Power & Energy Society™

The Institute of Electrical and Electronics Engineers, Inc.
Power & Energy Society

POWERCON

&

2008 IEEE POWER INDIA CONFERENCE

Schedule of Program

October 12 - 15, 2008

InterContinental The Grand, New Delhi, India

URL: http://ewh.ieee.org/r10/delhi/powercon.htm

Email: pesdelhi@ieee.org

کتابچه خلاصه مقالات در برنامه زمانبندی کنفرانس

0153-Development of insulation structures for thyristor valves for use on 800kV HVDC transmission schemes	J. Sturgess, A. Baker and F. Perrot, AREVA T&D Technology Centre, St Leonards Avenue, Stafford, ST17 4LX, United Kingdom, and N. M. MacLeod, AREVA T&D Power Electronics, St Leonards Avenue, Stafford, ST17 4LX, United Kingdom	03/04
0156-Load Frequency Control of Multi-Area Restructured Power System	E. Rakshani, Department of Electrical Engineering, Ferdowsi University of Mashhad, Iran, and J. Sadeh, Islamic Azad University, Gonabad Branch,Gonabad, Iran	05/08
0160-Variable Frequency Transformers for Increased Wind Penetration	V. Jayashankar, and T.Geetha, Indian Institute of Technology, Madras	10/10
0161-Stability Assessment of Power System Models For Higher Wind Penetration	V. Jayashankar, and T.Geetha, Indian Institute of Technology, Madras	02/04
0163-Design of Genetic Algorithm Based Fuzzy Logic Power System Stabilizers in Multimachine Power System	Manisha Dubey, Maulana Azad National Institute of Technology, Bhopal, 462 051 India	02/05
0166-Minimizing the Impact of Transients of Capacitive Voltage Transformers on Distance Relay	F. Badrkhani Ajaei, and M. Sanaye-Pasand, School of Electrical and Computer Engineering, college of Engineering, University of Tehran, Tehran,	07/07
0169-Real Time GPS Data Processing for 'Sag Measurement' on a Transmission Line	Uma maheshwar Singareddy, Department of Electrical & Computer Engineering, Tennessee Technological University, Cookeville, TN 38501, and Satish Mahajan, Department of Electrical & Computer Engineering Tennessee Technological University, Cookeville, TN 38501	06/05
0170-Pricing of System Security with Voltage Stability Constraint	M. De, Jadavpur University, Kolkata, India	04/08

Load Frequency Control of Multi-Area Restructured Power System

E. Rakhshani, and J. Sadeh

Abstract--**This paper presents the design of a linear quadratic regulator for load frequency control problem in a restructured competitive electricity market with a pragmatic viewpoint. In the practical environment, access to all of the state variables of system is limited and measuring all of them is also impossible. To solve this problem, in this paper the optimal output feedback regulator is proposed. In the output feedback method, only the measurable state variables within each control area are required to use for feedback. The performance of the proposed method is studied on a two-area power system considering different contracted scenarios. The results of the proposed controller are compared with the full-state feedback and state observer methods. The results are shown that when the power demands change, the output feedback method have a good ability to track of contracted and/or non-contracted demands.**

Index Terms-- **Deregulated power system, load frequency control, optimal output feedback, state observer control**

I. Introduction

ANALYSIS of the power system markets shows that the frequency control is one of the most profitable ancillary services at these systems. Major changes have been introduced into the structure of electric power utilities all over the world.

The main goal of the load frequency control (LFC) of a power system is to maintain the frequency of each area and tie-line power flow (in interconnected system) within specified tolerance by adjusting the MW outputs of the generators so as to accommodate fluctuating load demands. With the restructuring of electric markets, Load-Frequency Control requirements should be expanded to include the planning functions necessary to insure the resources needed for LFC implementation are within the functional requirements. So all of the methods that may be proposed must be having a good ability to track of contracted or non-contracted demands and can be used in a practical environment.

E. Rakhshani is with the Islamic Azad University, Gonabad Branch, Iran. (e-mail: elias.rakhshani@gmail.com).

J. Sadeh is with the Department of Electrical Engineering, Ferdowsi University of Mashhad, Iran and Islamic Azad University, Gonabad Branch, Iran. Fax: (98) 511 8763302, (e-mail: sadeh@um.ac.ir).

978-1-4244-1762-9/08/$25.00 ©2008 IEEE

A lot of studies have been made about LFC in a deregulated environment over the last decades. These studies try to modify the conventional LFC system to take into account the effect of bilateral contracts on the dynamics [1]-[3] and improve the dynamical transient response of system under competitive conditions [4]-[7].The conventional control strategy for the LFC problem is to take the integral of the ACE as the control signal. An integral controller provides zero steady state deviation, but it exhibits poor dynamic performance. To improve the transient response, various control strategies, such as linear feedback, optimal control and Kalman estimator method, have been proposed [4], [5]. However, these methods are idealistic or need some information of the system states, which are very difficult to know completely.

There have been continuing efforts in designing LFC with better performance using intelligence algorithms or robust methods [6]–[7]. The proposed methods show good dynamical responses, but some of them suggest complex and or high order dynamical controllers [7], which are not practical for industry practices yet.

In this paper, the dynamical response of the load-frequency control problem in the deregulated environment is improved with a pragmatic viewpoint. Because in the practical environment (real world), access to all of the state variables of system is limited and the measuring all of them is impossible. So some of these states must be estimated or neglected. To solve this problem, in this paper an optimal output feedback control is proposed. In the output feedback method, un-measurable states are neglected, so only the measurable state variables within each control area are required to use for feedback. The proposed method is tested on a two-area power system with different contracted scenarios. The results of the proposed controller are compared with the optimal full-state feedback and state observer methods. The results are shown that when the power demands changed, the output feedback method is so rational technique with so good track of contracted and/or non-contracted demands.

