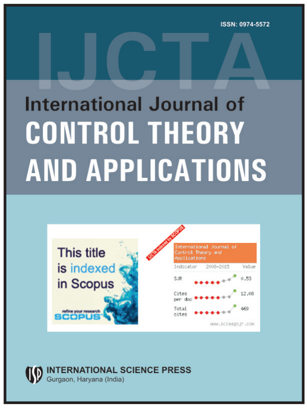


International Journal of Control Theory and Applications

ISSN : 0974-5572

Volume 10 • Number 16 • 2017

State Feedback Controller for Unified Power Quality Conditioner using PSO

Srinivasa Rao.Sura[a] and Sai Babu.Ch[b]

[a]*Asst. Professor, Department of EEE, GITAM University, Visakhapatnam Andhra Pradesh, India. Email: srinu722@gmail.com*
[b]*Professor, Department of EEE, JNT University, Kakinada, Andhra Pradesh, India. Email: chs_eee@yahoo.co.in*

Abstract: Power Quality (PQ) of electricity has become an essential need for consumers, at each and every level of its usage. Introduction of Custom power devices to the distribution system has rapidly increased electrical Power Quality and its reliability. One of the flexible custom power devices is unified power quality conditioner (UPQC), serving as a DSTATCOM and as well as a DVR. UPQC provides balanced sinusoidal source currents and load voltages in a power distribution network of distorted and unbalanced three-phase supply. Design of UPQC with particle swarm feedback controller based on optimization technique is proposed. Optimal performance here, besides feedback controllers which are conventional, various conditions of operation and stability to parametric uncertainties, is achieved by the proposed feedback controller.

Keywords: Unified power-quality conditioner (UPQC), particle swarm optimization (PSO) switching control, Linear quadratic regulator (LQR), control of state feedback, instantaneous symmetrical components theory, total harmonic distortion (THD).

1. INTRODUCTION

On the advancement of power electronic devices like adjustable speed drives, uninterrupted power supply, etc., in distribution system, problems regarding power quality such as voltage fluctuations, harmonics and flicker are escalating day by day. Different types of faults in network, lightening and capacitor bank switching may lead to different variations in power quality (PQ) problems like sagging/swelling in voltage. Along with these the usage of power electronic equipment's, unbalanced and nonlinear loads by the consumers has degraded the PQ in the power distribution network. But besides these, telecoms, information technology (I.T.) sectors, industries in which semiconductors are manufactured etc., are more often prone to problem in power quality and there is a requirement of higher quality of electric power [1]. Various schemes for the mitigation of the PQ issues have evolved in the literature. The most traditional scheme involves the use of passive filters. The passive filters consist of capacitor switch are tuned at a particular frequency. Although they are simple in operation, they have many limitations.

In order survive the hurdles with filters having passive behavior and to improvise the PQ in electrical distribution systems, the ideal of Active Power filters (APF) is depicted. The application of APFs in power distribution system is referred as Custom Power Devices[2]. Distribution Static Compensator DSTATCOM is a shunt connected custom power device. It alleviates the current related power quality problems in the distribution system. Dynamic Voltage Restorer (DVR) is a series compensated custom power device. DVR is primarily used for the protection from voltage sagging/swelling of loads which are sensitive, interruptions and harmonics in the supply side voltage[3]. Flexible custom power device, UPQC, is a combination of DSTATCOM and DVR, through which at the connected bus a sinusoidal nominal voltage can be sustained, and if at all there are source currents and load voltages harmonics can be damped.

In order to solve PQ problems with the help of UPQC different control algorithms came into existence[4]. In this few primary parts (like impedances of load and for source voltages or load currents the harmonic content present in them) are not taken in picture by most of these available design methodologies. Because of these apprehensions present in the system, satisfactory operation of UPQC is affected adversely, if in case this compensating problem of the system becomes complex to solve [5].

In this paper, a fresh technique, i.e. utilizing particle swarm optimization (PSO) is put forward for modelling a durable controller for feedback to sustain such parametric variations. A comprehensive simulation is used to illustrate the efficiency of proposed control method. A performance comparison is also done in this paper, between proposed UPQC feedback controller and LQR-based feedback controller which has been out dated presently.

2. UPQC LAYOUT

The proposed topology of UPQC connected to three phase, four wire electrical distribution system is considered from [6]. It consists of H-bridge inverters and interfacing transformers, six each adding to twelve, in order solve the two inverter circuits as shown. Each leg of both the shunt and series inverters are given independent control thought this network. Very low harmonic content is seen at the output (i.e., the usage of H-bridge inverter results in smooth tracking performance). Capacitor voltage balancing is refrained with the use of this network, because only one capacitor is used and when compared to other networks very low rating of the dc link is considered here. The inverters (i.e. both series and shunt) are assisted by same DC storage capacitor. Independent injecting of filter currents and filter voltages are allowed in this network. For switching frequency harmonics. Because of operation of different switches, the isolation and prevention of the DC capacitor from being shorted is carried out by the transformers[7].

