# A Novel Approach in Automatic Control Based on the Genetic Algorithm in STATCOM for Improvement Power System Transient Stability

Gh. Shahgholian, S. Eshtehardiha, H. Mahdavi-Nasab, M.R.Yousefi

**Abstract—STATic synchronous COMpensator (STATCOM) is a shunt-connected converter, which can affect rapid control of reactive flow in the transmission line by controlling the generated AC voltage. This article presents a new STATCOM voltage controller design for power system damping. The method of multiplicative uncertainty has been employed to model the variations of the operating points. The controller was tested for a number the step increase in torque reference. Voltage of capacitor STATCOM can be controlled by method of Linear Quadratic Regulator (LQR). In this article, matrixes coefficients and dominant poles of closed loop transfer function are selected based on genetic algorithm method. The results show an improvement in voltage control response in a short response time.**

***Index Terms*— Damping Control, Genetic Algorithm, Linear Quadratic Regulator, STATCOM**

## I. INTRODUCTION

Reactive power control is a critical consideration in improving the power quality of power systems. Reactive power increases transmission losses, degrades power transmission capability and decreases voltage regulation at the load end. In the past, Thyristor-Controlled Reactors (TCR) and Thyristor- Switched Capacitors were applied for reactive power compensation. However, with the increasing power rating achieved by solid-state devices, the Static Synchronous Compensator (STATCOM) is taking place as one of the new generation flexible AC transmission systems (FACTS) devices.

It has been proven that the STATCOM is a device capable of solving the power quality problems. One of the power quality problems that always occur at the system is the three phase fault caused by short circuit in the system, switching operation, starting large motors and etc. This problem happens in milliseconds and because of the time limitation, it requires the STATCOM that has continuous reactive power control with fast response [1].In order to increase the stability of the system and damping response which makes the inverter in the STATCOM to inject voltage or current to compensate the three phase fault [2].

With only excitation control, the system stability may not be maintained if a large fault occurs close to the generator terminal, or simultaneous transient stability and voltage regulation enhancement may be difficult to achieve. With the development of power electronics technologies, several Flexible AC Transmission System (FACTS) devices [3] at present or in the further can be used to increase the power transfer capability of transmission networks and enhance the stability of the power system. A STATCOM provides better dynamic performance and minimal interaction with the supply grid. The STATCOM is a shunt connected device. The STATCOM consists of voltage source inverter such as Gate Turn Off (GTO) Thyristor, a DC link capacitor and a controller [4].

The STATCOM is normally designed to provide fast voltage control and to enhance damping of inter-area oscillations. A typical method to meet these requirements is to superimpose a supplementary damping controller upon the automatic voltage control loop [5]. Many of the methods focus on decoupling the system variables and designing PI controllers. A STATCOM is a Multiple Input Multiple Output (MIMO) system. It is not possible to totally decouple the system variables. Therefore, the control performance may sometimes be poor. Other control methods apply state feedback control techniques [2], [6], however, very little detail is given in the literature about how to choose the optimal parameters. Some control methods apply state feedback control techniques [1], [7]. Two basic controls are implemented in a STATCOM. The first is the AC voltage regulation of the power system, which is realized by controlling the reactive power interchange between the STATCOM and the power system. The other is the control of the DC voltage across the capacitor, through which the active power injection from the STATCOM to the power system is controlled [8]. With the help of robust control theory and the Direct Feedback Linearization (DFL) technique, the nonlinear coordinated control of generator excitation and the STATCOM is investigated in [9]. The modeling and control design are usually carried in the standard synchronous d–q frame [10].

The remainder of the paper is organized as follows. Describes modeling of STATCOM in Section II, and the design of the proposed control algorithm is detailed in Section III Genetic algorithm is shown in Section IV. The

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computer simulation results are presented and discussed in Section V. Finally Section VI concludes this paper.

## II. Power Syestem Model with STATCOM

Controller design for power system stability studies requires proper and adequate mathematical representation of power system so as to include all significant components of the power system. Dynamic models, both nonlinear and linear, for single machine infinite bus as well as multi-machine systems installed with STATCOM are presented in this Section [11, 12].