II. Deregulated Power System for LFC with Two Areas

In the competitive environment of power system, the vertically integrated utility (VIU) no longer exists. Deregulated system will consist of GENCOs, DISCOs, transmission companies (TRANSCOs) and independent system operator (ISO). However, the common AGC goals, i.e. restoring the frequency and the net interchanges to their desired values for each control area, still remain. The power system is assumed to contain two areas and each area includes two GENCOs and also two DISCOs as shown in Fig. 1 and the block diagram of the generalized LFC scheme for a two area deregulated power system is shown in Fig. 2. A DISCO can contract individually with any GENCO for power and these transactions are made under the supervision of ISO.

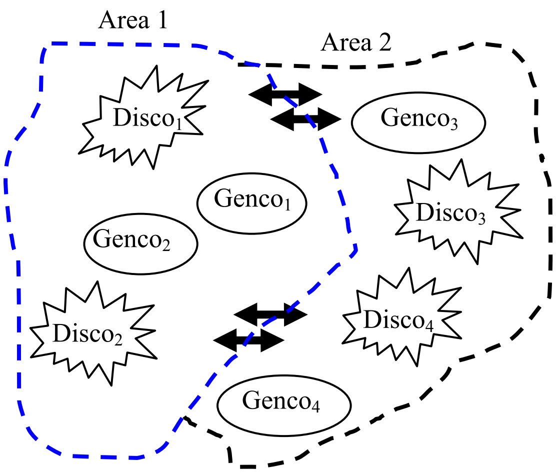


Fig. 1. Configuration of the power system.

To make the visualization of contracts easier, the concept of a "DISCO participation matrix" (DPM) will be used [2]; Essentially, DPM gives the participation of a DISCO in contract with a GENCO. In DPM, the number of rows has to be equal to the number of GENCOs and the number of columns has to be equal to the number of DISCOs in the system. Any entry of this matrix is a fraction of total load power contracted by a DISCO toward a GENCO. As a result, total of entries of column belong to DISCO_j of DPM is $\sum_i cpf_{ij} = 1$. The corresponding DPM for the considered power system having two areas and each of them including two DISCOs and two GENCOs is given as follows:

$$
\text{DPM} = \begin{array}{c} \\ 1 \\ 2 \\ 3 \\ 4 \end{array}
\begin{array}{c} \begin{array}{cccc} 1 & 2 & 3 & 4 \end{array} \\
\left[\begin{array}{cc:cc} cpf_{11} & cpf_{12} & cpf_{13} & cpf_{14} \\ cpf_{21} & cpf_{22} & cpf_{23} & cpf_{24} \\ \hdashline cpf_{31} & cpf_{32} & cpf_{33} & cpf_{34} \\ cpf_{41} & cpf_{42} & cpf_{43} & cpf_{44} \end{array}\right] \end{array}
\begin{array}{c} \text{DISCO} \\ \text{G} \\ \text{E N} \\ \text{C} \\ \text{O} \end{array}
$$

where *cpf* represents ''contract participation factor'' and is like signals, that carry information as to which GENCO has to follow load demanded by which DISCO.

The actual and scheduled steady state power flows on the tie line are given as:

$$\Delta P_{tie\,1-2,scheduled} = \sum_{i=1}^{2}\sum_{j=3}^{4} cpf_{ij}\Delta P_{Lj} - \sum_{i=3}^{4}\sum_{j=1}^{2} cpf_{ij}\Delta P_{Lj} \tag{1}$$

$$\Delta P_{tie\,1-2,actual} = (2\pi.T_{12}/s).(\Delta f_1 - \Delta f_2) \tag{2}$$

In equation (2), T_{12} is the tie-line synchronizing coefficient between two areas and at any given time, the tie line power error ($\Delta P_{tie1-2,error}$) is defined as:

$$\Delta P_{tie1-2,error} = \Delta P_{tie1-2,actual} - \Delta P_{tie1-2,scheduled} \tag{3}$$