Figure 1 shows a distribution system which is compensated by an UPQC. The load voltages are indicated, the source voltage by the impedances of feeders are indicated by resistance and the inductor. UPQC contains

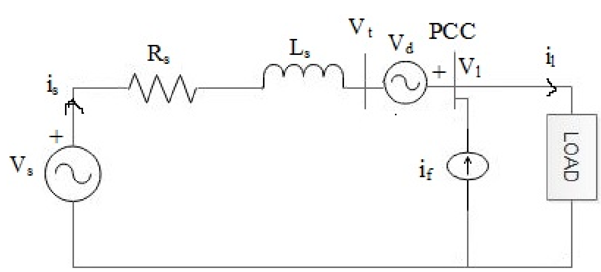


Figure 1: UPQC compensated distribution system

both series voltage source and shunt current source, shown in Figure 1, which helps in taking pure sinusoidal current and giving voltage which is distortion-free.

3. UPQC WITH STATE FEEDBACK CONTROL

Figure 2 depicts, the State space model of the system which is obtained from the equivalent circuit of UPQC.

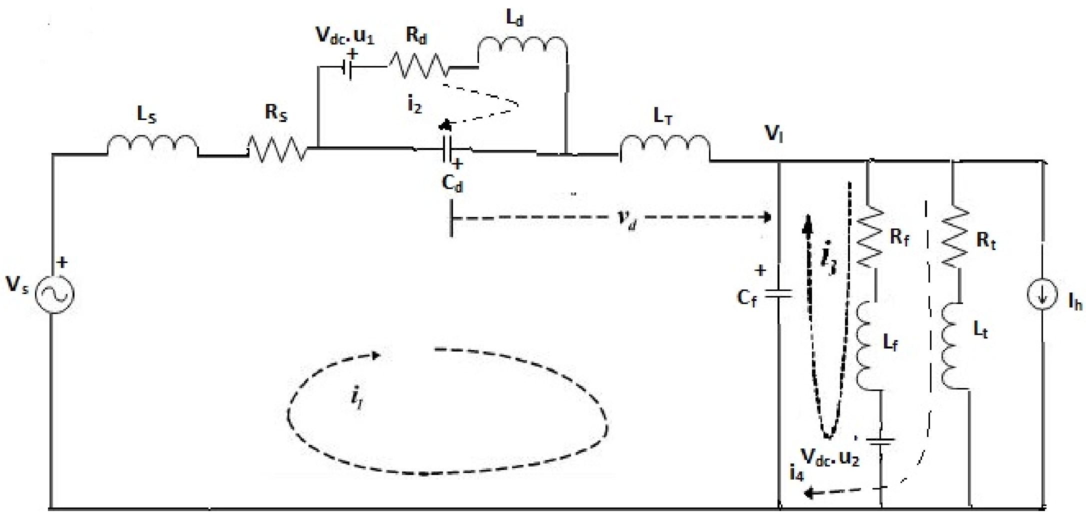


Figure 2: Equivalent circuit of UPQC compensated system

Variables (local) six in number (that is, loop currents and capacitor voltages, four and two in number respectively) are selected to achieve the state model. Loop currents are indicted as i_1, i_2, i_3, i_4 and capacitor voltages as v_{sd} and v_l respectively.

State vector is defined as follows:

$$x^{\mathrm{T}} = [i_1 \quad i_2 \quad i_3 \quad i_4 \quad v_{sd} \quad v_l] \tag{1}$$

The Figure 2 circuit has forcing functions are source voltage v_s, the nonlinear load current i_h, and switching variables u_1 and u_2.On replacing variables u_1 and u_2 by the continuous time variables u_{c1} and u_{c2} respectively and by defining the control vector as shown below:

$$u^{\mathrm{T}} = [u_{c1} \quad u_{c2}] \tag{2}$$

The state-space equation of the circuit can then be written as:

$$\dot{x} = \mathrm{A}x + \mathrm{B}_1 u + \mathrm{B}_2 v_s + \mathrm{B}_3 i_h \tag{3}$$

Where,

$$\mathrm{A} = \begin{bmatrix} -\mathrm{R}_s/(\mathrm{L}_s+\mathrm{L}_\mathrm{T}) & 0 & 0 & 0 & 1/(\mathrm{L}_s+\mathrm{L}_\mathrm{T}) & -1/(\mathrm{L}_s+\mathrm{L}_\mathrm{T}) \\ 0 & -\mathrm{R}_{se}/\mathrm{L}_{se} & 0 & 0 & -1/\mathrm{L}_{se} & 0 \\ 0 & 0 & -\mathrm{R}_f/\mathrm{L}_f & 0 & 0 & 1/\mathrm{L}_f \\ 0 & 0 & 0 & -\mathrm{R}_l/\mathrm{L}_l & 0 & 1/\mathrm{L}_l \\ 1/\mathrm{C}_d & -1/\mathrm{C}_d & 0 & 0 & 0 & 0 \\ 1/\mathrm{C}_f & 0 & -1/\mathrm{C}_f & -1/\mathrm{C}_f & 0 & 0 \end{bmatrix}$$

$$B_1 = \begin{bmatrix} 0 & 0 \\ V_{dc}/L_d & 0 \\ 0 & -V_{dc}/L_f \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \end{bmatrix}, B_2 = \begin{bmatrix} 1/(L_s + L_T) \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}, B_3 = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ -1/C_f \end{bmatrix}$$