A single machine infinite bus system with a STATCOM installed at the mid-point of the transmission line is shown in Fig. 1. The system consists of a step down transformer (SDT) with a leakage reactance $X_{SDT}$, a three phase GTO-based voltage source converter, and a DC. capacitor. The STATCOM is modeled as a voltage sourced converter (VSC) behind a SDT. The VSC generates a controllable AC voltage source $V_0\ (t)\ =\ V_0\ \sin\ (\omega t\text{-}\psi)$ behind the leakage reactance. Depending on the magnitude of $V_0$, current $I_{Lo}$ can be made to lead or lag the bus voltage $V_L$. Thus the STATCOM can be made to supply or absorb reactive power by controlling the voltage magnitude of the VSC. Generally, the STATCOM voltage is in phase with the bus voltage. However, some active power control may be possible through a limited control of phase angle $\psi$. This would necessitate a power source behind the capacitor voltage. The dynamic relation between the capacitor voltage and current in the STATCOM circuit are expressed as [13, 14],

$$\dot V_{DC} = \frac{I_{DC}}{C_{DC}} = \frac{m}{C_{DC}}(I_{sd}\cos\psi + I_{sq} j\sin\psi) \tag{1}$$

where, $I_{Lod}$ and $I_{Loq}$ are the direct and quadrature axes components of STATCOM current $I_{Lo}$. The output voltage phasor is

$$V_0 = mV_{DC}\langle\psi \tag{2}$$

The magnitude of the STATCOM voltage depends on m, which is a product of the AC/DC voltage ratio and the modulation ratio defined by the PWM. The dynamics of the generator and the excitation system are expressed through a fourth order model given as

$$\dot\delta = \omega_0\omega$$

$$\dot\omega = \frac{1}{M}[P_m - P_e - (x_d - x_d')I_d]$$

$$\dot e_{fd}' = [E_{fd} - e_q' - (x_d - x_d')I_d]\frac{1}{T_{do}} \tag{3}$$

$$\dot E_{fd} = -\frac{1}{T_A}(E_{fd} - E_{fdo}) + \frac{K_A}{T_A}(V_{to} - V_t)$$

The expressions for the power output, terminal voltage, and the d-q axes currents in the transmission line and STATCOM, respectively, are

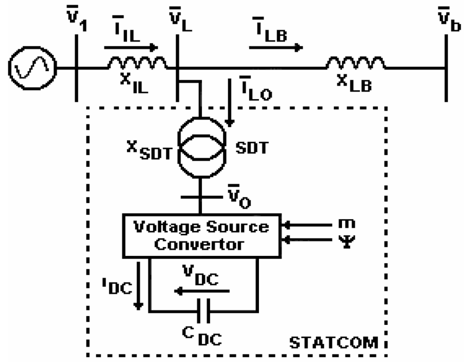


Fig. 1. A STATCOM installed in a single-machine infinite-bus power system

$$P_e = v_d I_d + v_q I_q, P_e = e_q' I_q + (x_q - x_d')I_q I_d$$

$$V_t = \sqrt{v_d^2 + v_q^2} = \sqrt{(e_q' - x_d' I_d)^2 + x_q I_q^2}$$

$$I_d = \frac{\left(1 + \frac{X_{LB}}{X_{SDT}}\right) e_q' - \frac{X_{LB}}{X_{SDT}} mV_{DC}\sin\psi - V_B\cos\delta}{X_{tL} + X_{LB} + \frac{X_{tL}}{X_{SDT}} + \left(1 + \frac{X_{LB}}{X_{SDT}}\right) x_d'} \tag{4}$$

$$I_q = \frac{\frac{X_{LB}}{X_{SDT}} mV_{DCo}\cos\psi + V_B\sin\delta}{\left[X_{tL} + X_{LB} + \frac{X_{tL}X_{LB}}{X_{SDT}}\right] + \left(1 + \frac{X_{LB}}{X_{SDT}}\right) x_q}$$

$$\Delta e_q = \Delta e_q' + (x_d - x_d')\Delta I_d$$

By linearizing, the full-state linearized model of the power system installed with STATCOM for small perturbation around a nominal operating condition is expressed as (5).