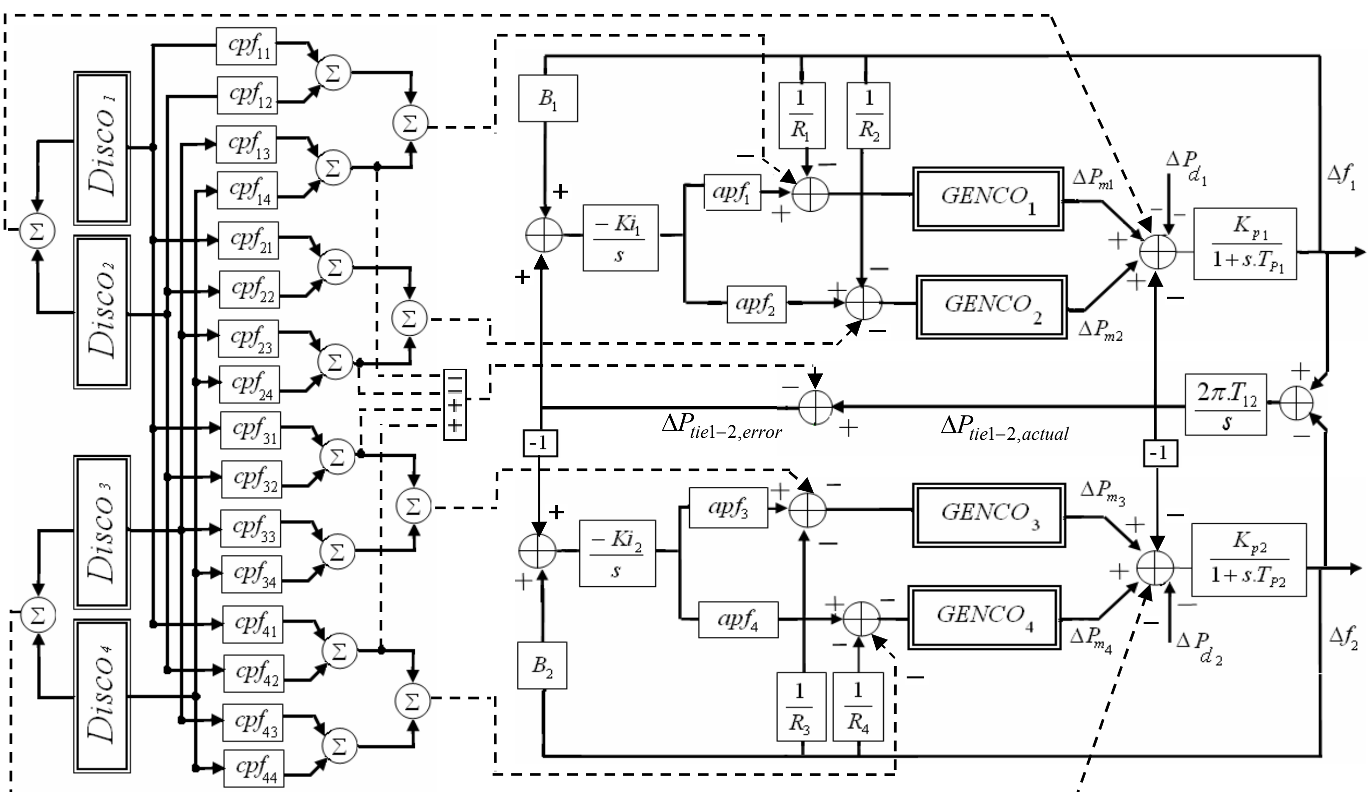


Fig. 2. Modified LFC system in a deregulated environment.

This error signal is used to generate the respective Area Control Error or ACE signals as in the traditional scenario [2]:

$$ACE_1 = B_1\Delta f_1 + \Delta P_{tie1-2,error} \tag{4}$$

$$ACE_2 = B_2\Delta f_2 + \Delta P_{tie2-1,error} \tag{5}$$

where B_1, B_2 are the frequency bias of areas1 and 2, respectively. The closed loop system in Figs. 2, 3 is characterized in state space form as:

$$\dot{x} = A\ .x + B\ .u \tag{6}$$

$$y = C\ .x \tag{7}$$

A fully controllable and observable dynamic model for a two-area power system is proposed, where x is the state vector and u is the vector of power demands of the DISCOs.

$$u = [\Delta P_{L1} \quad \Delta P_{L2} \quad \Delta P_{L3} \quad \Delta P_{L4} \quad \Delta P_{d1} \quad \Delta P_{d2}]^T$$

$$x = [\Delta f_1 \quad \Delta f_2 \quad \Delta P_{m1} \quad \Delta P_{m2} \quad \Delta P_{m3} \quad \Delta P_{m4} \quad \int ACE_1 \quad \int ACE_2 \quad \Delta P_{tie1-2,actual}]^T$$

where ΔP_L is contracted demand of DISCOs and ΔP_d is Un-contracted demand or area load disturbance and the deviation of frequency, turbine output and tie-line power flow within each control area are measurable outputs that can be used for output feedback.

The dashed lines in Fig. 2 show the demand signals based on the possible contracts between GENCOs and DISCOs that carry information as to which GENCO has to follow a load demanded by that DISCO. These new information signals were absent in the traditional LFC scheme. As there are many GENCOs in each area, the ACE signal has to be distributed among them due to their ACE participation factor in LFC and $\sum_j apf_{ij} = 1$. We can write:

$$d_n = \Delta P_{Loc,n} + \Delta P_{dn} \tag{8}$$

$$\Delta P_{Loc,n} = \sum_j \Delta P_{Lj} \tag{9}$$

$$\Delta P_{dn} = \sum_j \Delta P_{dj} \tag{10}$$

III. Controller Design

In this paper, to improve the dynamical response of system, optimal output feedback method is proposed, but the results are compared with full-order observer methods (senario1) and optimal full-state feedback (scenario 2, 3).

A. Optimal Output Feedback Control

For the system that is defined by equations (6) and (7), output feedback control law is:

$$u = -K.y \tag{11}$$

The objective of this regulator for the system may be attained by minimizing a performance index *(J)* of the type:

$$J = 1/2 \int [x^T(t).Q.x(t) + u^T(t).R.u(t)]dt \tag{12}$$

or

$$J = 1/2 \int x^T(Q + C^T K^T RKC)x\ dt \tag{13}$$

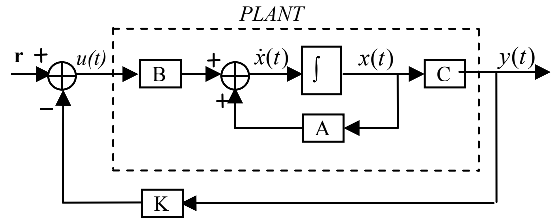


Fig. 3. Closed loop system with output feedback controller.