The system represented by the state-space model in Figure 3. Contains feeder impedance, load impedance and compensator parameters. Since all these state variables defined in the equation (3) are not measurable, the state variables can be written as from Figure 2 as follows:

$$\left.\begin{aligned} i_s &= i_1 \\ i_l &= i_4 \\ i_f &= i_4 - i_1 \\ i_{cf} &= i_1 - i_3 - i_4 \\ i_{cd} &= i_2 - i_1 \end{aligned}\right\} \tag{4}$$

Here respective capacitors (C_f and C_d) charging currents are i_{cf} and i_{cd}. We can represent the network parameters of transformed state vector z as follows:

$$z = \begin{bmatrix} i_f \\ i_{cf} \\ v_l \\ i_{cd} \\ v_{sd} \\ i_l \end{bmatrix} = \begin{bmatrix} -1 & 0 & 0 & 1 & 0 & 0 \\ 1 & 0 & -1 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ -1 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 & 1 \end{bmatrix} x = Px \tag{5}$$

The state-space equation (1) is transformed by using (5) as,

$$\begin{aligned} \dot{z} &= PAP^{-1}z + PB_1u + PB_2v_s + PB_3i_h \\ &= \Lambda z + \Gamma_1 u + \Gamma_2 v_s + \Gamma_3 i_h \end{aligned} \tag{6}$$

Taking as granted that full control over u, the control input is written as:

$$u = -K(z - z_{\text{ref}}) \tag{7}$$

Here the desired state is a vector (z_{ref}) and by using LQR method we can easily calculate feedback gain matrix is K. Proper choice of the reference for the transformed z (i.e., z_{ref}) has to be made for satisfactory working of state feedback controller

The reference vector is computed as $Z_{\text{ref}}^{\Gamma} = \left[i_f^{\text{ref}} \quad i_{cf}^{\text{ref}} \quad v_l^{\text{ref}} \quad i_{cd}^{\text{ref}} \quad v_{sd}^{\text{ref}} \quad i_l^{\text{ref}} \right]$, Γ where represents the transpose of the matrix. The reference quantities generation is explained in detailed in the next part.

4. GENERATION OF REFERENCE QUANTITIES AND CONTROL OF SWITCHING

The half cycle averaging of voltage and current waveforms is based on producing of proper reference quantities for UPQC. The conditions for generation of reference voltage and current quantities are described below. With the help of instantaneous symmetrical component theory, the sinusoidal steady state quantities are obtained here. Under the condition of the source voltages and load currents to be unbalanced, then the reference quantities are written in below equations (8).

$$\left.\begin{aligned}
&\mathrm{I}_{fabc}^{\mathrm{ref}} = \begin{bmatrix} \mathrm{I}_{fa}^{\mathrm{ref}} \\ \mathrm{I}_{fb}^{\mathrm{ref}} \\ \mathrm{I}_{fc}^{\mathrm{ref}} \end{bmatrix} = \mathrm{M}^{-1} \begin{bmatrix} \mathrm{I}_{f0}^{\mathrm{ref}} \\ \mathrm{I}_{f1}^{\mathrm{ref}} \\ \mathrm{I}_{f2}^{\mathrm{ref}} \end{bmatrix} = \begin{bmatrix} \mathrm{I}_{l0} \\ \dfrac{\beta |q_{lav}|}{|\mathrm{V}_{l1}|} \\ \mathrm{I}_{l2} \end{bmatrix} \\
&\mathrm{I}_{s}^{\mathrm{ref}} = \mathrm{I}_{l1} - \mathrm{I}_{f1}^{\mathrm{ref}} \\
&\mathrm{I}_{s}^{\mathrm{ref}} = \mathrm{I}_{l1} - \mathrm{I}_{f1}^{\mathrm{ref}} \\
&\mathrm{V}_{sdabc}^{\mathrm{ref}} = \begin{bmatrix} \mathrm{V}_{sda}^{\mathrm{ref}} \\ \mathrm{V}_{sdb}^{\mathrm{ref}} \\ \mathrm{V}_{sdc}^{\mathrm{ref}} \end{bmatrix} = \mathrm{M}^{-1} \begin{bmatrix} \mathrm{V}_{sd0}^{\mathrm{ref}} \\ \mathrm{V}_{sd1}^{\mathrm{ref}} \\ \mathrm{V}_{sd2}^{\mathrm{ref}} \end{bmatrix} = \mathrm{M}^{-1} \begin{bmatrix} -\mathrm{V}_{t0} \\ \mathrm{V}_{d1}^{\mathrm{ref}} + \omega \mathrm{L_T} \mathrm{I}_{s}^{\mathrm{ref}} e^{j90^0} \\ -\mathrm{V}_{t2} \end{bmatrix} \\
&\mathrm{I}_{cf}^{\mathrm{ref}} = \omega \mathrm{C}_f \mathrm{V}_l^{\mathrm{ref}} e^{j90^0} \\
&\mathrm{I}_{cd}^{\mathrm{ref}} = \omega \mathrm{C}_d \mathrm{V}_{sd}^{\mathrm{ref}} e^{j90^0}
\end{aligned}\right\} \tag{8}$$