$$\begin{bmatrix} \Delta\dot\delta \\ \Delta\dot\omega \\ \Delta\dot e_q' \\ \Delta\dot E_{fd} \\ \Delta\dot V_{DC} \end{bmatrix} = \begin{bmatrix} 0 & \omega_0 & 0 & 0 & 0 \\ -\frac{K_1}{M} & -\frac{D}{M} & -\frac{K_2}{M} & 0 & -\frac{K_{pDC}}{M} \\ -\frac{K_4}{T_{do}} & 0 & -\frac{K_3}{T_{do}} & -\frac{1}{T_{do}} & -\frac{K_{qDC}}{T_{do}} \\ -\frac{K_A K_5}{T_A} & 0 & -\frac{K_A K_6}{T_A} & -\frac{1}{T_A} & -\frac{K_A K_{VDC}}{T_A} \\ K_7 & 0 & K_8 & 0 & K_9 \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \Delta\omega \\ \Delta e_q' \\ \Delta E_{fd} \\ \Delta V_{DC} \end{bmatrix} + \begin{bmatrix} 0 & 0 \\ -\frac{K_{pm}}{M} & -\frac{K_{p\psi}}{M} \\ -\frac{K_{qm}}{T_{do}} & -\frac{K_{p\psi}}{T_{do}} \\ -\frac{K_A K_{Vm}}{T_A} & -\frac{K_A K_{V\psi}}{T_A} \\ K_{DC} & K_{d\psi} \end{bmatrix} \begin{bmatrix} \Delta m \\ \Delta\psi \end{bmatrix} \tag{5}$$

## III. LQR Design Method

In designing the LQR controller, the new gain of feedback must satisfy a few conditions stated below,

- the oscillations in $V_{dc}$ must respond less
- the overshoot of $V_{dc}$ must be improved,
- the voltage of the capacitor ($V_{dc}$) should be kept constant by control of the controller

Another MIMO design approach is the optimal control method linear quadratic regulator (LQR). The idea is to transfer the designer's iteration on pole locations as used in full state feedback to iterations on the elements in a cost function. This method determines the feedback gain matrix that minimizes in order to achieve some compromise between the use of control effort, the magnitude, and the speed of response that will guarantee a stable system.

For a given system

$$\dot{X}(t) = Ax(t) + Bu(t) \quad (6)$$

Determine the matrix $K$ of the LQR vector

$$U(t) = -Kx(t) \quad (7)$$

So in order to minimize the performance index,

$$J = \int_0^{\infty} (X^T Q X + U^T R U) dt \quad (8)$$

Where $Q$ and $R$ are the positive-definite Hermitian or real symmetric matrixes,the matrix $Q$ and $R$ determine the relative importance of the error and the expenditure of this energy.

*A. Flow chart of LQR controller*

| **Statement of the Problem** | |
|---|---|
| Given the plant as x(t) = Ax(t) + Bu(t)<br>the performance index as<br>$J = \int_0^{\infty} (X^T QX + X^T K^T RKX)dt = \int_0^{\infty} (X^T (Q + K^T RK)X)dt$<br>and the its conditions $x(t_0) = x_0; x(\infty) = 0,$<br>Find the optimal control, index. | |
| **Solution of the Problem** | |
| Step 1 | Solve the matrix algebraic Riccati equation<br>$A^T P + PA - PBR^{-1}B^T P + Q = 0$ |
| Step 2 | Solve the optimal state x* (t) from<br>$X^*(t) = (A - BR^{-1}B^T \overline{P})X^*(t)$<br>With initial condition $x(t_0) = x_0$ . |
| Step 3 | Obtain the optimal control u* (t) from<br>$u^*(t) = -R^{-1}B^T PX^*(t)$ |
| Step 4 | Obtain the optimal performance index from<br>$J^* = \frac{1}{2} e^{2at_0} x^{*\prime}(t_0) \bar{P} x^*(t_0)$ |

*B. Weight Matrix Selection*

The LQR design selects the weight matrix $Q$ and $R$ such that the performances of the closed loop system can satisfy the desired requirements mentioned earlier. The selection of $Q$ and $R$ is weakly connected to the performance specifications, and a certain amount of trial and error is required with an interactive computer simulation before a satisfactory design results.