By substituting equation (11) into (6), the closed-loop system equation are found to be:

$$\dot{x} = (A - BKC)x = A_c.x \tag{14}$$

This dynamical optimization may be converted to an equivalent static one that is easier to solve as follows. So a constant, symmetric, positive-semidefinite matrix P can be defined, as:

$$d(x^T Px)/dt \ = -x^T(Q + C^T K^T RKC)x \tag{15}$$

$$J = 1/2\ .x^T(0)Px(0) - 1/2\ \lim_{t\to\infty} x^T(t)P.x(t) \tag{16}$$

Assuming that the closed-loop system is stable so that *x(t)* vanishes with time, this becomes:

$$J = 1/2\ .x^T(0)Px(0) \tag{17}$$

If P satisfies (15), then we may use (14) to see that:

$$\begin{aligned} -x^T(Q + C^T K^T RKC)x &= d(x^T Px)/dt = \dot{x}^T Px + x^T P\dot{x} \\ &= x^T(A_c^T P + PA_c)x \end{aligned} \tag{18}$$

$$g \equiv A_c^T P + PA_c + C^T K^T RKC + Q = 0 \tag{19}$$

We may write (17) as:

$$J = 1/2\ .tr(PX) \tag{20}$$

Where the $n \times n$ symmetric matrix X is defined as:

$$X = E\{x(0).x^T(0)\} \tag{21}$$

So the best K must be selected, to minimize (13) subject to the constraint (19) on the auxiliary matrix P. To solve this modified problem, Lagrange multiplier approach will be used and the constraint will be adjoined by defining this Hamiltonian:

$$H = tr(PX) + tr(gS) \tag{22}$$

Now to minimize (20), partial derivatives of H with respect to all the independent variables P, S and K must be equal to zero.

$$0 = \partial H/\partial S = A_c^T P + PA_c + C^T K^T RKC + Q \tag{23}$$

$$0 = \partial H/\partial P = A_c S + SA_c^T + X \tag{24}$$

$$0 = 1/2\ .(\partial H/\partial K) = RKCSC^T - B^T PSC^T \tag{25}$$

To obtain the output feedback gain K with minimizing the (12), these three coupled equations (23), (24) and (25) must be solved simultaneously. The first two of these are Lyapunov equations and the third is an equation for the gain K. If R is positive definite and is nonsingular, then (25) may be solved for K [8]:

$$K = R^{-1} B^T PSC^T (CSC^T)^{-1} \tag{26}$$

To solve these equations, an iterative algorithm is presented in Appendix A.

IV. Simulation Results

In this section, to illustrate the performance of the proposed control against loads variations, simulations are performed for three scenarios of possible contracts under market condition and large load demands. Simulations were performed to a two-area interconnected electrical power system using three different controllers: optimal full-state feedback, state observer control and optimal output feedback proposed control. The simulations are done using MATLAB platform and the power system parameters are given in Tables I and II (Appendix B).

A. Scenario 1: transaction based on inner contracts

In this scenario, GENCOs participate only in load following control of their areas. It is assumed that all of the ACE participation factors are the same as 0.5 and a large step load of 0.1 *pu* is demanded by $GENCO_1$ and $GENCO_2$ .This scenario is simulated based on the following DPM:

$$DPM = \begin{bmatrix} 0.5 & 0.5 & 0 & 0 \\ 0.5 & 0.5 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

In the steady state, any GENCO generation must match the demand of the DISCOs in contract with it, as expressed as follows:

$$\Delta P_{mi} = \sum_j cpf_{ij} \Delta P_{Lj} \tag{27}$$

So for this scenario, we have,

$$\Delta P_{m1} = 0.1 \ pu \ MW \quad , \quad \Delta P_{m2} = 0.1 \ pu \ MW$$

$$\Delta P_{m3} = 0 \ pu \ MW \quad , \quad \Delta P_{m4} = 0 \ pu \ MW$$

The results for this case are given in Figs. 4–6, respectively. As Fig. 4 shows, the actual generated powers of the GENCOs reach the desired values in the steady state.

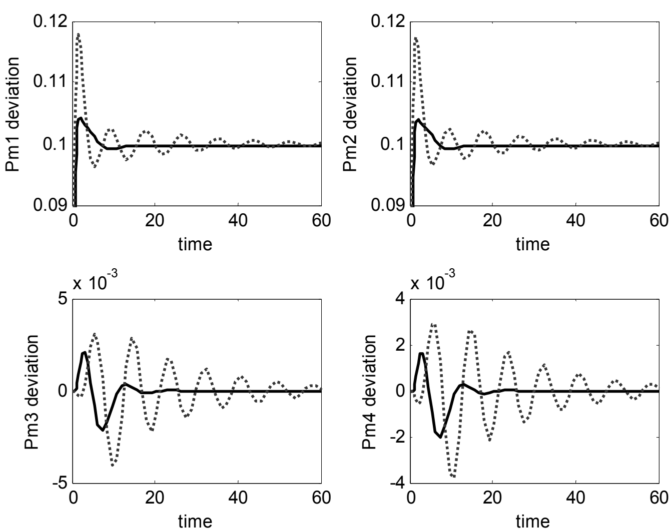


Fig. 4. GENCOs power change (pu MW): Solid (Optimal output feedback), Dotted (without controller).