$$\mathrm{M} = \frac{1}{\sqrt{3}} \begin{bmatrix} 1 & 1 & 1 \\ 1 & e^{j240^0} & e^{j120^0} \\ 1 & e^{j120^0} & e^{j240^0} \end{bmatrix}$$

Reference quantities obtained above are in phasor domain. These are then converted into instantaneous domain with respect to zero crossing of phase-a reference voltage phasor. These are tracked using the state feedback law of (7). Both terminal voltage and load currents of UPQC contains the fundamental harmonic components, whenever the source voltages and load currents are unbalanced and distorted. So, the current and voltages of load can be rewritten as,

$$i_l = i_l^{\mathrm{fund}} + i_l^{\mathrm{har}};\ v_l = v_l^{\mathrm{fund}} + v_l^{\mathrm{har}} \tag{9}$$

Here the fundamental and harmonic components are shown by *fund* and *har* subscripts respectively. The harmonics exist in the he load currents can be damped by the shunt filter, by this we write:

$$i_f^{\mathrm{ref}} = i_f^{\mathrm{fund}} + i_l^{\mathrm{har}} \tag{10}$$

where, i_f^{fund} is obtained from (10)

Same manner, v_{sd}(reference) is given by

$$v_{sd}^{\mathrm{ref}} = v_{sd}^{\mathrm{fund}} - v_t^{\mathrm{har}} \tag{11}$$

where, v_{sd}^{ref} is generated using (11)

Measuring, i_f, i_{cf}, v_l, i_{cd}, v_{sd}, i_l quantities are used to derive the actual vector z in the system. The control gain (K) is selected on such a way that of the control signal (u) after obtaining the reference and actual vectors. Figure 4 show and explains this criteria.

Right after completion of the initial transient, the control is dependent only on feedback controller sign and the response of the feedback controller vary to the extent bounded up to which power electronics devices frequency of highest switching. In order to stop this from happening we apply hysteresis switching logic i.e.:

$$\left.\begin{array}{r}(u_{c1} \quad u_{c2})^{\mathrm{T}} = u_c = -\mathrm{K}\{z - z_{\mathrm{ref}}\} \\ (u_1 \quad u_2)^{\mathrm{T}} = u = \mathrm{hys}\{z - z_{\mathrm{ref}}\}\end{array}\right\} \tag{12}$$

If $h > \lim$ then $\mathrm{hsy}(h) = -1$

(in case of phase-a series inverter $\bar{s}_{a1} = 1$ and $\bar{s}_{a2} = 1$)

If $h < \lim$ then $\mathrm{hsy}(h) = 1$

(in case of phase-a series inverter $s_{a1} = 1$ and $s_{a2} = 1$)

In this the "*hys*" function is defined for a small limit (lim) around zero and $h = \mathrm{K}(z - z_{\mathrm{ref}})$.

From [6] *upqc* topology depicts the switching command s_{a1}, $\bar{s}_{a1}$, s_{a2} and $\bar{s}_{a2}$. The switching signal $\bar{s}_{a1}$ is the complementary signal to s_{a1} and the same condition applies for other switches in other legs respectively. Similarly, for other phases in the series and shunt inverter, the switching logic has been retrieved. The switching functions u_1 and u_2 are retrieved by (12) after computation of u_{c1} and u_{c2}.

5. FEEDBACK CONTROLLER DEPENDENT ON LQR AND ITS DRAWBACKS

In this LQR method, for finding the feedback gain K, a performance index J is selected as follows:

$$\mathrm{J} = \int_0^{\infty} \{(\mathrm{Z} - \mathrm{Z}_{\mathrm{ref}})^{\Gamma} \mathrm{Q}(\mathrm{Z} - \mathrm{Z}_{\mathrm{ref}}) + u_c^{\Gamma} \mathrm{R} u_c\}\, dt \tag{13}$$

Where Q and R are the state vector and input vector weighing matrices respectively. The weighing matrices Q and R are positive semi-definite respectively. Q and R weighing matrices set relative weights of state deviation and input usage respectively. Minimization of the performance index (J) is done in order to retrieve the optimal control law by calculating ARE i.e. Algebraic Riccati Equation[6].

