Design of ADRC Load Frequency Controller for Three Area Power System

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ABSTRACT

In this paper a novel control strategy, the active disturbance rejection control (ADRC), is applied to the representative power system problem. In the ADRC framework, the disturbance and unmeasured dynamics associated with processes are treated as an additional state variable, which is then estimated and compensated for in real time. This reduces a normally complex, time-varying, nonlinear, and uncertain dynamic process to an approximately linear, time-invariant, cascade-integral form, where a simple proportional-derivative (PD) controller suffices. Furthermore, with only two tuning parameters, the controller provides a simple, easy-to-use solution to complex engineering problems in practice. Simulation studies are performed on system has three areas. Each area has three parallel-operating generating units that are owned by different generation companies (GenCos). Every generating unit has a non-reheat turbine unit, a generator, and a governor. The simulation results verified the effectiveness of the ADRC.

Keywords: *Automatic Generation Control (AGC), Area Control Error (ACE), Optimal Linear Quadratic Regulator (LQR), DC Link Introduction*

1. INTRODUCTION

Power systems are used to convert natural energy into electric power. They transport electricity to Factories and houses to satisfy all kinds of power needs. To optimize the performance of electrical equipment, it is important to ensure the quality of the electric power. It is well known that three-phase alternating current (AC) is generally used to transport the electricity. During the transportation, both the active power balance and the reactive power balance must be maintained between generating and utilizing the AC power. Those two balances correspond to two equilibrium points: frequency and voltage. When either of the two balances is broken and reset at a new level, the equilibrium points will float. A good quality of the electric power system requires both the Frequency and voltage to remain at standard values during operation. Thus a control system is essential to cancel the effects of the random load changes and to keep the frequency and voltage at the standard values .Although the active power and reactive power have combined effects on the frequency and voltage, the control problem of the frequency and voltage can be decoupled . For stable operation of power systems, both constant frequency and constant tile-line power exchange should be provided [4]. Therefore an area control error (ACE), which is defined as a linear combination of power net- Interchange and frequency deviations [1], is generally taken as the controlled output of LFC. As the ACE is driven to zero by the LFC, both frequency and tie-line power errors will be forced to zeroes [1].

The applications show that, for a number of complex control problems, ADRC results in extremely simple controller design but achieves high performance in tracking And disturbance rejection. The basic idea of ADRC is to use an extended state observer (ESO) to estimate the internal and external disturbances in real time. Then, through disturbance rejection, the originally complex and uncertain plant dynamics is reduced to a simple cascade integral plant, which can be easily controlled by a PD controller. Two important features of ADRC are 1) its lack of dependence of the model; and 2) the excellent disturbance rejection performance.

2. DYNAMIC MODELING OF THE POWER SYSTEM

In this section, the dynamic model of a three-area interconnected power system will be developed. each area of the power system consists of one generator,one governor, and one turbine unit. It includes three inputs, which are the controller input U(s) (also denoted as u), load disturbance $\Delta P_L(s)$, and tie-line power error $\Delta P_{tie}(s)$, one ACE output Y(s), and one generator output Δf. ΔPv is denoted as valve position change, ΔPe electrical power, and ΔPm mechanical power. The ACE alone is a measurable output. For each area, it is defined by (1), where B is area frequency response characteristic [1].

$$ACE = \Delta Ptie + B\Delta f \qquad (1)$$

We use transfer function (TF) to model the one-area generator unit. Let the transfer function from ΔPe(s) to ΔPm(s) be

$G_{ET}(s) = Num_{ET}(s) / Den_{ET}(s)$,

where $Num_{ET}(s)$ and $Den_{ET}(s)$ are the numerator and denominator of the $G_{ET}(s)$. The representations of $Num_{ET}(s)$ and $Den_{ET}(s)$ vary from different generating units. For the non-reheat turbine unit, $G_{ET}(s)$ is given by

$$G_{ET}(s) = \frac{Num_{ET}(s)}{Den_{ET}(s)} = \frac{1}{(T_g s + 1)(T_{ch} s + 1)} \qquad (2)$$

$$Y(S) = G_P(S)U(S) + G_D(S)\Delta P_L(S)Gtie(S)\Delta Ptie \qquad (3)$$

controller that minimizes the cost of the system in state variable form is a function of the present states of the system weighted by the components of a constant gain matrix K_1 of dimension m*n and can be defined by .