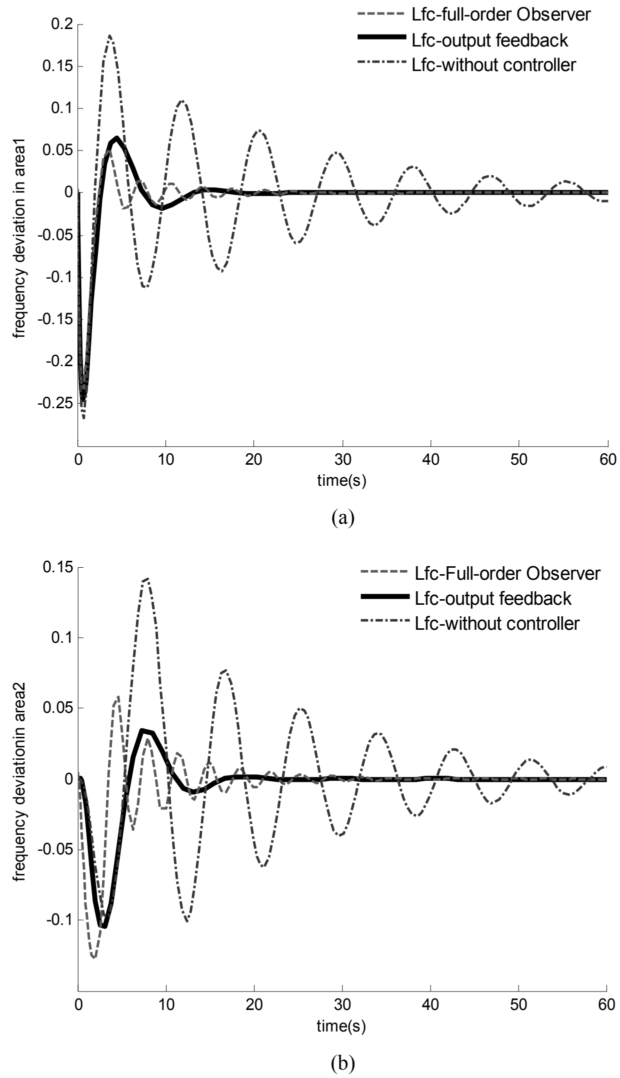


Fig. 5. (a) Frequency deviation in area 1 (rad/s), (b) Frequency deviation in area 2 (rad/s): Dashed (Full-order observer), Solid (Optimal output feedback), Dot-dashed (Without controller).

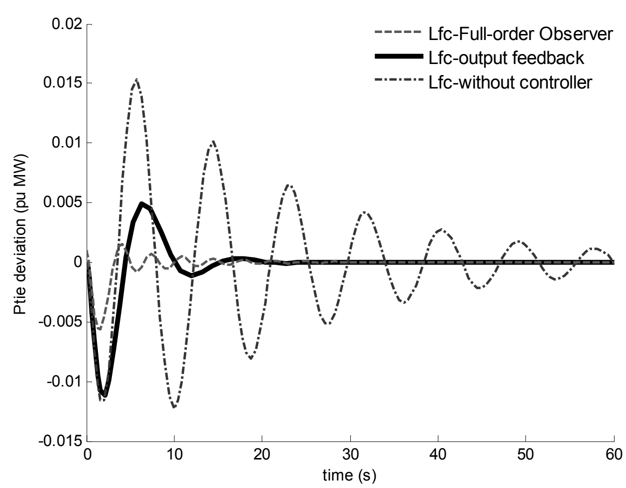


Fig. 6. Deviation of tie line power flow: Dashed (Full-order observer), Solid (Optimal output feedback), Dot-dashed (Without controller).

B. Scenario 2: transaction based on free contracts

In this scenario, DISCOs have the freedom to have a contract with any GENCO in their or other areas. So all the DISCOs contract with the GENCOs for power base on following DPM:

$$DPM = \begin{bmatrix} 0.5 & 0.25 & 0 & 0.3 \\ 0.2 & 0.25 & 0 & 0 \\ 0 & 0.25 & 1 & 0.7 \\ 0.3 & 0.25 & 0 & 0 \end{bmatrix}$$

It is considered that each DISCO demands 0.1 *pu MW* total power from GENCOs as defined by entries in *DPM* and each GENCO participates in ACE as defined by following *apf*s:

$$apf_1 = 0.75 \quad , \quad apf_2 = 1 - apf_1 = 0.25$$
$$apf_3 = 0.5 \quad , \quad apf_4 = 1 - apf_3 = 0.5$$

The simulation results for this case are given in Figs. 7–9. As shown in Fig. 7, the actual generated powers of the GENCOs properly reach their desired values in the steady state as given by equation (27). That is,

$$\Delta P_{m1} = 0.105 \quad pu \quad MW \quad , \quad \Delta P_{m2} = 0.045 \quad pu \quad MW$$
$$\Delta P_{m3} = 0.195 \quad pu \quad MW \quad , \quad \Delta P_{m4} = 0.055 \quad pu \quad MW$$

Using the proposed method, the frequency deviation of each area and the tie-line power have a good dynamic response in comparing with initial system without controller (Figs. 7, 8).