For both the series and shunt are given good importance in the input weighing matrix. The obtained feedback gain is given by:

$$\mathrm{K} = \begin{bmatrix} 7.339 & 4.8205 & 11.8275 & 0 & 0 & 0 \\ 0 & 0 & 0 & 3.3888 & 11.6077 & 0 \end{bmatrix}$$

The impedance values of feeder and the load are not rooted quantities, they may tend to change accordingly, the load impedances changes from every now and then. The explanation of PSO technique is done in the following parts below.

6. TWO AREA CONTROL

In multi area power system, the primary objectives of the LFC are to keep the system frequency at nominal value, to provide load sharing between generators proportionately and to maintain the tie line power exchange at schedule value. For disturbances occurred in an inter power exchanged two areas control system, will be met by frequency reduction and increased tie line power generation in all the areas associated. Area control error (ACE) of each area should be maintained zero for stable operation of inter-connected systems. The ACE is the summation of the frequency and tie line error, i.e. $\mathrm{ACE} = \Delta f + \Delta \mathrm{P}_{tie}$

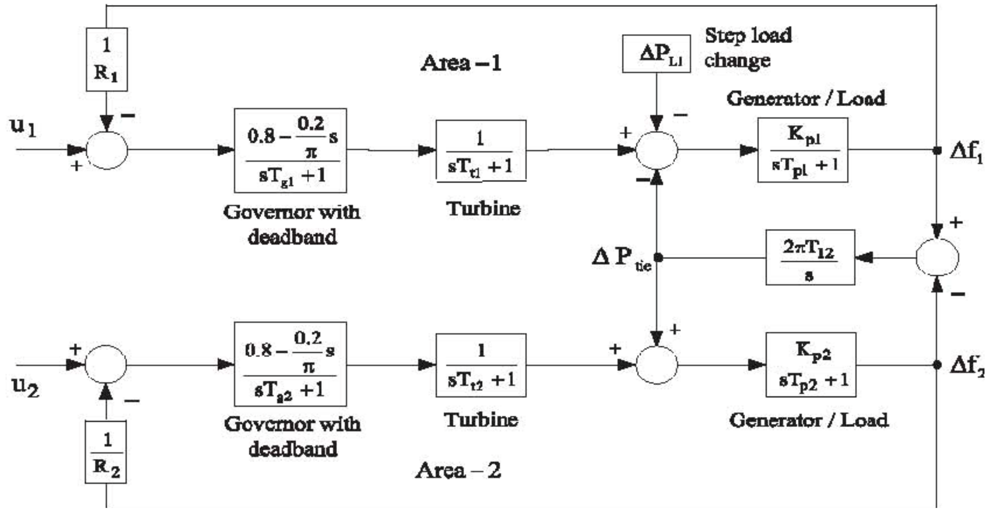


Figure 3: Transfer function model of two area interconnected power system with governor dead band

7. PSO-DEPENDENT ON UPQC FEEDBACK CONTROLLER

Modelling the UPQC-state feedback controller, PSO methodology is described. For the multi area LFC system, the population size is chosen as 40 and the maximum no of iterations for optimization are 40. Best value of constriction factors c_1 and c_2 are taken as $c_1 = c_2 = 1.5$ and $\omega_{max} = 0.95$ and $\omega_{min} = 0.45$. The simulation is realized in case of step load change, $\Delta P_L = 0.2$ pu MW in area-1, occurring at $t = 1$ sec and the frequency change in area-1, area-2 and tie-line power change is observed. Fitness function plot shown in Figure 4, show the convergence characteristic of the proposed method. Fitness function plot indicates that the proposed algorithm requires around 30 iterations to converge. No significant change of the objective function values are observed after 30 iterations.

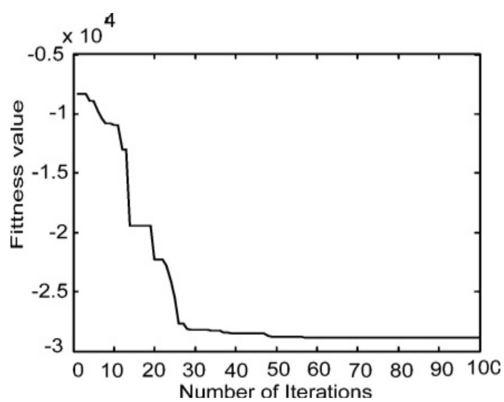


Figure 4: Fitness plot

Linear inertia weight (χ) in decremental form is taken for the PSO based feedback controller, initiating at 0.9 and closing at 0.4. The cognitive and social inertia constant (C_1, C_2) are considered as 1.49. Here 50 particles and 100 iterations are taken in order to perform PSO method. The values of the proposed UPQC system are considered from [6]. After finding the two best values (i.e. local and global respectively), the particle updates its velocity and positions with following equation.