## IV. Genetic Algorithm

GA as a powerful and broadly applicable stochastic search and optimization techniques is perhaps the most widely known types of evolutionary computation method today. The GA has been used in various optimization problems including optimal control problems [15].

The genetic algorithm is an algorithm which is based on natural evolution and the survival of the best chromosome. There are three basic differences between genetic algorithm and optimization classical methods. Firstly, the genetic algorithm works on the encoded strings of the problem parameters. Each string is the representative of one answer to the problem, and the real quantities of the parameters are obtained from the decoding of these strings. Secondly, the genetic algorithm is a search algorithm which works on a population of search spaces. This quality causes the genetic algorithm to search different response spaces simultaneously reducing the possibility of being entrapped at local optimized points. Thirdly, the genetic algorithm does not need previous data from the problem response space such as convexity and derivable.

Then produce a new population and determine the optimization function rate of the produced chromosomes in the new population. Then, with regard to the amount of optimization function we continue to produce a new population until we reach to the desired point.

*R and Q design by genetic algorithm*

The target function is as follows.

$$F_{obj} = \left\{ (100Ess^{0.5} + Mp^2) + (ts - tr)^{0.5} \right\} \quad (10)$$

That $ts$ is settling time, $Mp$ is overshoot and $Ess$ is steady state error and $tr$ is rise time.

Through this method the time-consuming stage of determining $Q$ and $R$ matrices is performed with great precision and the system is optimized to reach the intended specifications in closed loop automatically and at the end, the output of the system is optimized with less overshoot, less oscillation, low settling time, and little steady error stage.

## V. The Result of Simulation Power System Studies

The primary function of a STATCOM is to provide voltage regulation within the power system. To provide the best performance, a STATCOM should be placed at those buses which provide high voltage response for incremental changes in reactive power injection. To verify the effectiveness of the proposed damping control, a digital simulation study of a single-machine infinite-bus power system installed with a STATCOM is carried out [16]. Parameters of a single-machine infinite-bus, shown in fig. 1, are listed below in pu.

H=3.0s, D=4.0, $T_{d0}$=5.044s, $x_d$=1.0, $x_q$=0.6, $X_d$=0.3, $x_{tL}$=0.3, $X_{SDT}$=0.15, $K_A$=10.0, $T_A$=0.01s, $T_C$=0.05s, $C_{DC}$=1.0, $V_{DC0}$=1.0, $P_{e0}$=0.8, $V_{t0}$=1.0, $V_{B0}$=1.0, $V_{L0}$=1.0, $c_0$=0.25, $\Psi_0$=$52^0$

Simulations are carried out to show how the system recovers after a major disturbance. In this study, while the system was operating at its normal condition, the step increase in torque reference at *t=5* sec. After the clearance changed load at *t=100* sec, the system resumed to its original operating status.

### A. Without Controller on STATCOM

Power angle deviation of the machine, without controller on STATCOM is shown in Fig. 2. And speed deviation of the machine without controller on STATCOM is shown in Fig. 3. In This Figures, it has seen that, in the power angle there is some oscillation, and it is harmful for the machine shaft, but the speed deviation in the machine is not considerable.

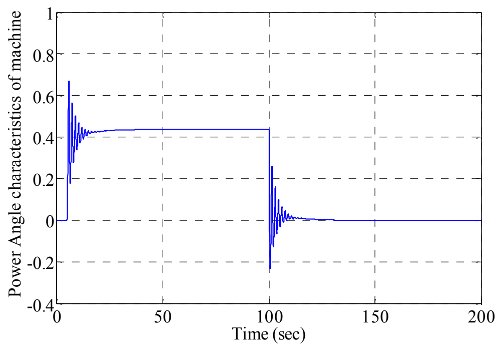


Fig. 2. Power angle of machine without controller on STATCOM

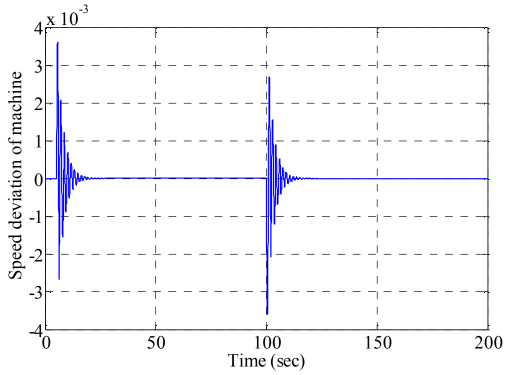


Fig. 3. Speed deviation of machine without controller on STATCOM

The STATCOM bus DC voltage in the network is shown in Fig. 4. In This Figure, the voltage of the capacitor ($V_{DC}$) deviation is very large and this is harmful to the capacitor.

