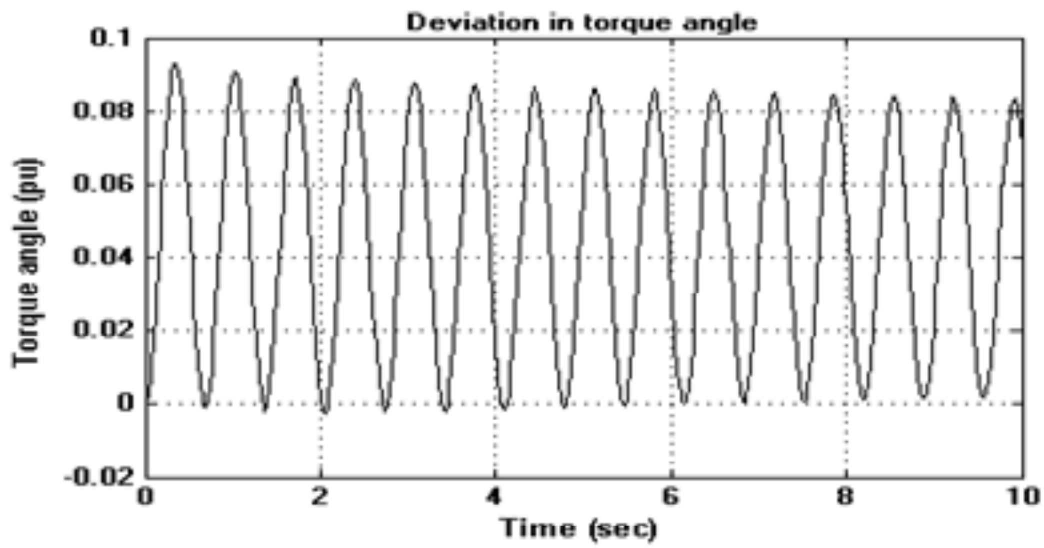

Figure 6: Deviation in Torque Angle (Δδ) without using PSS

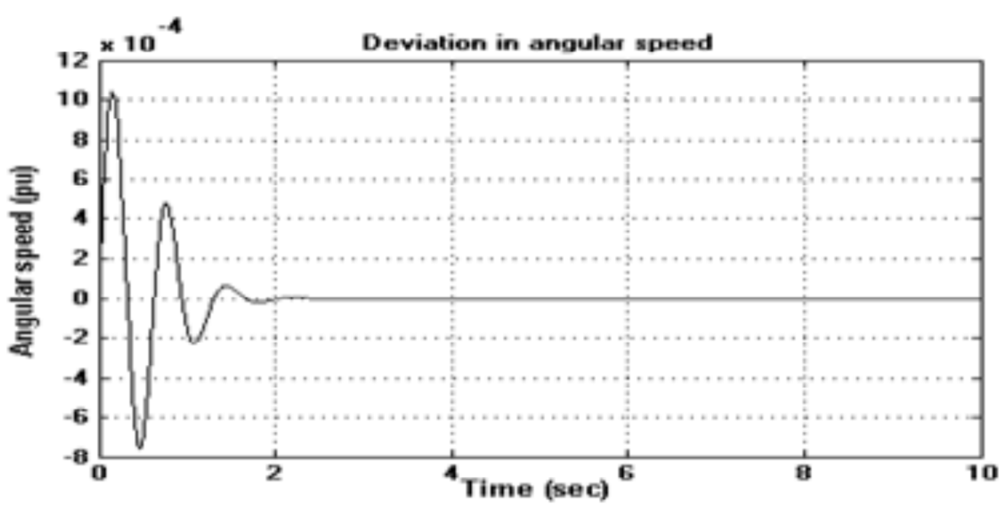

Figure 7: Deviation in angular speed (Δω) with using QFT–PSS

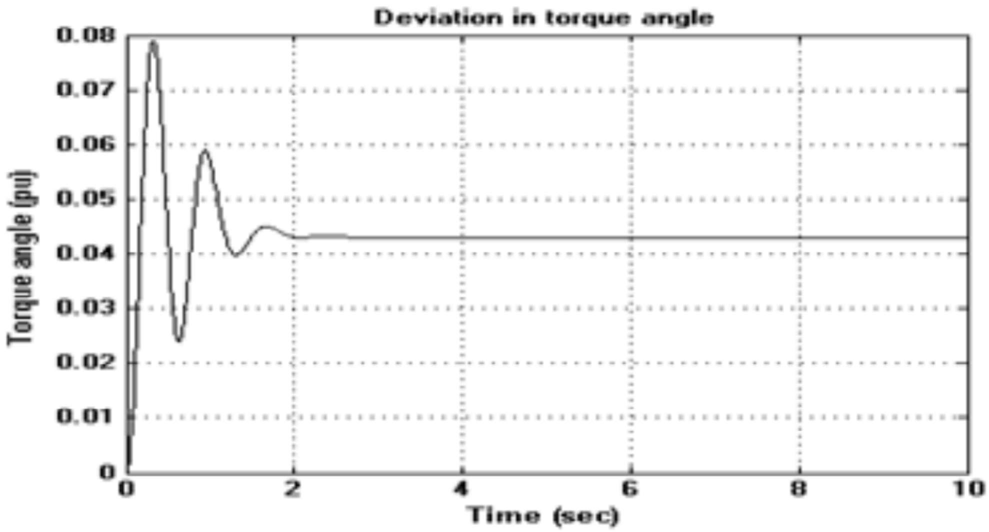

Figure 8: Deviation in Torque Angle (Δδ) with using QFT–PSS

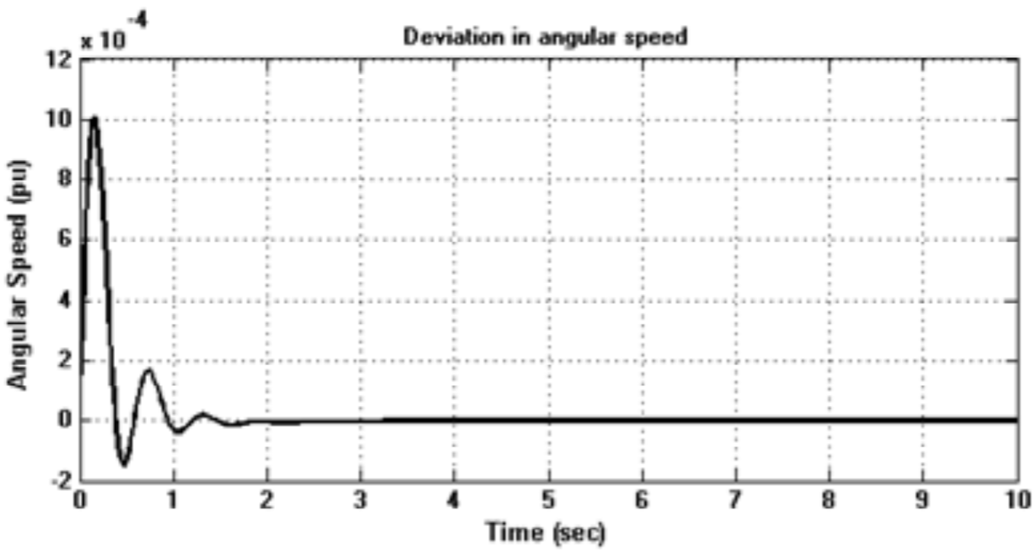

Figure 9: Deviation in angular speed (Δω) with using LQR

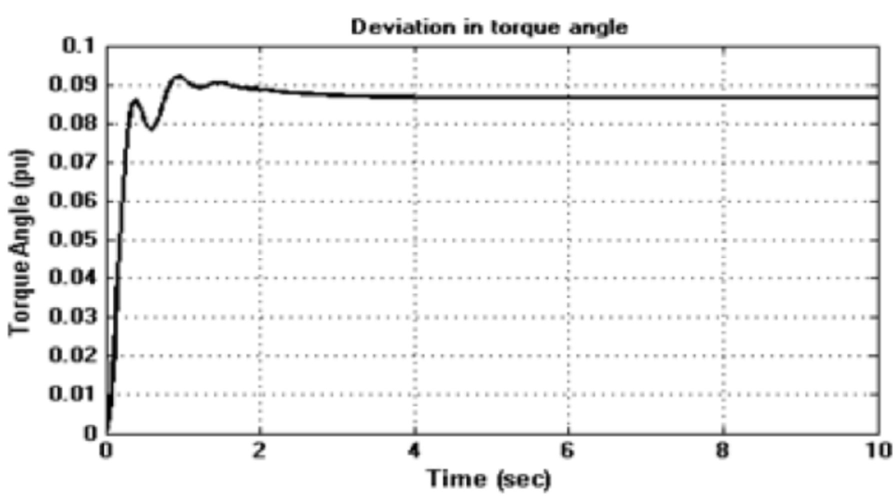

Figure 10: Deviation in Torque Angle (Δδ) with using LQR

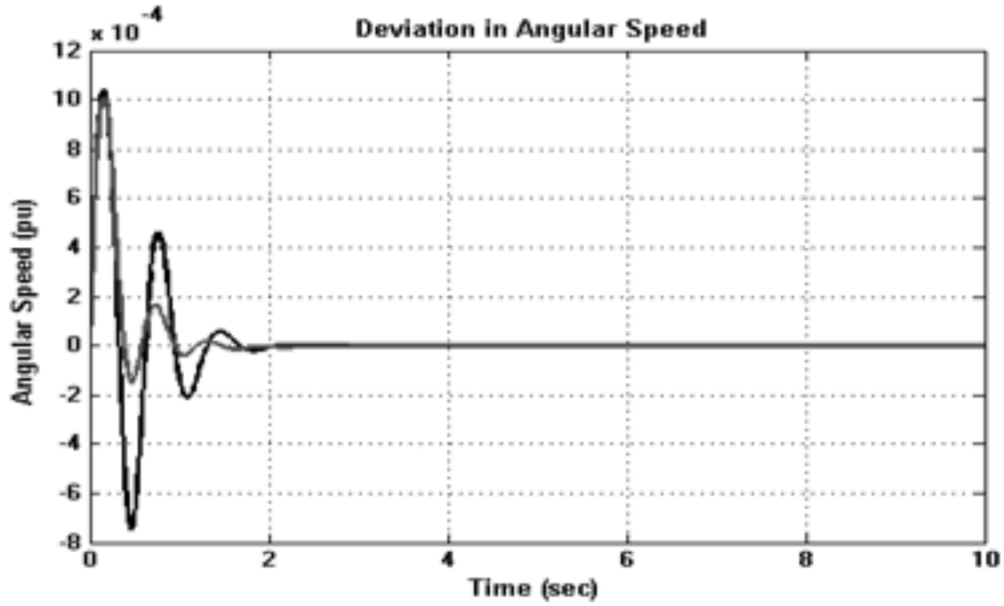

Figure 11: Deviation in angular speed (Δω) with using LQR and QFT-PSS

Table 1
Comparison of results based on settling time of () and

Optimization techniques Parameters involved	*QFT-PSS (in sec)*	*LQR (in sec)*
Angular Speed Deviation (Δω)	2.5	1.8
Torque Angle Deviation (Δδ)	2.7	2.6

VII. CONCLUSION

In this paper, the two methods are used to damp the electromechanical modes of oscillation in single machine infinite bus (SMIB) power system. The quantitative feedback theory (QFT) gives the better response and it follows the parameter changes in the generator. So whatever low frequency oscillation present in the system, the QFT has handled the situation. In linear quadratic regulator, the controller is designed based on the performance of the system and it produces the excellent result when compared to the QFT method. Therefore, from the settling time of oscillation, LQR offers the quick damping of oscillation and it rapidly makes the system stable. This technique can also be applied in multi machine systems for better dynamic stability.

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