$$V_i^{n+1} = \omega V_i^n + c_1 r_1 (P_i^n - X_i^n) + c_2 r_2 (G_i^n - X_i^n) \quad (14)$$

$$X_i^{n+1} = X_i^n + V_i^{n+1} \quad (15)$$

By using above (14) and (15), the feedback gains are found and are given by

$$K = \begin{bmatrix} 13.6759 & 6.5009 & 20 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1.5219 & 14.0233 & 0 \end{bmatrix}$$

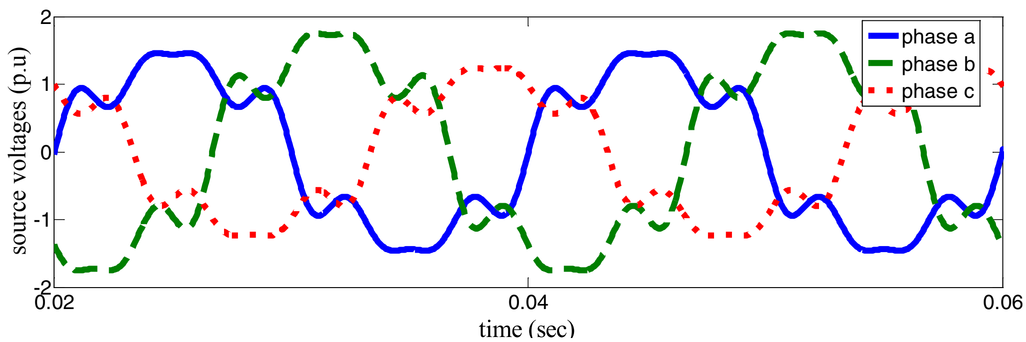
It is seen that on moving the critical eigenvalue towards left, its value is 3 times that of value achieved by the normal LQR. So, that we obtain more stability.

8. SIMULATION RESULTS

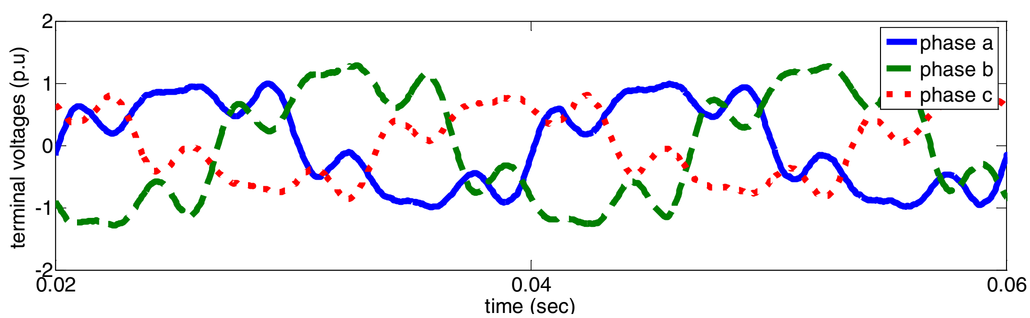
For the state feedback controller of the UPQC, their system parameters are similar to-referring from [6]. Here, conjunctionally a three-phase rectifier load taking 0.5 p.u as output current along with R-L load is considered. An assumption is included that *dc* capacitor C_{dc} voltage is unvaried as only stable state is taken in to picture. Control algorithm's working effectiveness is displayed by considering the case of parameters in the following section.

A simulation results of PSO based state feedback UPQC with Load and Feeder Impedances:

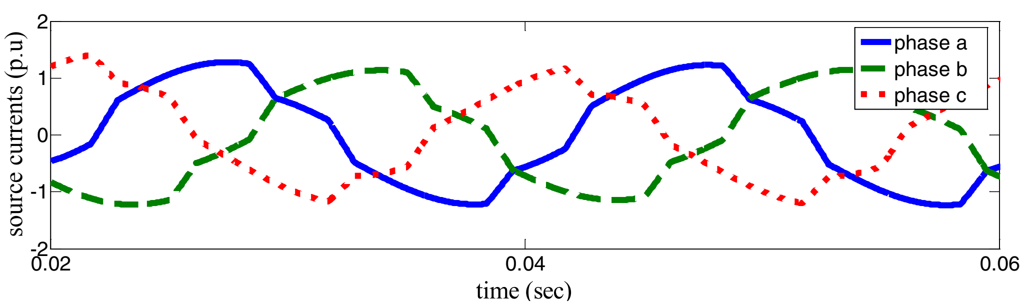
Remembering that in all Figures, phase a is displayed by the solid line, phase *b* is shown by the dashed line, and phase *c* is shown by the dotted line.