$$u = -K\,x \qquad (4)$$

Define the transfer function of the generator as

$$G_{GEN}(s) = \frac{1}{Den_M(s)} = \frac{1}{Ms + D} \qquad (5)$$

where $Den_M(s)$ represents the denominator of $G_{Gen}(s)$. The Laplace transform of the one-area power generating plant can be simplified as where

(6)

$$G_P(S) = \frac{RBNum_{ET}(S)}{Num_{ET}(S) + RDen_{ET}(S)Den_M(S)} \qquad (7)$$

$$G_D(S) = \frac{-RBDen_{ET}(S)}{Num_{ET}(S) + RDen_{ET}(S)Den_M(S)} \qquad (8)$$

$$G_{tie}(S) = \frac{Num_{ET}(S) + RDen_{ET}(S)Den_M(S) - RBDen}{Num_{ET}(S) + RDen_{ET}(S)Den_M(S)} \qquad (9)$$

3. THE INTERCONNECTED POWER SYSTEMS

Tie-Lines

In an interconnected power system, different areas are connected with each other via tie-lines. When the frequencies in two areas are different, a power exchange occurs through the tie-line that connected the two areas. The tie-line connections can be modeled. The Laplace transform representation of the block diagram in Figure 7 is given by

$$\Delta P_{tie}(s) = \frac{1}{s} T_{ij}\left(\Delta F_i(s) - \Delta F_j(s)\right) \qquad (10)$$

where ΔP_{tieij} is tie-line exchange power between areas i and j, and T_{ij} is the tie-line synchronizing torque coefficient between area i and j. From Figure 1, we can see that the tie-line power error is the integral of the frequency difference between the two areas

Area Control Error

we need to include the information of the tie-line power deviation into our control input. As a result, an area control error (ACE) is defined as

$$ACE_i = \sum_{j=1,....n,\, j\neq 1} \Delta P_{tieij} + B_i \Delta f_i \tag{10}$$

where B_i is the freqyency response characteristics of area [i].

$$B_i = D_i + \frac{1}{R_i} \tag{11}$$

is completely controllable, there exists a feedback matrix K such that (A-BK) is a stable matrix.

Parallel operation

If there are several power generating units operating in parallel in the same area, an equivalent generator will be developed for simplicity. The equivalent generator inertia constant (*Meq*), load damping constant (*Deq*) and frequency response characteristic (*Beq*) can be represented as follows

$$M_{eq} = \sum_{i=1,...n} Mi \tag{12}$$

$$Deq = \sum_{i=1,...n} D_i \tag{13}$$

$$B_{eq} = \sum_{i=1,...n} \frac{1}{R_i} + \sum_{i=1,...n} D_i \tag{14}$$

DESIGNING OF ACTIVE DISTURBANCE REJECTION CONTROLLER

The ADRC for area 1 can be designed and represented by the following

$$sZ(s) = (A - LC)Z(s) + BU(s) + LY(s) \tag{19}$$

$$U(s) = k\,(R(s) - Z(s)) - k\,Z(s) - k\,Z(s) \tag{20}$$

$$U(s) = \frac{U_O(s) - Z_4(s)}{b} \tag{21}$$

where The ADRCs for the other two areas have the similar structure to the one for area 1. Where

$$Z(s)=\begin{bmatrix} Z_1(s) \\ Z_2(s) \\ Z_3(s) \\ Z_4(s) \end{bmatrix}, A=\begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 \end{bmatrix}, B=\begin{bmatrix} 0 \\ 0 \\ b \\ 0 \end{bmatrix}, L=\begin{bmatrix} 4\omega_0 \\ 6\omega_0^2 \\ 4\omega_0^3 \\ \omega_0^4 \end{bmatrix}, k_1=\omega_c^3,$$

$$k_2=3\omega_c^2, k_3=3\omega_c \, and C=\begin{bmatrix} 1 & 0 & 0 & 0 \end{bmatrix}$$

The ADRCs for the other two areas have the similar structure to the one for area 1. The design parameters of the ADRCs in different areas are given in Table I.

