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Practical viewpoints on load frequency control problem in a deregulated power system

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ABSTRACT

An attempt is made in this paper to present feasible and practical methods to improve dynamic response of load frequency control problem in a deregulated power system. In the practical environment, access to all of the state variables of system is limited and measuring all of them is also impossible. Access and also measuring the state variable is one of the most problems on application of control methods in real world. To solve this problem, in this paper, two methods with pragmatic viewpoint are proposed. The first method is optimal output feedback control and the second is based on state observer method. In the output feedback method, only the measurable state variables within each control area are required to use for feedback. But when we have fewer sensors available than the number of states or it may be undesirable, expensive, or impossible to directly measure all of the states, using a reduced-order observer is proposed. These proposed designs, which are presented in this paper, have been developed in order to over-come this problem and are tested on a two-area power system considering different contracted scenarios. The results show that when the power demands change, the output feedback method is the most rational technique with the best dynamic response. Also, with using a reduced-order observer, the dynamic response of system is improved. In fact, using these methods is necessary for load frequency control problem in a practical environment.

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1. Introduction

Investigation of the power system markets shows that frequency control is one of the most profitable ancillary services at these systems. The basic theory of LFC is much consolidated and well known [1–3]. But 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. Thus, the LFC system keeps track of the momentary active power imbalance, detects it, corrects it and communicates an adequate amount of the balance energy service basis, to the market operating system. A lot of studies have been made about LFC in a deregulated environment [4]. These studies try to modify the conventional LFC system to take into account the effect of bilateral contracts on the dynamics and continued with proposed model in [5]. After that more researches are done to improve the dynamical response of system under competitive conditions [6]. The conventional control strategy for the LFC problem is to take the integral of the area control error (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 [6,7]. 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 [8] or robust methods [9,10]. These methods show good dynamical responses, but some of them suggest complex and or high order dynamical controllers [10], 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 should be estimated or neglected for feedback. To solve this problem, in this paper, two methods are proposed. The first method is the optimal output feedback control and the second is based on state observer method. In the output feedback method, by selecting desired output matrix (C), un-measurable states are

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Nomenclature

f	frequency
B	frequency bias
R	droop characteristic
u	input vector
x	state vector
ζ	deviation of scheduled tie-line power flow
K_i	integration controller gain
AGC	automatic generation control
LFC	load frequency control
GENCO	Generation company
DISCO	Distribution company
ISO	independent system operator
VIU	vertically integrated utility
TRANSCO	Transmission company
ACE	area control error
apf	area participation factor
gpf	generator participation factor
AGPM	Augmented Generation Participation Matrix
K_P	power system equivalent gain
T_P	power system equivalent time constant
T_G	time constant of governor
T_T	time constant of turbine
T_{T-G}	augmented time constant of turbine–governor set
d	total demand
ΔP_{Loc}	total local contracted demand
ΔP_M	power generation of GENCO
ΔP_L	contracted demand of DISCO
ΔP_{UL}	un-contracted demand
ΔP_d	area load disturbance
T_{12}	tie-line synchronizing coefficient between areas
ΔP_{tie}	net tie-line power flow
$\Delta P_{\mathrm{tie,error}}$	tie-line power error
$\Delta P_{\mathrm{tie,actual}}$	tie-line actual power

neglected for feedback, so only the measurable state variables in output within each control area are required to use for feedback. But in the second method, un-measurable states are estimated using a reduced-order observer method. These proposed methods are tested on a two-area power system considering different contracted scenarios. The results of proposed controllers are separately compared with full-state and full-order observer methods. The results show that when the power demands change, the output feedback method is the most rational technique with the best response. Also, with using a reduced-order observer, the dynamic response of the system is improved. In fact, using these methods is necessary for LFC problem in a practical environment.

