IEEE Xplore® DIGITAL LIBRARY

IEEE

SEARCH RESULTS

You searched for: **((Authors:sadeh) AND 2009)**

You refined by:

Author: Sadeh, J.

Results per Page 25 Showing 1 - 3 of 3 results

Considering failure probability for back-up relay in determination of the optimum routine test interval in protective system using Markov model

Damchi, Y.; Sadeh, J.;
Power & Energy Society General Meeting, 2009. PES '09. IEEE
Digital Object Identifier: 10.1109/PES.2009.5275612
Publication Year: 2009 , Page(s): 1 - 5

IEEE CONFERENCES

A reduced-order estimator with prescribed degree of stability for two-area LFC system in a deregulated environment

Rakhshani, E.; Sadeh, J.;
Power Systems Conference and Exposition, 2009. PSCE '09. IEEE/PES
Digital Object Identifier: 10.1109/PSCE.2009.4839943
Publication Year: 2009 , Page(s): 1 - 8

IEEE CONFERENCES

Considering Different Network Topologies in Optimal Overcurrent Relay Coordination Using a Hybrid GA

Noghabi, A.S.; Sadeh, J.; Mashhadi, H.R.;
Power Delivery, IEEE Transactions on
Volume: 24 , Issue: 4
Digital Object Identifier: 10.1109/TPWRD.2009.2029057
Publication Year: 2009 , Page(s): 1857 - 1863

IEEE JOURNALS

A Reduced-Order Estimator with Prescribed Degree of Stability for Two-Area LFC System in a Deregulated Environment

E. Rakhshani, and J. Sadeh, *Member, IEEE*

Abstract—**This paper presents a reduced-order estimator by using an LQR regulator with a prescribed degree of stability for two-area load frequency control problem in a deregulated power system. In the practical power system, access to some of the state variables in LFC system is limited and measuring is also impossible. So a reduced-order estimator is proposed. But to access a good dynamic response a controller with prescribed degree of stability is combined with this estimator model. The results of the simulation are shown that with using this method, the load frequency control requirements in a practical environment are satisfied and also with so good dynamic responses, sensitivity to plant-parameter variations is reduced.**

Index Terms—**Load frequency control, Deregulated power system, Reduced-order observer, Prescribed degree of stability.**

I. Nomenclature

B	Frequency bias
ACE	Area Control Error
R	Droop characteristic
LFC	Load Frequency Control
apf	Area participation factor
DPM	Disco Participation Matrix
cpf	Contract participation factor
AGC	Automatic Generation Control
T_T	Turbine time constant
T_G	Governor time constant
K_P	Power system equivalent gain
T_P	Power system equivalent time constant
ΔP_m	Power generation of GENCO
ΔP_L	Contracted demand of DISCO
GENCO	Generation Company
DISCO	Distribution Company
TRANSCO	Transmission Company
VIU	Vertically Integrated Utility
ISO	Independent System Operator
EMS	Energy Management systems
T_{12}	Tie-line synchronizing coefficient between areas

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).

978-1-4244-3811-2/09/$25.00 ©2009 IEEE

II. Introduction

FOR satisfactory operation of a power system, the frequency should remain nearly constant. The frequency of a system is dependent on active power balance. As frequency is a common factor throughout the system, a change in active power demand at one point is reflected throughout the system by a change in frequency. So load frequency control is a very important issue in power system operation and control. But in recent years, major changes have been introduced into the structure of electric power utilities all around the world. The reason for this was to improve efficiency in the operation of the power system by means of deregulating the industry and opening it up to private competition. This new development in the power system restructuring requires innovations in the Energy Management systems (EMS). The AGC is one of main functions of EMS, and is also required to be innovated for the adaptation to the market systems with several kinds of the bidding strategies. Its basic theory is much consolidated and well known [1]–[5].

The aims of LFC are: (a) to achieve zero static frequency error; (b) to distribute generation among areas so that interconnected tie-line flows match a prescribed schedule; and (c) to balance the total generation against the total load. But with the restructuring of electric markets, LFC requirements should be expanded to include the market contracts and planning functions. 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 [6]-[7] and improve the dynamical transient response of system under competitive conditions [8]-[13]. To improve the transient response, various control strategies, such as linear feedback, optimal control and Kalman estimator method, have been proposed [8], [9]. There have been continuing efforts in designing LFC with better performance using intelligence algorithms or robust methods [10]–[11].

In this paper, a reduced-order estimator by using an LQR regulator with a prescribed degree of stability is proposed. This regulator is used for two-area load frequency problem in a deregulated power system. In the practical power system, access to some of the state variables in LFC system i.e. area control error (ACE), integration of ACE and output of governors, is limited and measuring is also impossible. So a reduced-order estimator is proposed to estimate un-measurable states. But to access a good dynamic response a controller with prescribed degree of stability is combined with this reduced-order estimator model. The proposed method is tested on a two-area power system with one contracted scenario. The results of the simulation are shown that this method provides a control system that satisfied the load frequency control requirements in a practical power system with so good dynamic responses. Furthermore, with using this method, sensitivity to plant-parameter variations is reduced.