Table I: ADRC parameters

	Order of ESO	ω_C	ω_O	b
Area1	3	4	20	78.77
Area 2	3	4	20	76.25
Area 3	3	4	20	74.27

The test system has three areas. Each area has three parallel-operating generating units that are owned by different generation companies (GenCos). Every generating unit has a non-reheat turbine unit, a generator, and a governor. The schematic diagram of the system is shown in Figure 4, where the three areas are connected with each other through tie-lines. In this figure, ΔP_{L1}, ΔP_{L2}, and ΔP_{L3} are power load changes added to the three areas.The tie-line synchronizing coefficients between any two areas are T_{12} = 0.2 *p.u./rad.*, T_{23} = 0.12 *p.u./rad.* and T_{13} = 0.25 *p.u./rad.*. The ramp rate factor that is used to describe the ate of change in the power plant output is given as

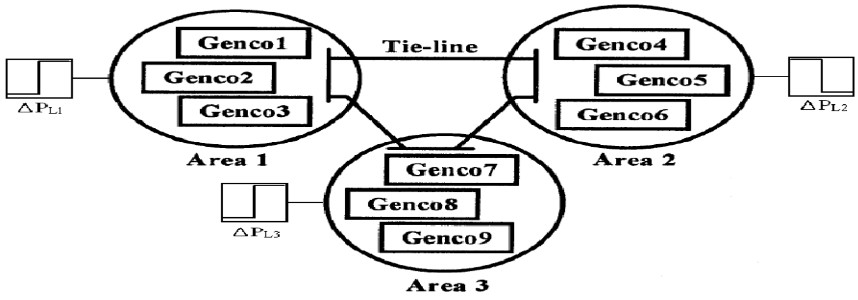

Figure 1: Schematic diagram of the three-area nine-unit power system[9]

$$\alpha = \frac{Ramprate \times 5min}{Regulation\, requirement}$$

a step load change with large amplitude is added to each area. The purposeof this case is to test the robustness of the controllers against large disturbances. The amplitudes of the load changes for the three areas are *ΔPL1* = 100 *MW (*0.1 *p.u.)*, *ΔPL2* = 80*MW (*0.08 *p.u.)* and *ΔPL3* = 50 *MW (*0.05 *p.u.)* respectively. The power loads are added to the systems at *t* = 2 second. However, the control effort of ADRC shows an overshoot at the switching edge of the load change. This is due to a slight lag of ESO in response to the external disturbance. Nevertheless the overshoot magnitude of ADRC is reasonable. So it will not affect their which the regulation requirement for each area is 100 *MW*.

4. CONCLUDING REMARKS

This paper proposed an ADRC based decentralized LFC for an interconnected three-area power system. Our control objective is to regulate ACE, frequency errors, and net tie-linepower deviations to zeroes in the presences of power load changes and system uncertainties. The ADRC is designed forthe power system containing both thermal and hydraulic turbines. The simulation results further verified the effectiveness.