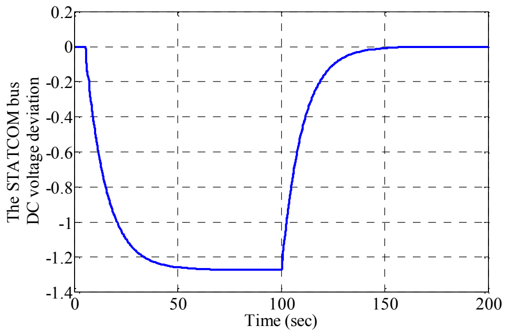


Fig. 4. The STATCOM bus DC voltage without controller

### B. With LQR Manual Controller on STATCOM

In the design of LQR weight matrices, $R$ and $Q$ are the determining elements for the quotient related to closed loop feedback system. The arrays of $R$ and $Q$ matrices in LQR control method in the form of manual and genetic algorithm are presented in Table. 1. The non-diagonal arrays in these matrixes are zeros.

Power angle of the machine with LQR manual controller on the STATCOM is shown in Fig. 5 and Fig. 6, and it has seen the improvement in the oscillation and steady state time of the system. In the following figures, these two state are separately shown (While the load is increased in t=5sec and While the load is decreased in t=100sec).

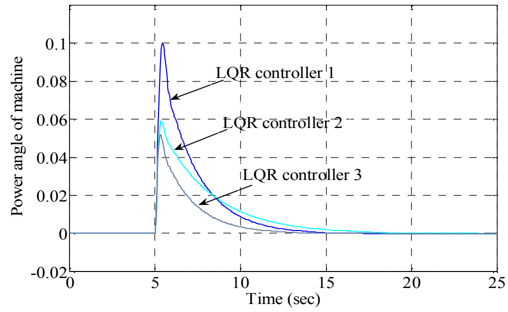


Fig. 5. Power angle of machine with manual LQR controller on STATCOM (While the load is increased in t=5sec)

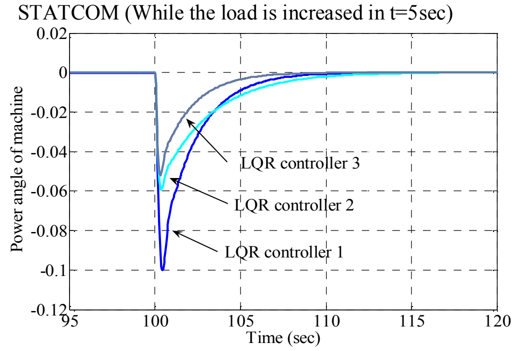


Fig. 6. Power angle of machine with manual LQR controller on STATCOM (While the load is decreased in t=100sec)

Speed deviation of the machine with LQR manual controller on the STATCOM is shown in Fig. 7 and Fig. 8.

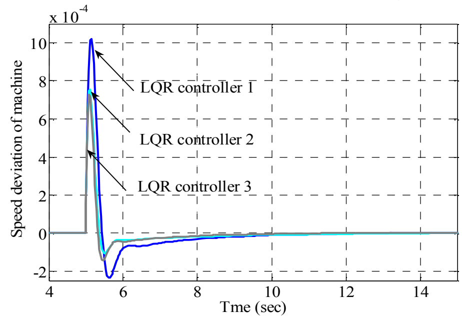


Fig. 7. Speed deviation of machine with manual LQR controller on STATCOM (While the load is increased in t=5sec)

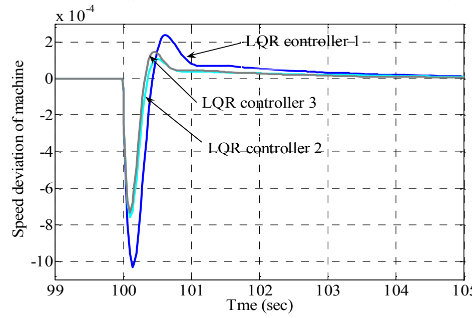


Fig. 8. Speed deviation of machine with manual LQR controller on STATCOM (While the load is decreased in t=100sec)

The STATCOM bus DC voltage in the network with manual LQR controller on STATCOM is shown in Fig. 9 and Fig. 10. In This Figure, the voltage of the capacitor ($V_{DC}$) deviation is controlled and this is less harmful so large to the capacitor.