III. Deregulated Power System for LFC

Deregulated system will consist of generation companies (GENCOs), distribution companies (DISCOs), transmission companies (TRANSCOs) and independent system operator (ISO). GENCO, TRANSCO, DISCO, ISO and many ancillary services (AGC) of a vertically integrated utility will have a different role to play and therefore have to be modeled differently. There are crucial differences between the AGC operation in a vertically integrated industry and horizontally integrated industry. In the reconstructed power system after deregulation, operation, simulation and optimization have to be reformulated although basic approach to AGC has been kept the same. The power system is assumed to contain two areas and each area includes two GENCOs and also two DISCOs as shown in Fig. 1. But to make the visualization of contracts easier and understand how these contracts are implemented, the concept of a "DISCO participation matrix" (DPM) will be used [7]. 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

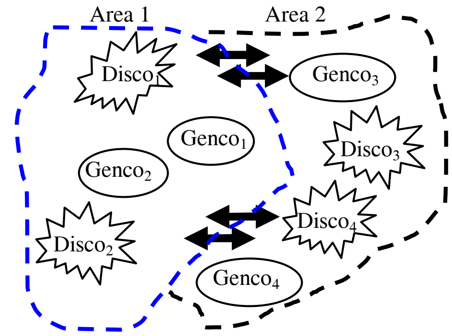


Fig. 1. Configuration of the power system.

including two DISCOs and two GENCOs is given as follows:

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

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.

As shown in Figs. 2 and 3, a DISCO can contract individually with any GENCO for power and these transactions are made under the supervision of ISO. Where ΔP_{CD} and ΔP_L includes contracted demand signals based on the possible contracts between GENCOs and DISCOs. This signals carry information as to which GENCO has to follow a load demanded by that DISCO.

The block diagram of the modified LFC for a two area power system is shown in Fig. 3. The actual and scheduled steady state power flows on the tie-line are given as:

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

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

In equation (2), T12 is the tie-line synchronizing coefficient between two areas and at any given time, the tie line power

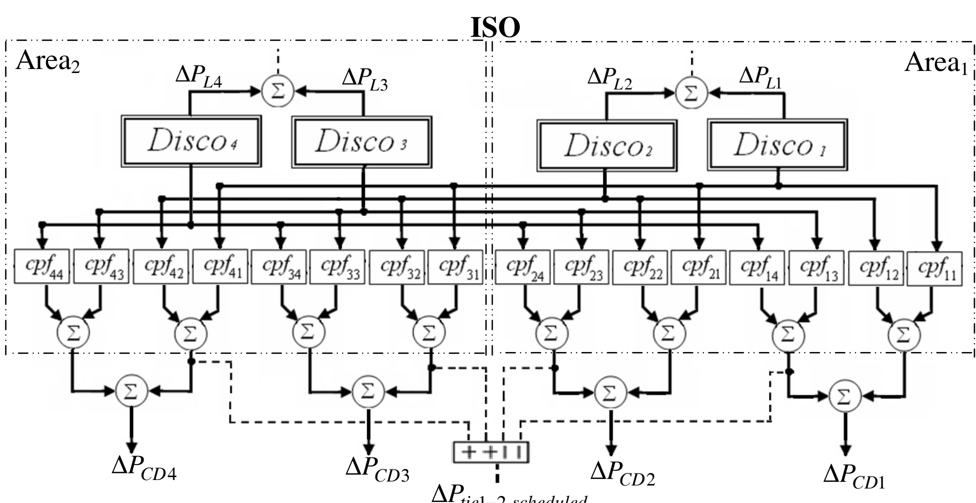


Fig. 2. Market process for LFC system in this study.

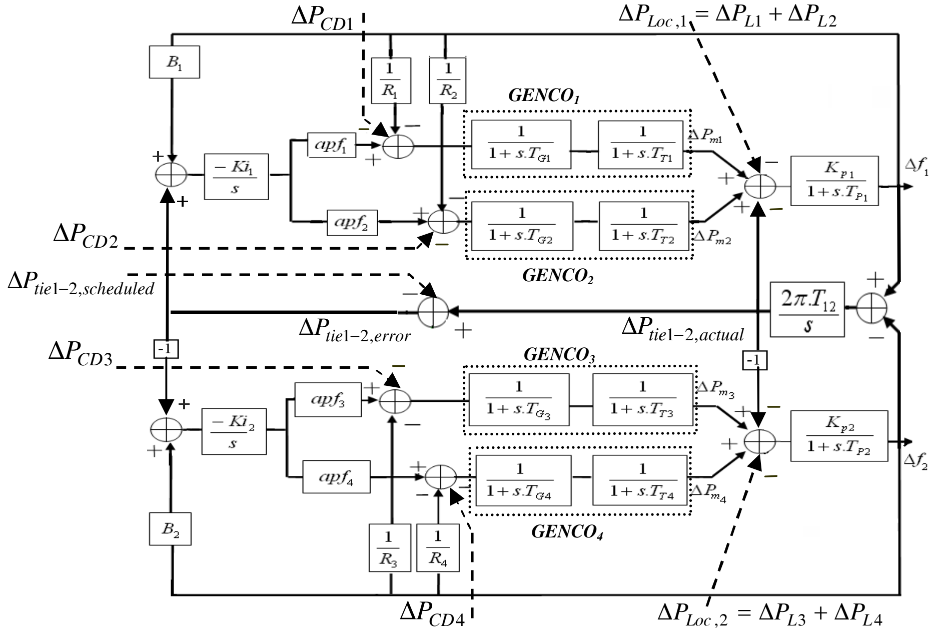


Fig. 3. Modified two-area LFC system in a competitive environment.

error ($\Delta P_{tie1-2,error}$) is defined as:

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

This error signal is used to generate the respective Area Control Error or *ACE* signals as in the traditional scenario [7]:

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

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

where B_1 and B_2 are the frequency biases of two areas. 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 $\sum_j apf_{ij}=1$.