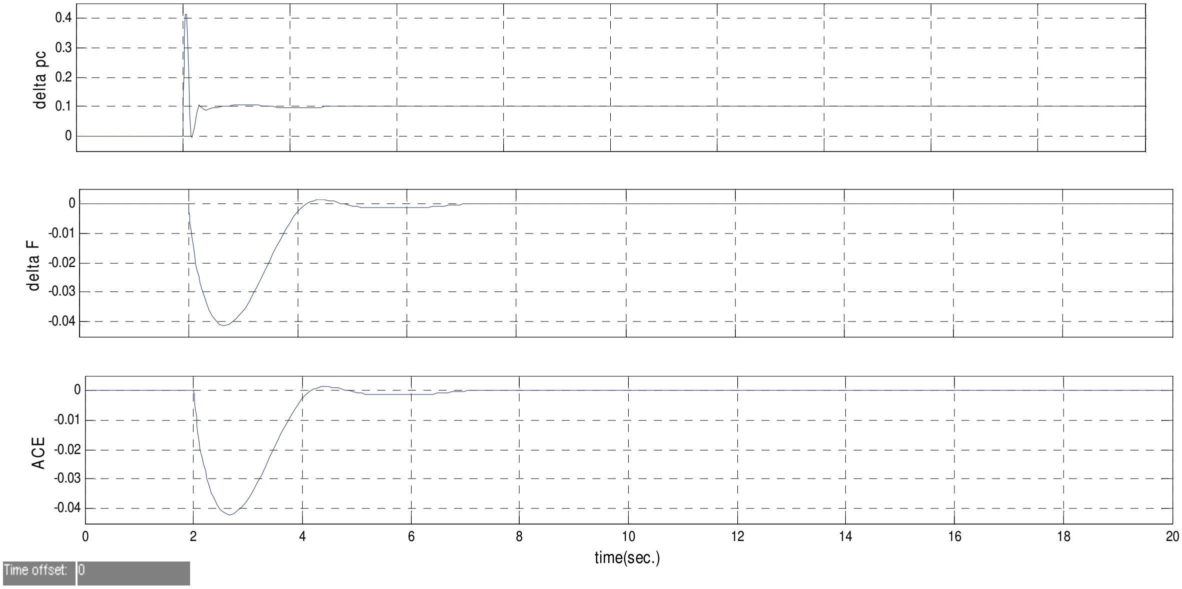

Figure 2: System responses of area 1(ΔPc (p.u.), Δf (Hz), ACE (p.u.))

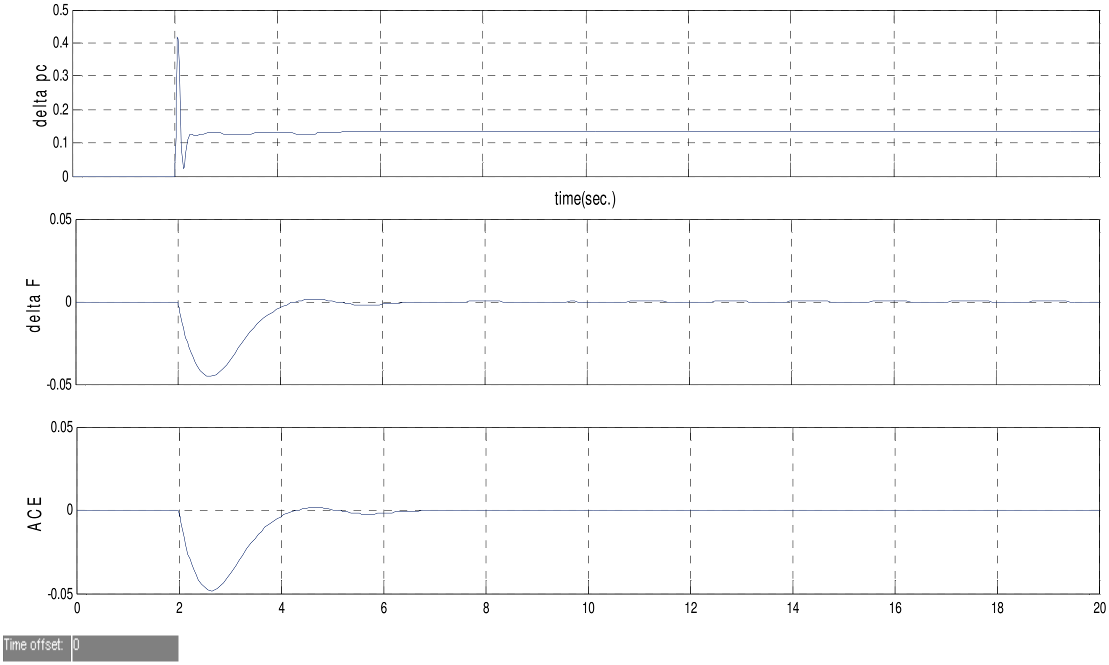

Figure 3: System responses of area 2 (ΔPc (p.u.), Δf (Hz), ACE (p.u.))