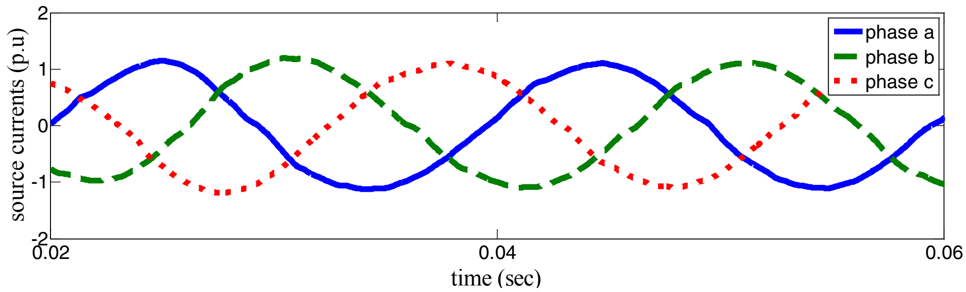
(a)



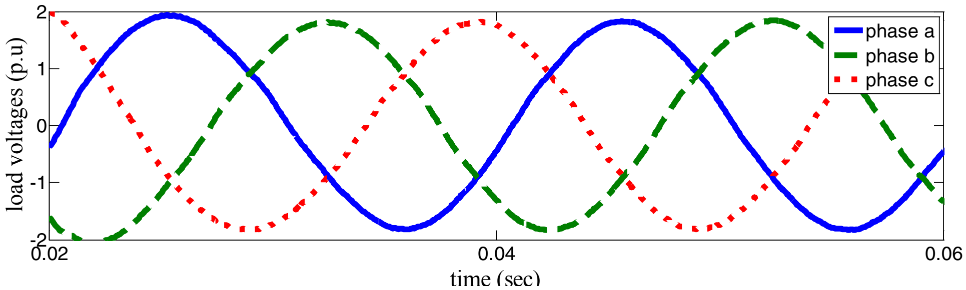
(b)



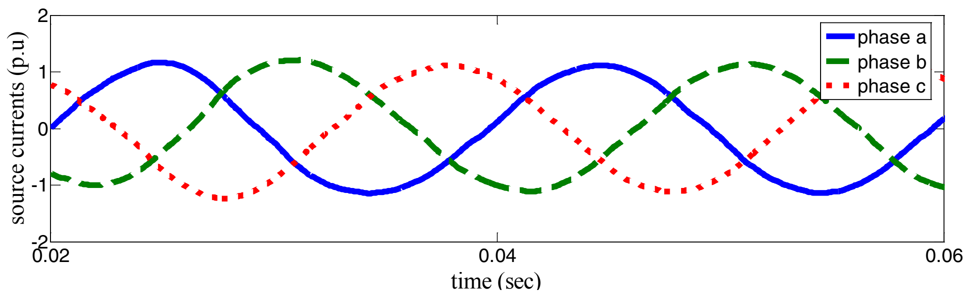
(c)


source currents (p.u)
time (sec)
phase a
phase b
phase c
2
1
0
-1
-2
0.02
0.04
0.06

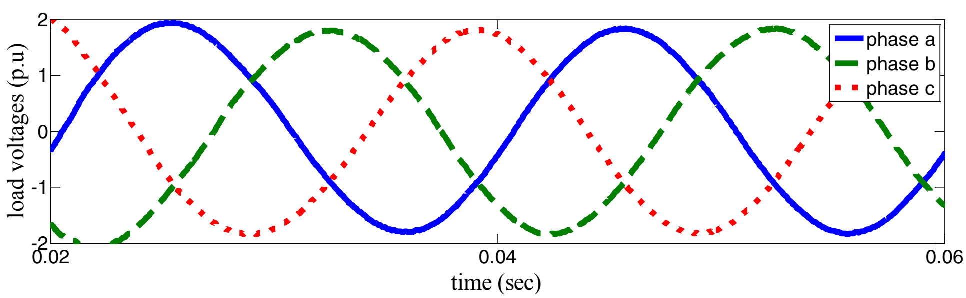
(d)


load voltages (p.u)
time (sec)
phase a
phase b
phase c
2
1
0
-1
-2
0.02
0.04
0.06

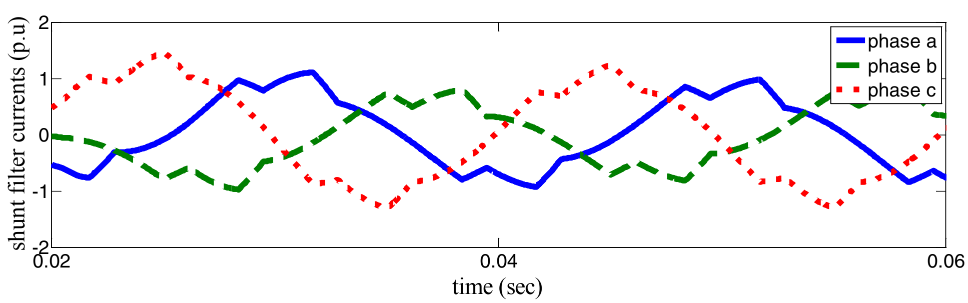
(e)


source currents (p.u)
time (sec)
phase a
phase b
phase c
2
1
0
-1
-2
0.02
0.04
0.06