The dashed lines in Fig. 3 show the market signals such as: ΔP_{CD} and ΔP_{Loc} from the market process. These new information signals were absent in the traditional LFC scheme. In the steady state, any GENCO generation must match the demand of the DISCOs in contract with it, as expressed as follows:

$$\Delta P_{mi} = \sum_j cpf_{ij} \Delta P_{Lj} \tag{6}$$

The closed loop system for this study is characterized in state space form as:

$$\dot{x} = A.x + B.u \quad , \quad x(t_0) = x_0 \tag{7}$$

$$y = C.x \tag{8}$$

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.

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

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

The deviation of frequency, turbine output and tie-line power flow within each control area are measurable outputs, other states such as: integration of *ACE* are not measurable. Note that the used LFC system in this paper is a modified system of the proposed model in [7]. This model is Ninth-order and fully controllable model. As shown in fig. 3, (dotted lines around the turbines and governors blocks), the outputs of GENCOs are used as some of the states variables for simulation. Furthermore, based on Fig. 4, un-measurable states such as $\int ACE_1$ and $\int ACE_2$ are estimated by a reduced-order observer controller.

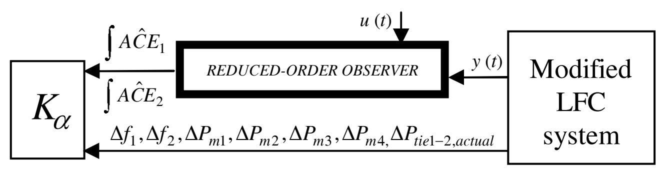


Fig. 4. Schematic diagram of applied reduced-order observer for LFC.

IV. Design of Proposed Method for LFC System

In this paper to improve the dynamical response of system pragmatically, a reduced order observer method is improved by adding a controller with prescribed degree of stability. Brief theories of these methods are described in this section:

A. *Overview of reduced-order observer*

Control systems are used to regulate an enormous variety of machines, products, and processes. They control quantities such as motion, temperature, heat flow, fluid flow, fluid pressure, tension, voltage, and current. Most concepts in control theory are based on having sensors to measure the quantity under control. There are at least four common problems caused by sensors. First, sensors are expensive. Sensor cost can substantially raise the total cost of a control system. Second, sensors and their associated wiring reduce the reliability of control systems. Third, some signals are impractical to measure. Fourth, sensors usually induce significant errors such as stochastic noise, cyclical errors, and limited responsiveness [14]. Observers can be used to augment or replace sensors in a control system. Observers are algorithms that combine sensed signals with other knowledge of the control system to produce observed signals. These observed signals can be more accurate, less expensive to produce, and more reliable than sensed signals. A full-order observer estimates all the states in a system, regardless whether they are measurable or not but when some of the state variables are measurable using a reduced-order observer is so better. The block diagram of a reduced-order observer is shown in Fig. 5.

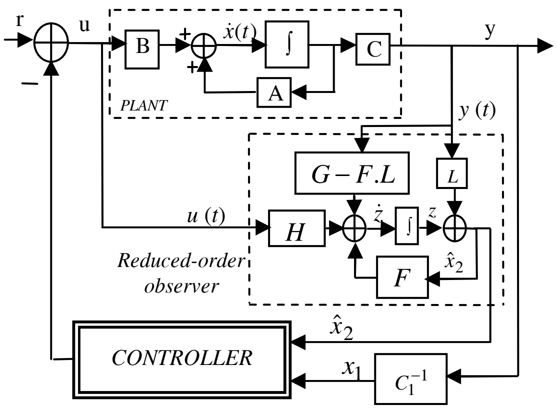


Fig. 5. Block diagram of a reduced-order observer with controller.