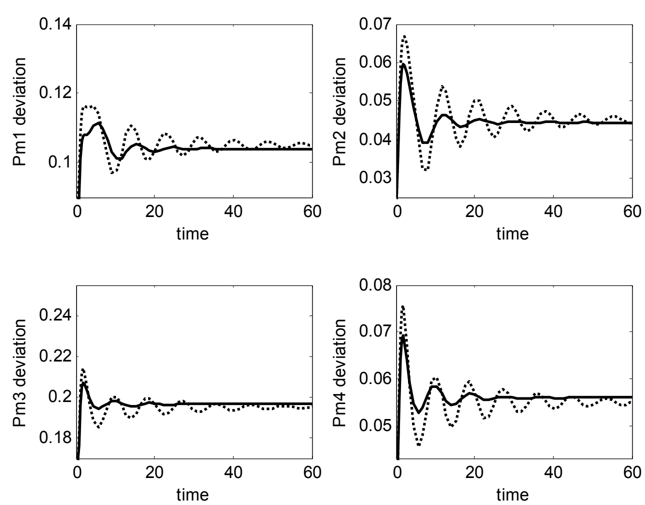
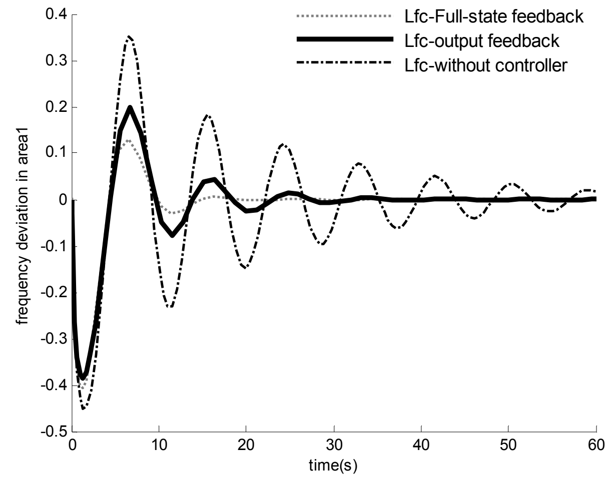
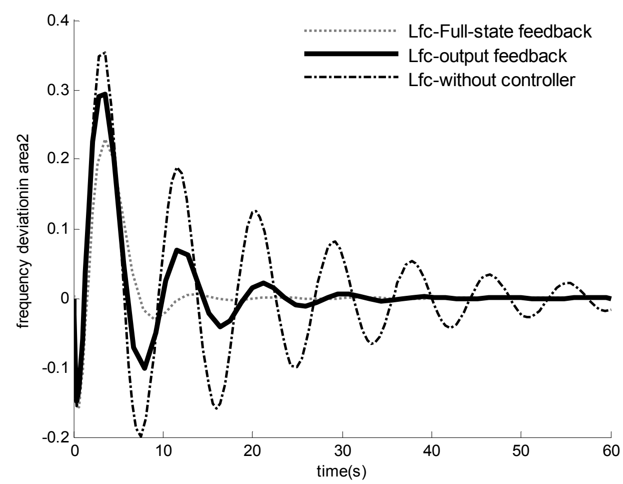


Fig. 7. GENCOs power change (pu MW): Solid (Optimal output feedback), Dotted (without controller).

The off diagonal blocks of the DPM correspond to the contract of a DISCO in one area with a GENCO in another area. As Fig. 9 shows, the tie-line power flow properly converges to the specified value of equation (1) in the steady state, i.e. $\Delta P_{tie1-2,scheduled} = -0.05 \quad pu$



(a)



(b)

Fig. 8. (a) Frequency deviation in area 1 (rad/s), (b) Frequency deviation in area 2 (rad/s): Dotted (Full-state feedback control), Solid (Optimal output feedback), Dot-dashed (Without controller).

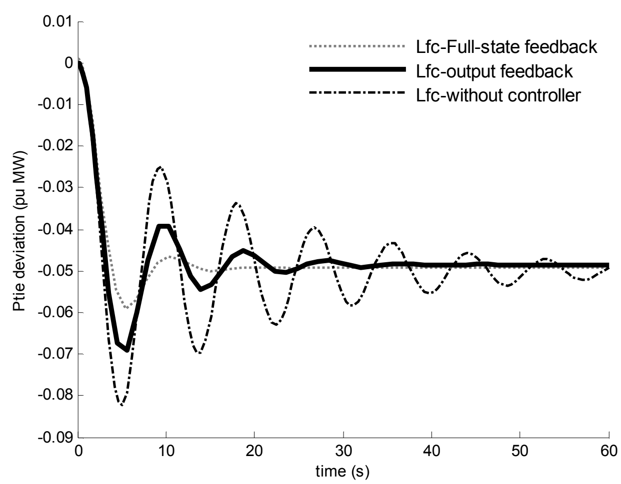


Fig. 9. Deviation of tie line power flow (pu MW): Dotted (Full-state feedback control), Solid (Optimal output feedback), Dot-dashed (Without controller).

C. Scenario 3: contract violation

In this case, DISCOs may violate a contract by demanding more or less power than that specified in the contract. This excess power is reflected as a local load of the area (un-contracted demand). In this section, it is assumed that in addition to the specified contracted load demands, $DISCO_1$ in area 1, demand 0.1 *pu MW* as large un-contracted loads. The *DPM* is the same as in scenario 2 and the un-contracted load in each area is taken up by the GENCOs in the same area and the tie-line powers should be the same as in scenario 2 in the steady state. The purpose of this scenario is to test the effectiveness of the proposed controller against uncertainties and large load disturbances ΔP_d. Using full-state feedback control dynamic response of system will improved so well, but base on these simulations (scenario 3) it is seen that this method have a weak ability to tracking un-contracted demands changes. The power system responses for this scenario are shown in Figs. 10–12.

The un-contracted load of $DISCO_1$, is taken up by the GENCOs of its area according to the ACE participation factors in the steady state. So for this scenario, the actual generated power of the GENCOs in the areas in the steady state must match the demand of the DISCOs as expressed as follows:

$$\Delta P_{mi} = \sum_j cpf_{ij} \Delta P_{Lj} + apf_i \ \Delta P_{dn} \qquad (28)$$

$$\Delta P_{dn} = \sum_j \Delta P_{dj} \qquad (29)$$

As shown in Fig. 10, using equations (28) and (29), the actual generated power of the GENCOs in the areas in the steady state is given by $\Delta P_{d1} = 0.1 \quad pu \quad , \quad n, j = 1$

And

$$\Delta P_{m1} = 0.105 + (0.75 \times 0.1) = 0.18 \quad puMW$$

$$\Delta P_{m2} = 0.045 + (0.25 \times 0.1) = 0.07 \quad puMW$$

$$\Delta P_{m3} = 0.195 \quad puMW \quad , \quad \Delta P_{m4} = 0.055 \quad puMW$$

The results of frequency deviations and tie line power flow are shown in Figs. 11-12, respectively. These figures also are comparing the performance of the full-state feedback control with the proposed controller.