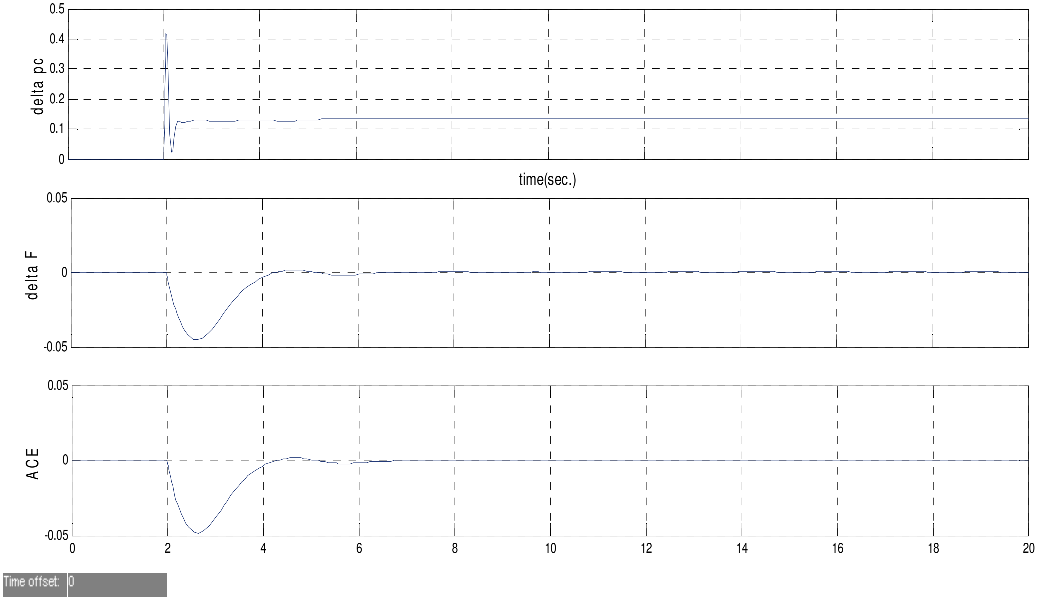

Figure 4: System responses of area 3 (ΔPc (p.u.), Δf (Hz), ACE (p.u.))

REFERENCES

[1] P. Kundur . *Power System Stability and Control.* McGraw-Hill, 1994. N. Jaleeli, L.S. Vanslyck, D. N. Ewart . (1992 ,Aug.) . L. H. Fink, and A. G. Hoffmann,"Understanding Automatic Generation Control", *IEEE Transaction on Power System*, vol. 7, no. 3, pp.1106-1122

[2] P. K. Ibraheem and D. P. Kothari . (2005, Feb.) . Recent Philosophies of Automatic Generation Control Strategies in Power Systems . *IEEE Transaction on Power Systems*, vol. 20, no. 1, pp. 346-357.

[3] M. Kothari, N. Sinha and M. Rafi . (1998,Jun.) . Automatic Generation Control of an Interconnected Power System under Deregulated Environment . *Power Quality,* vol. 18, pp. 95–102.

[4] K. Okada, R. Yokoyama, G. Shirai, H. Sasaki . (1988, Apr.)Decentralized Load Frequency Control with Load Demand Prediction in Multi-area Power Systems . in *Proceedings of International Conference on Control*, vol. 13, no. 15, pp. 649-654.

[5] Y. Zhang, L. Dong, Z. Gao, "Load Frequency Control for Multi-areaPower System", in Proceedings of American Control Conference, St.Louis, MI, Jun. 2009, pp. 2773-2778.

[6] Z. Gao, "Active Disturbance Rejection Control: A Paradigm Shift inFeedback Control System Design," in Proceedings of American Control Conference, Minneapolis, MN, Jun. 2006, pp. 2399–2405.

[7] G. Tian, and Z. Gao, "Frequency Response Analysis of Active Disturbance Rejection Based Control System," in Proceedings of IEEE International Conference on Control Applications, Singapore, Oct. 2007,pp. 1595–1599.

[8] W. Zhou, and Z. Gao, "An Active Disturbance Rejection Approach toTension and Velocity Regulations in Web Processing Lines," inProceedings of IEEE International Conference on Control Applications,Singapore, Oct. 2007, pp. 842–848.

[9] Sun, and Z. Gao, "A DSP-Based Active Disturbance Rejection Control Design for a 1-kW H-bridge DC-DC Power Converter," IEEETransactions on Industrial Electronics, vol. 52, no.5, pp. 1271–1277, Oct.2005.