Suppose we can measure some of the state variables contained in x, and the state vector x is partitioned into two sets, such as: x_1 or variables that can be measured directly and x_2 or variables that cannot be measured directly.

$$\begin{cases} \dot{x}_1 = A_{11}.x_1 + A_{12}.x_2 + B_1.u \\ \dot{x}_2 = A_{21}.x_1 + A_{22}.x_2 + B_2.u \end{cases} \tag{9}$$

and the observation equation is:

$$y = C_1.x_1 \tag{10}$$

where C_1 is square and nonsingular matrix. The full order observer for the states is then:

$$\begin{cases} \dot{\hat{x}}_1 = A_{11}.\hat{x}_1 + A_{12}.\hat{x}_2 + B_1.u + L_1.(y - C_1.\hat{x}_1) \\ \dot{\hat{x}}_2 = A_{21}.\hat{x}_1 + A_{22}.\hat{x}_2 + B_2.u + L_2.(y - C_1.\hat{x}_1) \end{cases} \tag{11}$$

But we do not need to solve first observer equation for x_1 because these states can be solved directly by equation (10):

$$\hat{x}_1 = x_1 = C_1^{-1}.y \tag{12}$$

In this case the observer for those states that cannot be measured directly is designed as follows:

$$\dot{\hat{x}}_2 = A_{21}.C_1^{-1}.y + A_{22}.\hat{x}_2 + B_2.u \tag{13}$$

The dynamic behavior of this reduced order observer is governed by the eigenvalues of A_{22}. Since there is no assurance that the eigenvalues of A_{22} are suitable, we need a more general system for the reconstruction of x_2. We take:

$$\hat{x}_2 = L.y + z \tag{14}$$

where:

$$\dot{z} = F.z + G.y + H.u \tag{15}$$

After more computational efforts, we can find [13]:

$$\begin{cases} F = A_{22} - LC_1A_{12} \\ H = B_2 - LC_1B_1 \\ G = (A_{21} - LC_1A_{11})C_1^{-1} + FL \end{cases} \tag{16}$$

Note that for stability of the observer dynamic system, the eigenvalues of F must lie in the left hand-side of s plane. More details about this observer can be found in [13].

B. Linear quadratic controller with prescribed degree of stability

In the conventional optimal regulator, the problem is to design a controller gain K, so that the eigenvalues of the closed loop system

$$\dot{x}(t) = (A - BK).x(t) \tag{17}$$

are placed at desired locations and, simultaneously, minimize a performance index:

$$J = \int x(t)^T.Q.x(t) + u(t)^T.R.u(t) \tag{18}$$

Where, Q is a positive semi definite matrix and R is a positive definite matrix. And for the system that is defined by equations (7) and (8), feedback control law is:

$$u = -K.y \tag{19}$$

Where:

$$K = R^{-1}.B^T.P \tag{20}$$

$$A^T.P + P.A - P.B.R^{-1}.B^T.P + Q = 0 \tag{21}$$

Now, we define a modified quadratic function for the system defined by (7) (still assumed completely controllable) which leads to a linear-control law of the type represented by (19), with the additional property that the closed-loop-system poles lie to the left of Re(s) = -α, α>0, in the s-plane [15]-[16].

In place of the performance index (18), this performance index is defined:

$$J_o = \int_{t_0}^{\infty} e^{\alpha t}\left[x^T(t).Q.x(t) + u^T(t).R.u(t)\right]dt \tag{22}$$

Where, α is a constant value that can be selected by a designer. As before; R is positive definite symmetric and constant, Q is nonnegative definite symmetric and constant. To minimize (22) subject to the conditions of (7), set:

$$\hat{x}(t) = e^{\alpha t}.x \quad , \quad \hat{u} = e^{\alpha t}.u \tag{23}$$

Then (7) are equivalent to:

$$\dot{\hat{x}}(t) = (A + \alpha I_n)x.(t) + B.\hat{u}(t) \quad , \quad \hat{x}(t_0) = e^{\alpha t_0}.x_0 \tag{24}$$

While $(u^T R.u + x^T Q.x).e^{\alpha t} = \hat{u}^T.R.\hat{u} + \hat{x}^T.Q.\hat{x}$, and thus minimization with respect to (7) of (22) is equivalent to minimization with respect to (24) of:

$$J_o = \int_{t_0}^{\infty} (\hat{x}^T(t).Q.\hat{x}(t) + \hat{u}^T(t).R.\hat{u}(t)) \tag{25}$$

In the following sentences:

a) The minimum value of (22) (expressed in terms of x_0) is the same as the minimum value of (25) [expressed in terms of $\hat{x}(t_0)$, taking account of $\hat{x}(t_0) = e^{\alpha t_0}.x_0$].

b) If $\hat{u} = f(x)$ is the optimal control for (24) and (25), $u = e^{-\alpha t} f(xe^{\alpha t})$ is the optimal control for (7) and (22), and conversely.

The first point is not as significant as the second; we know that, for (24) and (25); the optimal control is:

$$\hat{u}(t) = -K_{\alpha}\hat{x}(t) \tag{26}$$

Where:

$$K_{\alpha} = R^{-1}B^{T}P_{\alpha} \tag{27}$$

And P_{α} is the unique non-negative definite solution of modified Riccati equation:

$$(A+\alpha I_n)^T P_{\alpha} + P_{\alpha}(A+\alpha I_n) - P_{\alpha}BR^{-1}B^{T}P_{\alpha} + Q = 0 \tag{28}$$

The main advantage of this scheme over conventional optimal design is [16]:

- Reduction of trajectory sensitivity to plant-parameter variations as a result of any closed-loop control, which is greater for α > 0 than for α = 0.

V. Simulation Results

In order to demonstrate the effectiveness of the proposed strategy, simulations are performed for one scenario of possible contracts and it is assumed that all of the changes in load demands occur in bilateral contract and there is no any violation of contracted demands.