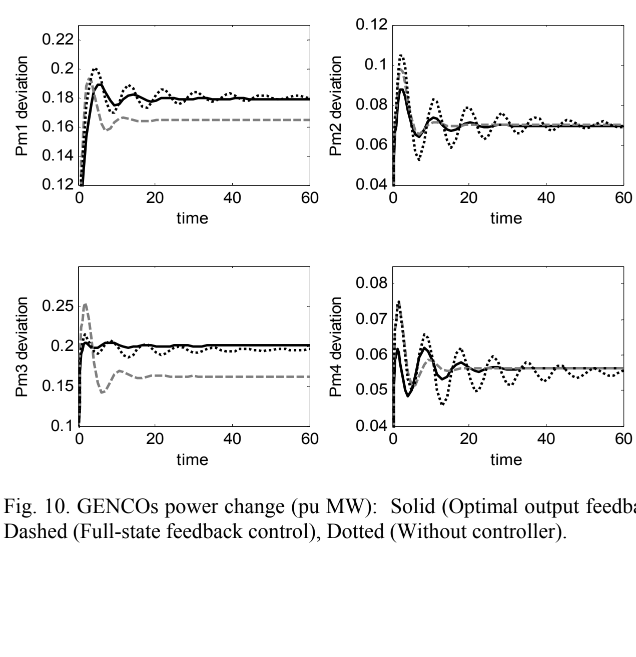


Fig. 10. GENCOs power change (pu MW): Solid (Optimal output feedback), Dashed (Full-state feedback control), Dotted (Without controller).

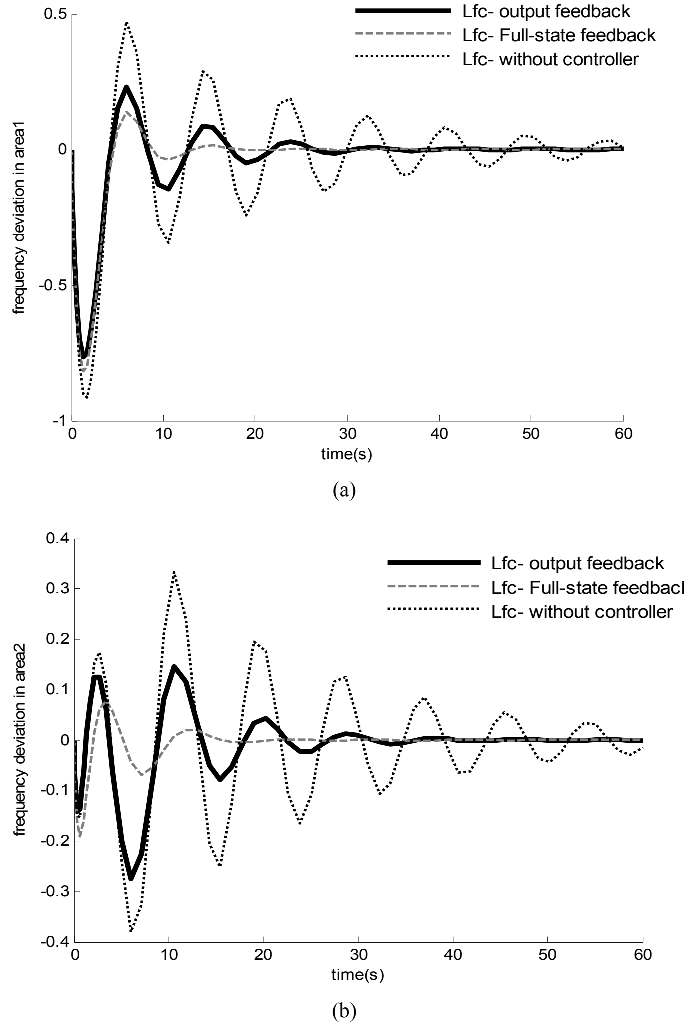


Fig. 11. (a) Frequency deviation in area1 (rad/s), (b) Frequency deviation in area 2 (rad/s): Solid (Optimal output feedback), Dashed (Full-state feedback control), Dotted (Without controller).

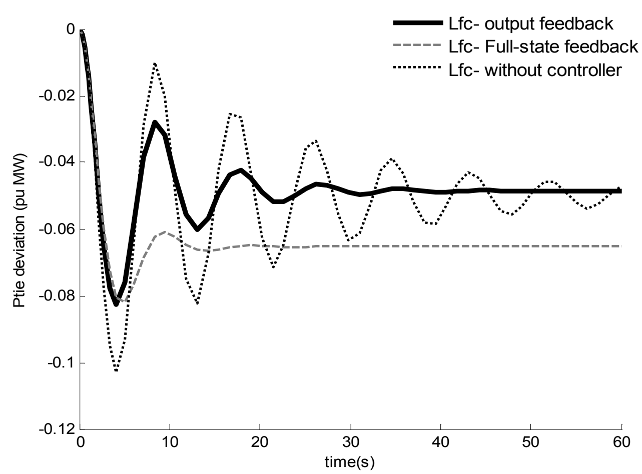


Fig. 12. Deviation of tie line power flow (pu MW): Solid (Optimal output feedback), Dashed (Full-state feedback control), Dotted (Without controller).