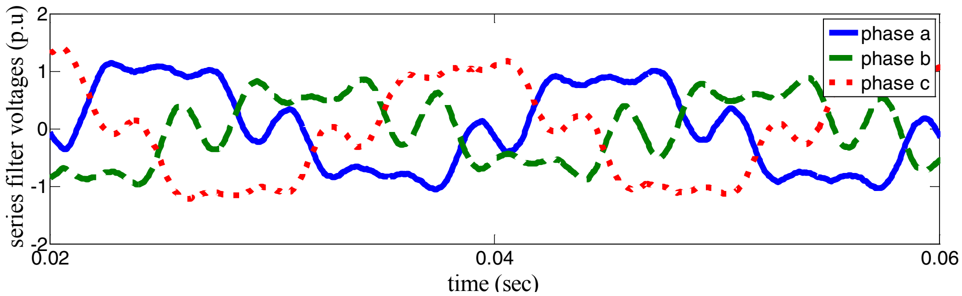
(f)


load voltages (p.u)
time (sec)
phase a
phase b
phase c
2
1
0
-1
-2
0.02
0.04
0.06

(g)


shunt filter currents (p.u)
time (sec)
phase a
phase b
phase c
2
1
0
-1
-2
0.02
0.04
0.06

(h)



(i)

Figure 6: The results of UPQC with PSO state feedback (a) Supply voltages. (b) Terminal voltages without UPQC. (c) Source currents without UPQC. (d) LQR based Compensated source currents (e) Compensated Load voltages with LQR. (f) PSO based Compensated source currents. (g) PSO based Compensated Load voltages. (h) Shunt filter currents. (i) Series filter voltages. The harmonic content in the source current and load voltages is shown in Table 1 and 2 respectively.

Table 1
Source current THDs comparison of LQR and PSO techniques

THD %	*Without compensation*	*Ordinary LQR*	*With PSO*
I_{sa}	9.70	2.8	1.5
I_{sb}	10.0	2.9	1.6
I_{sc}	11.1	2.6	1.69

Table 2
Load voltage THDs comparison of LQR and PSO techniques

THD %	*Without compensation*	*Ordinary LQR*	*With PSO*
V_{ta}	3.4	1.2	0.5
V_{tb}	3.6	1.3	0.7
V_{tc}	3.3	1. 9	0.5

9. CONCLUSION

The PSO and the LQR methods are used for the designing of the UPQC-state feedback controller. Since, LQR requires provisional test method for selecting the values like **Q** and **R,** the PSO-state feed-back controller is considered as more advantageous than LQR. Sub-optimal performance is lacking in PSO-based feed-back controller in the case of partial state feedback. When compared to the state feed-back controller modelled by the LQR, from the simulation results, we can conclude that by modelling a controller for the state feedback with the help of a PSO we tend to achieve a better outcomes like decreased values of source currents and load voltages THD's. Thus the effectiveness in numerous working situations is considered for verifying the strength of the feedback controller dependent on PSO. From these observations it can be concluded that under all the operating conditions proposed PSO dependent controller outperformed the LQR dependent feedback controller.

REFERENCES

[1] N.G. Hingorani, "Introducing Custom Power", IEEE Spectrum. Vol. 32. pp. 41-48.95.

[2] F.Z. Peng and J. S. Lai, "Generalized instantaneous reactive power theory for three-phase power systems," IEEE Trans. Instrum. Meas., Vol. 45, No. 1, pp. 293–297, Feb. 1996.

[3] A. Ghosh and G. Ledwich, "A unified power quality conditioner (UPQC) for simultaneous voltage and current compensation," *Elect.Power Syst. Res.*, Vol. 59, No. 1, pp. 55–63, Aug. 2001.

[4] H. Fujita and H. Akagi, “The unified power quality conditioner: The integration of series active filters and shunt active filters,” *IEEE Trans.Power Electron.*, Vol. 13, No. 2, pp. 315–322, Mar. 1998.

[5] A. Ghosh and A. Joshi, “A new approach to load balancing and power factor correction in power distribution system,” IEEE Trans. Power Del., Vol. 15, No. 1, pp. 417–422, Jan. 2000

[6] K. Srinivas Bhaskar, Mahesh K. Mishra, and B. Kalyan Kumar, “Particle Swarm Optimization based feedback controller design of Unified Power Quality conditioner(UPQC),”IEE Transaction on Power Delivery, Vol. 25, No. 4, pp. 2814-2824, Oct. 2010.

[7] Y. Rong, C. Li, H. Tang, and X. Zheng, “Output feedback control of single-phase UPQC based on novel model,” *IEEE Trans. Power Del.*, Vol. 24, No. 3, pp. 1586–1597, Jul. 2009.