In this simulation, the reduced-order observer with a prescribed degree of stability controller was applied for the two control area power system in the deregulated power system. The first step was the design of the reduced-order observer, and the next step was to design the added controller with prescribed degree of stability for more improvement in dynamical responses. Applying the feedback control law with prescribed degree of stability to the system given by (7), (19) and (21) are modified and given by (24), (26)-(28). Also, in this simulation, α constant is set to 0.1. The performance of the proposed method is compared with the reduced-order observer using a conventional optimal LQR controller. The simulations are done using MATLAB platform and the power system parameters are taken from references [12]-[13].

A. *Scenario: 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 based on following *DPM*:

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

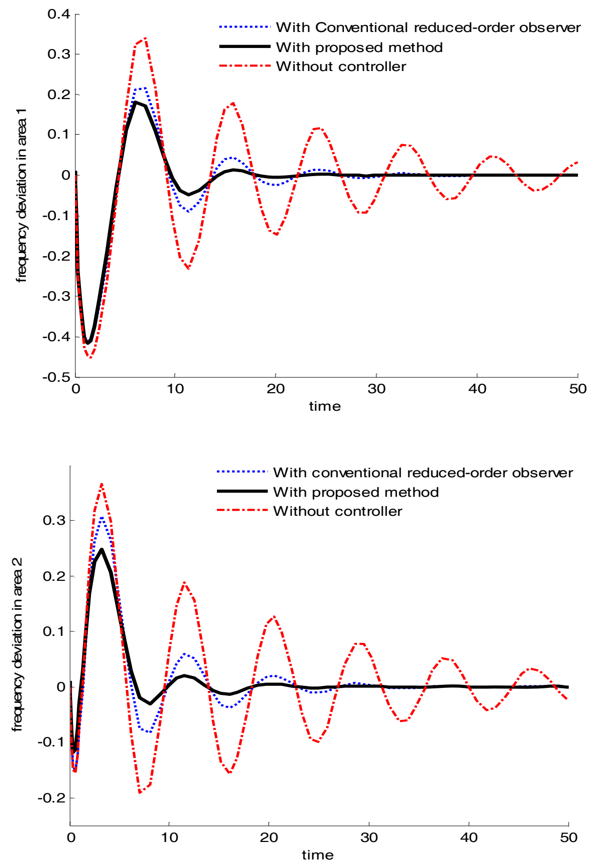
It is considered that each DISCO demands 0.1 *pu MW* total power from other GENCOs as defined by entries in *DPM* and these GENCOs participates in AGC as defined by these *apf*s:

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

The results for this case are given in Figs. 6–8. Using the proposed method, the frequency deviation of all areas is quickly driven back to zero and has a good dynamic response (Fig. 6). Also, 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. 7 shows, the tie line power flow properly converges to the specified value of equation (1) in the steady state, i.e. $\Delta P_{tie1-2,scheduled} = -0.05 \ \ puMW$.

As shown in Fig.8, the actual generated powers of the GENCOs, according to (6), properly converge to the desired value in the steady state. So for this scenario, we have:

$$\Delta P_{m1} = 0.5 \ \ (0.1) + 0.25 \ \ (0.1) + 0 + 0.3 \ \ (0.1) = 0.105 \ puMW$$
$$\Delta P_{m2} = 0.045 \quad puMW \ ,$$
$$\Delta P_{m3} = 0.195 \quad puMW \ ,$$
$$\Delta P_{m4} = 0.055 \quad puMW$$



(a)

(b)

Fig. 6. (a) Frequency deviation in area1 (rad/s), (b) Frequency deviation in area2 (rad/s).

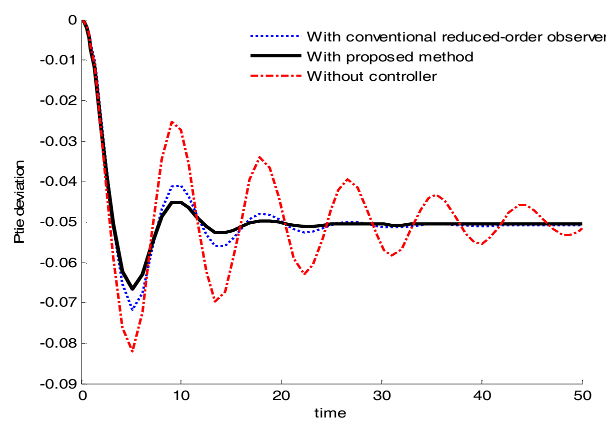


Fig.7. Deviation of tie line power flow (pu MW).