The simulation results shown that the proposed optimal output feedback controller track the un-contracted load changes and achieve good robust performance better than the full-state feedback controllers for a wide range of load disturbances (Figs. 10-12).

V. CONCLUSION

A new optimal controller for the AGC problem in deregulated power systems is proposed using the modified AGC scheme in this paper. This control strategy was chosen because of the practical viewpoints.

In research of LFC problem, a special attention should be given to the load frequency control requirements and ability of used controller in tracking of load changes under the market conditions and should be paid attention that some of the state variables are not accessible for measuring in a practical environment. Adding to this, when the system is subjected to wide changes in the operating conditions, computational effort needed, and the memory requirements. So with a pragmatic viewpoint, an optimal output feedback controller is presented to satisfy all of these requirements.

The proposed method is tested on a two-area power system considering different contracted scenarios. The results of the proposed controller are compared with the state feedback and state observer methods. The simulation results demonstrated the effectiveness of the proposed method for modified LFC in a multi-area competitive power system.

VI. APPENDIX

A. Used algorithm for solving optimal output feedback gain matrix [8]:

1. Initialize:
   set $k = 0$
   Determine a gain K_0 so that $A\text{-}BK_0C$ is asymptotically stable.
2. k-th iteration:
   Set $A_k = A\text{-}BK_k C$
   Solve for P_k and S_k in
   $$0 = A_k^T P_k + P_k A_k + C^T K_k^T R K_k C + Q$$
   $$0 = A_k S_k + S_k A_k^T + X$$
   Set $J_k = tr(P_k X)$
   Evaluate the gain update direction
   $$\Delta K = R^{-1} B^T P S C^T (C S C^T)^{-1} - K_k$$
   $$K_{k+1} = K_k + \alpha \Delta K$$
   Where α is chosen so that $A - BK_{k+1}C$ is asymptotically stable and:
   $$J_{k+1} = 1/2 \quad tr(P_{k+1} X) \le J_k$$
   If J_{k+1} and J_k are close enough to each other, go to 3
   Otherwise, set k=k+1 and go to 2
3. Terminate:
   Set $K = K_{k+1}$, $J = J_{k+1}$
   Stop.

B. The parameter values of the power system are given in Tables I and II:

TABLE I
GENCOS PARAMETERS

GENCOs Parameters	Area1		Area2	
	$GENCO_1$	$GENCO_2$	$GENCO_3$	$GENCO_4$
$T_T (s)$	0. 32	0. 30	0. 03	0. 32
$T_G (s)$	0. 06	0. 08	0. 06	0. 07
$R\ (Hz/pu)$	2. 4	2. 5	2. 5	2. 7

TABLE II
CONTROL AREA PARAMETERS

Control area parameters	Area1	Area2
$K_P (pu/Hz)$	102	102
$T_P (s)$	20	25
$B (pu/Hz)$	0. 425	0. 396
$T_{12} (pu/Hz)$	0. 245	

VII. REFERENCES

[1] J. Kumar, Kah-Hoe Ng and G. Sheble, "AGC Simulator for Price-based Operation Part 1: A Model," *IEEE Trans. on Power Systems*, vol. 12, no. 2, May. 1997.
[2] J. Kumar, Kah-Hoe Ng, G. Sheble, "AGC Simulator for Price-based Operation Part 2: Case Study Results," *IEEE Trans. on Power Systems*, vol. 12, no. 2, May 1997.
[3] V. Donde, A. Pai and I. A. Hiskens, "Simulation and Optimization in an AGC System after Deregulation," *IEEE Trans. on Power Systems*, vol. 16, no. 3, pp. 481–489, Aug. 2001.
[4] F. Liu, Y.H. Song, J. Ma, S. Mei and Q. Lu, "Optimal load-frequency control in restructured power systems," *IEE Proceedings Generation, Transmission and Distribution*, vol. 150, no. 1, pp. 87–95, Jan. 2003.
[5] D. Rerkpreedapong and A. Feliachi, "Decentralized Load Frequency Control for Load Following Services," *IEEE Power Engineering Society Winter Meeting*, vol. 2, no. 1, pp 1252–1257, Jan. 2002.
[6] A. Demiroren and H.L. Zeynelgil, "GA application to optimization of AGC in three-area power system after deregulation," *Electrical Power and Energy Systems*, vol. 29, no.3, pp.230-240, March. 2007.
[7] H. Shayeghi, H. A. Shayanfar and O. P. Malik, "Robust Decentralized Neural Networks Based LFC in a Deregulated Power System," *Electric Power Systems Research*, vol. 77, pp 241–251, April. 2007.
[8] F.L. Lewis and V.L. Syrmos, *Optimal Control*, Prentice Hall, Englewood Cliffs, New Jersey, 1995.

VIII. BIOGRAPHIES

Elyas Rakhshani was born in Mashhad, Iran in 1982. He received the B.Sc. degree in the power engineering from Islamic Azad University of Iran, Birjand branch, Iran in 2004 and M.Sc. degree in Control Engineering from Islamic Azad University of Iran, Gonabad branch, Iran in 2008. His research interests are Power System Control, Dynamics and Operation, Optimal Control and Neural Computing.

Javad Sadeh was born in Mashhad, IRAN in 1968. He received the B.Sc. and M.Sc. in electrical engineering from Ferdowsi University of Mashhad in 1990 and 1994 respectively and the Ph.D from Sharif University of Technology, Tehran Iran with the collaboration of the electrical engineering laboratory of the National Polytechnic Institute of Grenoble (INPG), France in 2000. Since then he served as an assistant professor at the Ferdowsi University of Mashhad. His research interests are Power System Protection, Electromagnetic Transients in Power System and Restructuring.