2. Multi-area LFC in a deregulated environment

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 still remain. In the system, any GENCO in any area may supply both DISCOs in its user pool and DISCOs in other areas through tie-lines between areas. In another words, for restructured system having several GENCOs and DISCOs, any DISCO may contract with any GENCO in another control area independently. This case is called as 'bilateral transactions'. The transactions have to be implemented through an independent system operator. The impartial entity, ISO, has to control many ancillary services, one of which is AGC. In deregulated environment, any DISCO has the liberty to buy power at competitive prices from different GENCOs, which may or may not have contract in the same area as the DISCO. This section gives a brief overview of this generalized model that uses all the information required in a VIU industry plus the contract data information. Based on the idea presented in [9], the concept of an 'Augmented Generation Participation Matrix' (AGPM) to express the possible contracts following is presented here. The AGPM shows the participation factor of a GENCO in the load following contract with a DISCO. The number of rows and columns of AGPM matrix is equal to the total number of GENCOs and DISCOs in the overall power system, respectively. So, the AGPM structure for a large-scale power system with N control areas is given by

$$\mathrm{AGPM} = \begin{bmatrix} \mathrm{AGPM}_{11} & \cdots & \mathrm{AGPM}_{1N} \\ \vdots & \ddots & \vdots \\ \mathrm{AGPM}_{N1} & \cdots & \mathrm{AGPM}_{NN} \end{bmatrix},$$

where

$$\mathrm{AGPM}_{ij} = \begin{bmatrix} gpf_{(s_i+1)(z_j+1)} & \cdots & gpf_{(s_j+1)(z_j+m_j)} \\ \vdots & \ddots & \vdots \\ gpf_{(s_i+n_j)(z_j+1)} & \vdots & gpf_{(s_j+n_i)(z_j+m_j)} \end{bmatrix},$$

$$\text{for } i,j = 1,\ldots,N \quad \text{and}$$

$$s_i = \sum_{k=1}^{i-1} n_i, \;\; z_j = \sum_{k=1}^{i-1} m_j, \;\; s_1 = z_1 = 0.$$

In the above, n_i and m_i are the number of GENCOs and DISCOs in area i and gpf_{ij} refers to 'generation participation factor' and shows the participation factor of GENCO$_i$ in the total load following requirement of DISCO$_j$ based on the possible contract. The sum of all entries in each column of an AGPM is unity. The diagonal sub-matrices of AGPM correspond to local demands and off-diagonal sub-matrices correspond to demands of DISCOs in one area on GENCOs in another area. The details and block diagram of the generalized AGC scheme for a two-area deregulated power system are shown in Fig. 1. Dashed lines show interfaces between areas and the demand signals based on the possible contracts. These new information signals are 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 the LFC task and $\sum_{j=1}^{n_i} apf_{ji} = 1$. We can write [9]:

$$d_i = \Delta P_{Loc,i} + \Delta P_{di} \tag{1}$$

where

$$\Delta P_{Loc,i} = \sum_{j=1}^{m_i} \Delta P_{Lj-i}, \quad \Delta P_{di} = \sum_{j=1}^{m_i} \Delta P_{ULj-i} \tag{2}$$

$$\zeta_i = \sum_{\substack{k=1 \\ k\neq 1}}^{N} \Delta P_{tie,ik,scheduled} \tag{3}$$

$$\eta_i = \sum_{\substack{j=1 \\ j\neq 1}}^{N} T_{ij}.\Delta f_j \tag{4}$$

$$\Delta P_{tie,ik,scheduled} = \sum_{j=1}^{n_i} \sum_{t=1}^{m_k} apf_{(s_i+j)(z_k+t)} \Delta P_{Lt-k} - \sum_{t=1}^{n_k} \sum_{j=1}^{m_i} apf_{(s_k+t)(z_i+j)} \Delta P_{Lj-i} \tag{5}$$

$$\Delta P_{tie,i,error} = \Delta P_{tie,i,actual} - \zeta_i \tag{6}$$

$$\Delta P_{m,k-i} = \rho_{ki} + apf_{ki} \sum_{j=1}^{m_i} \Delta P_{ULj-i} \quad k = 1,2,\ldots,n_i \tag{7}$$

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