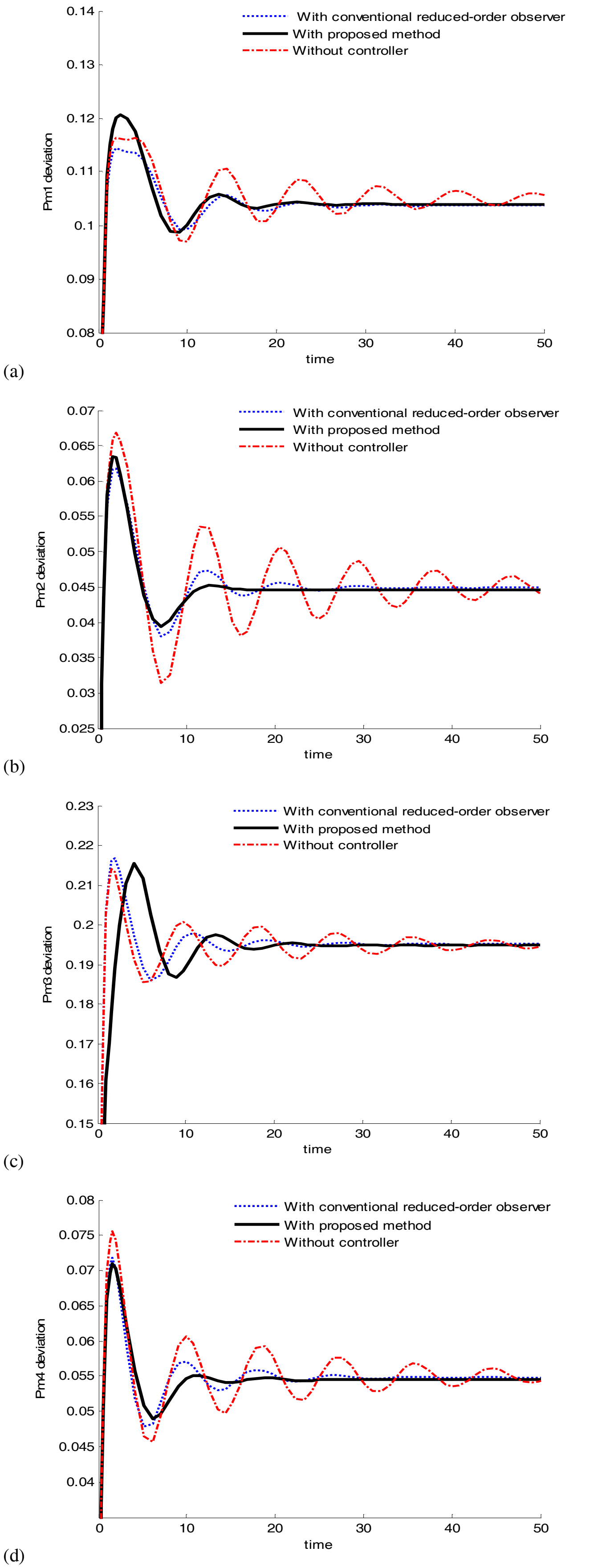


Fig.8. (a) to (d) are the deviation of turbine power (pu MW) of the GENCO1 to GENCO4.

VI. Additional Property of the Proposed Method on Trajectory Sensitivity

In this section, to examine the effectiveness of the proposed method on reduction of trajectory sensitivity to plant-parameter variations, another case is simulated. In this case, previous scenario in section V is simulated with 25% increases in system parameters i.e. GENCOs parameters and control area parameters. This new power system parameters after this increasing, are shown in Table I. (Initial parameters are taken form [12] and [13]). The frequency deviation of two areas, with 25% increase in system parameters are depicted in Figs. 9. It is observed that, with using the reduced-order estimator with a prescribed degree controller, the oscillations are damped out in around 20s, whereas the initial system, are unstable. Also, the dynamic response of proposed method is better than conventional reduced-order observer. Table II shows the eigenvalues of the power system described in section III, for this simulated case. It can be seen that two of the eigenvalues, (Δf_1 and Δf_2), are on the right half of s-plane and without any control making the system unstable. Note that, the stability of the system is determined by the location of the eigenvalues of system matrix. The system is stable if the eigenvalues have negative real parts.

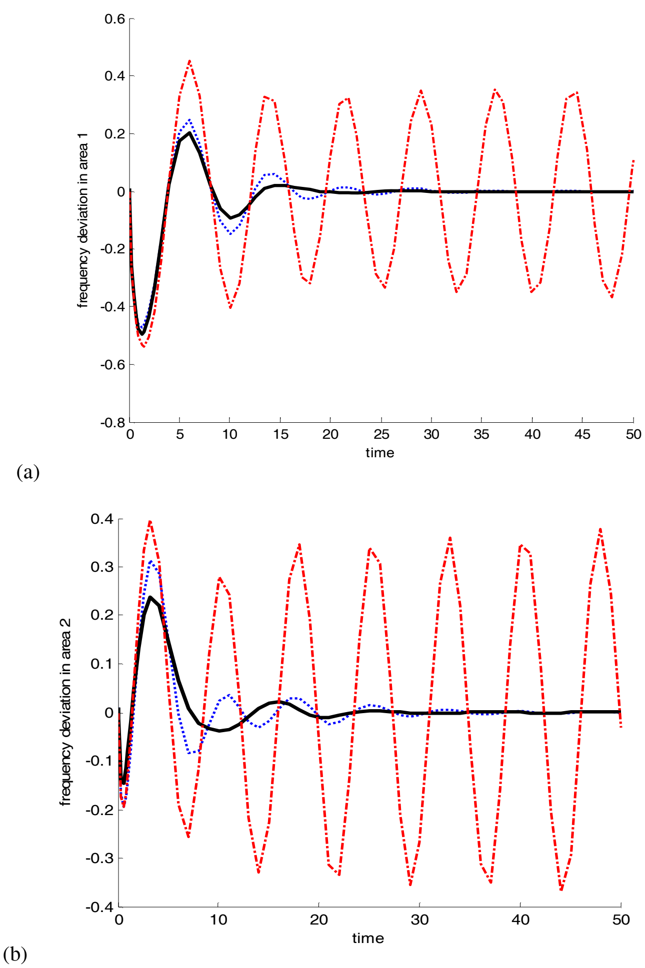


Fig. 9. a) Frequency deviation in area1 (rad/s), (b) Frequency deviation in area2 (rad/s): Dot-dashed (Without controller), Solid (With proposed method), Dotted (With conventional reduced-order observer).