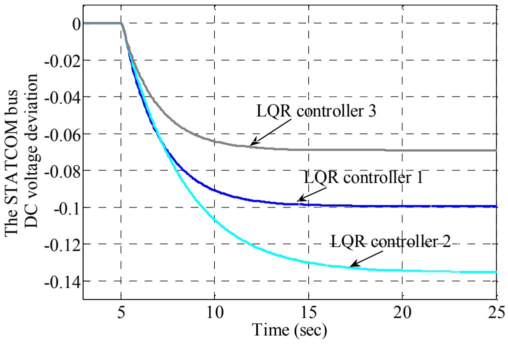


Fig. 9. The STATCOM bus DC voltage with manual LQR controller on STATCOM (While the load is increased in t=5sec)

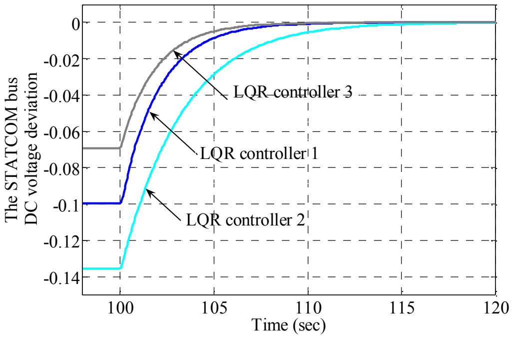


Fig. 10. The STATCOM bus DC voltage with manual LQR controller on STATCOM (While the load is decreased in t=100sec)

Table 1. LQR Controller parameters

| | |
|---|---|
| **LQR (1,2,3) Manual** | Q=diag(1.8813, 2.8375, 2.0198, 1.2762, 1.4357 )<br>R=diag(0.3469, 1.3229) |
| | Q=diag(0.6771, 0.05, 2.0344, 2.2759, 1.9545)<br>R=diag(0.4695, 0.8418) |
| | Q=diag(0.6295, 0.1551, 3.3706, 2.4199, 0.8609)<br>R=diag(0.0995, 0.2513) |
| **LQR GA** | Q=diag(0.6149, 4.7837, 1.3052, 1.392, 2.4377)<br>R=diag(0.2019, 0.4434) |

### *C. With LQR-GA Controller on STATCOM*

With using genetic algorithm the following results are obtained. With paying close attention to these results, it is observed that the LQR-GA is more effective in control of the system, both in power angle deviation and in DC voltage of the STATCOM bus. For this purpose the genetic algorithm on the system, within several successive seasons, has improved the convergence of the system and has brought the best chromosome of that generation into optimum amount from generation to generation. Power angle of the machine with LQR-GA controller on the STATCOM is shown in Fig. 11 and Fig. 12, and it has seen the great improvement in the oscillation and steady state time of the system.

Speed deviation of the machine with LQR-GA controller on the STATCOM is shown in Fig. 13 and Fig. 14.

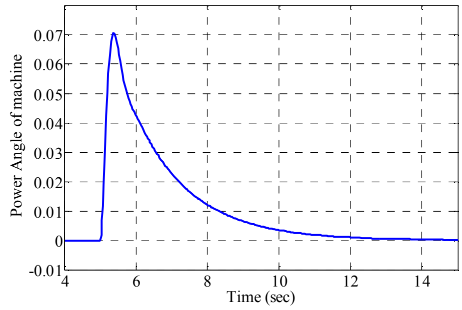


Fig. 11. Power angle of machine with LQR-GA controller on STATCOM (While the load is increased in t=5sec)

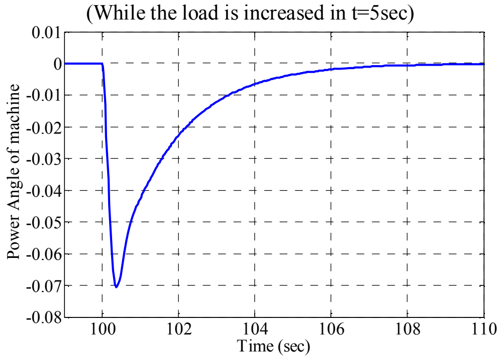


Fig. 12. Power angle of machine with LQR-GA controller on STATCOM (While the load is decreased in t=100sec)

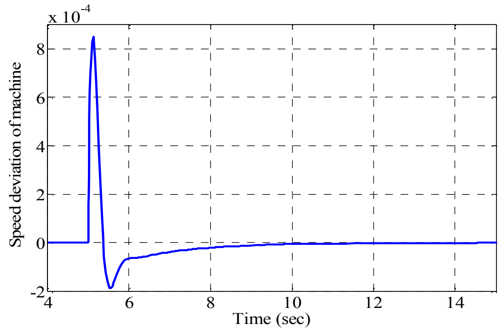


Fig.13. Speed deviation of machine with LQR-GA controller on STATCOM (While the load is increased in t=5sec)

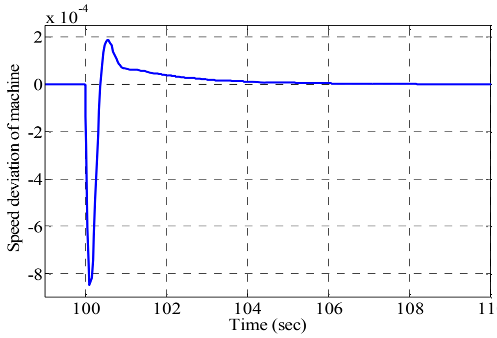


Fig. 14. Speed deviation of machine with LQR-GA controller on STATCOM (While the load is decreased in t=100sec)

The STATCOM bus DC voltage in the network with LQR-GA controller on STATCOM is shown in Fig. 15, and Fig. 16. The improvement of the STATCOM bus DC voltage is shown in these figures, and the voltage of the capacitor ($V_{DC}$) deviation is controlled and this is less harmful so large to the capacitor.

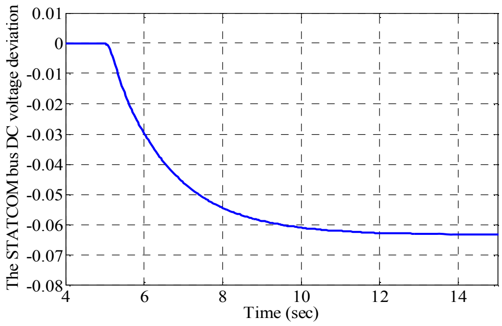


Fig. 15. The STATCOM bus DC voltage with LQR-GA controller on STATCOM (While the load is increased in t=5sec)

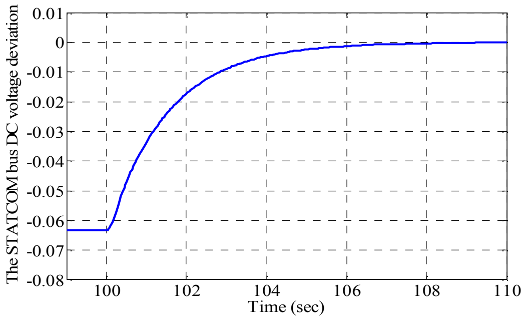


Fig. 16. The STATCOM bus DC voltage with manual LQR controller on STATCOM (While the load is decreased in t=100sec)

## VI. CONCLUSION

A balance between voltage regulation and power oscillation damping is achieved by cooperative effort of excitation and STATCOM in this paper. The optimum method for linear controller design is able to control the dynamic behavior of the STATCOM. Dynamic performance of DC voltage of STATCOM can be controlled by method of LQR. Genetic algorithm can be used to design the LQR matrixes of closed loop system to achieve the optimum dynamic response. The results demonstrate the improvement in dynamic behavior of power system control response compared with simple LQR method.

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