TABLE I
SIMULATED PARAMETERS (WITH 25% INCREASE)

GENCOs PARAMETERS:	Area1		Area2	
$T_T(S)$	0. 4	0. 375	0. 375	0. 4
$T_G(s)$	0. 075	0. 1	0. 075	0. 0875
R (Hz/pu)	3	3.125	3.125	3.375
CONTROL AREA PARAMETERS:				
K_P (pu/Hz)	127.5		127.5	
$T_P(s)$	25		31.25	
B (pu/Hz)	0. 532		0.495	

TABLE II
EIGENVALUES OF THE SYSTEM

Modes	Initial system without controller	Conventional reduced-order control	Proposed method
Δf_1	0.0029 + 0.8341i	-0.1597 + 0.8161i	-0.3351 + 0.8490i
Δf_2	0.0029 - 0.8341i	-0.1597 - 0.8161i	-0.3393 - 0.8554i
ΔP_{m1}	-0.2019 + 0.6056i	-0.2136 + 0.6101i	-0.2543 + 0.5655i
ΔP_{m2}	-0.2019 - 0.6056i	-0.2136 - 0.6101i	-0.2543 - 0.5655i
ΔP_{m3}	-0.4758	-0.4475	-0.4547
ΔP_{m4}	-1.6640	-1.7273	-1.7588
$\int ACE_1$	-1.9190	-1.9326	-2.1884
$\int ACE_2$	-2.1849	-2.2425	-1.9877
ΔP_{tie}	-2.2316	-2.1842	-3.1424

As shown in Table II, with using the proposed method, eigenvalues of unstable condition (Δf_1 and Δf_2), are shifted towards the left half of the s-plane significantly. In fact, with using a prescribed degree of stability controller (with α=0.1), the real parts of these eigenvalues are shifted about 0.1 more than conventional method (with α=0).

VII. CONCLUSION

In this paper, a new designed method for two area LFC system in a deregulated environment is proposed. First, with a practical viewpoint a reduced-order observer control is designed, then for a better dynamic response, an optimal controller with prescribed degree of stability is added to control process. The performance of the proposed controller is evaluated through the simulation of two area power system under deregulation based on the bilateral policy scheme. Furthermore, dynamic responses of the proposed method are compared with the reduced-order observer using a conventional optimal LQR controller. The results show that, with the proposed method, the system speed and frequency oscillations are damped out rapidly and sensitivity to plant-parameter variations is reduced.

VIII. APPENDIX:

In this paper, the state matrix (A), the input matrix (B) and the output matrix (C) of the proposed LFC model is as follow. Where Rank [*A*, *B*] =9 and the system is full rank with complete controllability and observability. Furthermore, the number of rows in estimated matrix $\hat{x}_2$ is the same as number of state variables that cannot be measured directly. Where:

$$\hat{x}_2 = [\int A\hat{C}E_1 \quad \int A\hat{C}E_2]^T$$

$$x_1 = [\Delta f_1 \quad \Delta f_2 \quad \Delta P_{m1} \quad \Delta P_{m2} \quad \Delta P_{m3} \quad \Delta P_{m4} \quad \Delta P_{tie1-2,actual}]^T$$

$$A = \begin{bmatrix}
\frac{-1}{T_{p1}} & 0 & \frac{K_{p1}}{T_{p1}} & \frac{K_{p1}}{T_{p1}} & 0 & 0 & 0 & 0 & \frac{-K_{p1}}{T_{p1}} \\
0 & \frac{-1}{T_{p2}} & 0 & 0 & \frac{K_{p2}}{T_{p2}} & \frac{K_{p2}}{T_{p2}} & 0 & 0 & \frac{K_{p2}}{T_{p2}} \\
\frac{-1}{2\pi R_1.(T_{g1}+T_{T1})} & 0 & \frac{-1}{(T_{g1}+T_{T1})} & 0 & 0 & 0 & \frac{-K_{i1}.apf_1}{(T_{g1}+T_{T1})} & 0 & 0 \\
\frac{-1}{2\pi R_2.(T_{g2}+T_{T2})} & 0 & 0 & \frac{-1}{(T_{g2}+T_{T2})} & 0 & 0 & \frac{-K_{i1}.apf_2}{(T_{g2}+T_{T2})} & 0 & 0 \\
0 & \frac{-1}{2\pi R_3.(T_{g3}+T_{T3})} & 0 & 0 & \frac{-1}{(T_{g3}+T_{T3})} & 0 & 0 & \frac{-K_{i2}.apf_3}{(T_{g3}+T_{T3})} & 0 \\
0 & \frac{-1}{2\pi R_4.(T_{g4}+T_{T4})} & 0 & 0 & 0 & \frac{-1}{(T_{g4}+T_{T4})} & 0 & \frac{-K_{i2}.apf_4}{(T_{g4}+T_{T4})} & 0 \\
\frac{B_1}{2\pi} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\
0 & \frac{B_2}{2\pi} & 0 & 0 & 0 & 0 & 0 & 0 & -1 \\
\frac{T_{12}}{2\pi} & \frac{-T_{12}}{2\pi} & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}_{9\times 9}$$

$$B=\begin{bmatrix}
\frac{-K_{p1}}{T_{p1}} & \frac{-K_{p1}}{T_{p1}} & 0 & 0\\
0 & 0 & \frac{-K_{p2}}{T_{p2}} & \frac{-K_{p2}}{T_{p2}}\\
\frac{cpf_{11}}{T_{g1}+T_{T1}} & \frac{cpf_{12}}{T_{g1}+T_{T1}} & \frac{cpf_{13}}{T_{g1}+T_{T1}} & \frac{cpf_{14}}{T_{g1}+T_{T1}}\\
\frac{cpf_{21}}{T_{g2}+T_{T2}} & \frac{cpf_{22}}{T_{g2}+T_{T2}} & \frac{cpf_{23}}{T_{g2}+T_{T2}} & \frac{cpf_{24}}{T_{g2}+T_{T2}}\\
\frac{cpf_{31}}{T_{g3}+T_{T3}} & \frac{cpf_{32}}{T_{g3}+T_{T3}} & \frac{cpf_{33}}{T_{g3}+T_{T3}} & \frac{cpf_{34}}{T_{g3}+T_{T3}}\\
\frac{cpf_{41}}{T_{g4}+T_{T4}} & \frac{cpf_{42}}{T_{g4}+T_{T4}} & \frac{cpf_{43}}{T_{g4}+T_{T4}} & \frac{cpf_{44}}{T_{g4}+T_{T4}}\\
cpf_{31}+cpf_{41} & cpf_{32}+cpf_{42} & -(cpf_{13}+cpf_{23}) & -(cpf_{14}+cpf_{24})\\
-(cpf_{31}+cpf_{41}) & -(cpf_{32}+cpf_{42}) & cpf_{13}+cpf_{23} & cpf_{14}+cpf_{24}\\
0 & 0 & 0 & 0
\end{bmatrix}_{9\times 4}$$

$$C=\begin{bmatrix}
1&0&0&0&0&0&0&0&0\\
0&1&0&0&0&0&0&0&0\\
0&0&1&0&0&0&0&0&0\\
0&0&0&1&0&0&0&0&0\\
0&0&0&0&1&0&0&0&0\\
0&0&0&0&0&1&0&0&0\\
0&0&0&0&0&0&0&0&1
\end{bmatrix}_{7\times 9}$$

IX. References

[1] P. Kunder, *Power system stability and control*, USA: McGraw-Hill; 1994.

[2] H. Saadat, *Power system analysis*, USA: McGraw-Hill; 1999.

[3] O. I. Elgerd and C. E. Fosha, "Optimum megawatt-frequency control of multi-area electric energy systems," *IEEE Trans. on Power Apparatus and Systems*, vol. PAS-89, pp. 556–563, Apr. 1970.

[4] N. Jaleeli et al., "Understanding automatic generation control," *IEEE Trans. on Power Systems*., vol. 7, no. 3, pp. 1106–1112, Aug. 1992.

[5] A. Feliachi, "Load frequency control using reduced order models and local observers", *Electrical Power and Energy Systems*, vol. 7, no. 2, pp. 72–75, 1987.

[6] 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.

[7] V. Donde, A. Pai and I. A. Hiskens, "Simulation and Optimization in a AGC System after Deregulation," *IEEE Trans. on Power Systems*, vol. 16, no. 3, pp. 481–489, Aug. 2001.

[8] 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.

[9] 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.

[10] 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.

[11] 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.

[12] J. Sadeh and E. Rakhshani, "Multi-area load frequency control in a deregulated power system using optimal output feedback method," 5th International Conference on European Electricity Market, EEM 2008. pp 1– 6, May. 2008.

[13] E. Rakhshani and J. Sadeh, "Simulation of two-area AGC system in a competitive environment using reduced-order observer method," 5th International Conference on European Electricity Market, EEM 2008. pp 1– 6, May. 2008.

[14] G. Ellise, *Observers in control systems: a practical guide,* Academic press, Elsevier Inc.; 2002.

[15] Anderson, B. D. O. and Moor, J. B., Linear System Optimization with Prescribed Degree of Stability, Proc. Inst. Eng., 1969, vol. 116, no. 2, pp. 100-106.

[16] B. Kalyan Kumar, S.N. Singh, S.C. Srivastava,''A decentralized nonlinear feedback controller with prescribed degree of stability for damping power system oscillations,'' Electric Power Systems Research 77 (2007) 204-211

X. 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.