International Journal on Future Revolution in Computer Science & Communication Engineering
Volume: 4 Issue: 3

ISSN: 2454-4248
280 – 285

Problems and Solutions of Various Areas of Load Frequency Control of Power System

Krishan Arora* , Dr. Parvinder Kaur**, Dr. Vikram Kumar Kamboj***
*Ph.D Research Scholar, Maharishi Markandeshwar University, Mullana, Ambala & Assistant Prof. Lovely Professional University, Jalandhar, Punjab
krishan.12252@lpu.co.in
** Professor and Head, Maharishi Markandeshwar University,Mullana,Ambala.
***Assistant Professor and Coordinator, DAV University, Jalandhar, Punjab.

Abstract: Controlling of frequency is one of the biggest beneficial ancillary assistance for the power systems by managing the limited equity of energy and frequency. Frequency control is mostly adepted by means of primary frequency regulation and Load Frequency Control. The prime intention of Load Frequency Control is to restore the scope of primary frequency regulation, recovery of frequency to its titular equivalent and reduce un-settled flow of tie-line power among various service operations. In this research paper, the author firstly work out on the single service area Load Frequency Control problem as a disturbance rejection issue and then review the system's outcome and the generation rate constraints. Secondly, decentralized LFC for two, three/multi-area power systems are developed and finally multi-area power systems is recommended by investigating the conclusion on the stability of the closed-loop system. In this paper, Load Frequency Control with communication delay in deregulated market are developed. It is also analyzed that the load frequency control problem is an exemplary disturbance rejection issue with restrictions, parameter fluctuations, structural abnormalities and communication delays. Modern soft computing approaches are supposed to be applied to enhance the performance of control area.

***Key Words**: Load Frequency Control, Robustness, Disturbance Rejection, Generation Rate Constraints*

*****

1. INTRODUCTION

Load Frequency Control (LFC) problem is the utmost crucial and novel field of research in interconnected power systems has a deep history in the power system operation and control. The generators operated in the service area fluctuate the speed consistently for balancing the frequency and power angles to the specific amount in both fixed and vigorous situations. The frequency and tie line power will be deviated if there is any immediate variation in load occurs in any service area. Therefore frequency should be stable at specified rating so that power system works satisfactorily because variation in frequency is in direct proportion to authenticity and efficiency of the power system otherwise it can hamper control area, reduces the performance of load and system protection arrangements. So it is mandatory to manage the frequency at specified and acceptable limits. But continuous variation in load cannot be ignored because of fluctuating load nature. So, by accommodating the generation regularly we can keep the system frequency within acceptable limits. A good load frequency control system has the capability to balance the system frequency and tie line power at their described boundaries.

Generally Load frequency control is categorized in three zones:

Primary control: The speed governor of the generating unit regulates this control which leads to automatic response to immediate variation of load or frequency. If the fluctuation in control area frequency is larger than dead band of speed governor then by using primary control, it will results in a variation in generation of unit power. These are generally operated in the order of seconds.

Secondary control: By balancing the outcomes of selected generators, secondary control manages power interchange among different service areas and resumes the frequency to its rated value. These are operated in the minutes time-scale.

Tertiary control: It is very much useful to run the power system efficiently and maintains the security levels. Tertiary control is generally operated every 5 minutes.

Primary control function is provided by speed governor which in turns results to overall generation change in spite of load change location. Moreover, primary control action is generally incapable of resuming the system's frequency in an interconnected power system thatswhy secondary control action is recommended to balance the set point of load reference via speed-changer motor. Secondary control is generally specified as load frequency control.

2. LOAD FREQUENCY CONTROL OF SINGLE SERVICE AREA

Assume the situation of a single generator which supply power in a single service area whose linear model shown in Figure 2.1

2.1 Mathematical model of Generator

With the little fluctuation in swing equations of synchronous machine, we get

$$\frac{2H}{\omega}\frac{d\Delta\delta^2}{dt^2} = \Delta P_m - \Delta P_e \qquad (2.1)$$

Or in terms in small variation in speed

$$\frac{d\Delta\omega/\omega_s}{dt} = \frac{1}{2H}(\Delta P_m - \Delta P_e) \qquad (2.2)$$

After Laplace transform, it reveals

$$\Delta\Omega(s) = \frac{1}{2Hs}[\Delta P_m(s) - \Delta P_e(s)] \qquad (2.3)$$

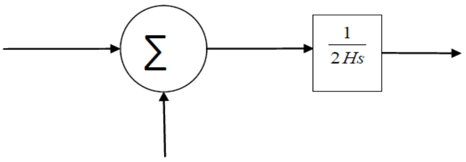

Figure 2.1 Mathematical model of generator

2.2 Mathematical model of Load

A large number of electrical drives are covered by the load on a power system . The load speed characteristic of the load is as:

$$\Delta P_e = \Delta P_L + D\Delta\omega \qquad (2.4)$$

where

ΔP_L is the non-frequency unstable fluctuation in load,

$D\Delta\omega$ is the frequency stable fluctuation in load.

D indicates variation in load with respect to variation in frequency.

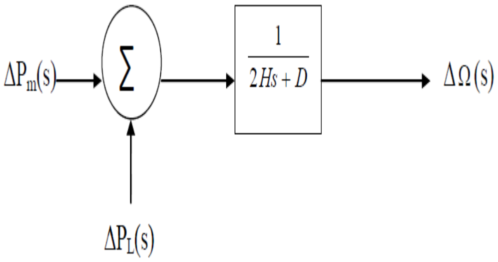

Figure 2.2 Mathematical model of Load

2.3 Mathematical model of Prime Mover

Prime mover is the major cause of power generation. Generation of power can be either through hydro turbines near waterfalls or through steam turbine by burning of various fuels. The model of turbine describes the variation in mechanical power output ΔPm with respect to steam valve position ΔPV.

$$G_T = \frac{\Delta Pm(s)}{\Delta Pv(s)} = \frac{1}{1+\tau s} \qquad (2.5)$$

where the turbine constant is in the spectrum of 0.2 - 2 sec

2.4 Mathematical model of speed governor

The electrical power overtakes the input mechanical power as electrical load increases abruptly. This difference of power on the load side is balanced by the kinetic energy of the turbine. Because of this kinetic energy, the energy stored in the machine is reduced and the governor gives signal to supply more volume of water, steam or gas to enhance the speed of the prime mover to balance deviation in speed.

$$\Delta P_g = \Delta P_{ref} - \frac{1}{R}\Delta f \qquad (2.6)$$

In s-domain

$$\Delta P_g = \Delta P_{Ref} - \frac{1}{R}\Delta f \qquad (2.7)$$

Assume linear time constant, the command ΔP_g is converted into the steam valve position command ΔPV and we get the relation in s-domain

$$\Delta P_v = \frac{1}{1+\tau g}\Delta P_g(s) \qquad (2.8)$$

By linking together all the above block diagrams, we get the following for isolated area system

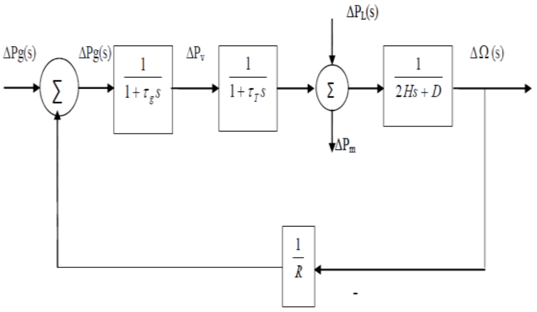

Figure 2.3 Complete Block diagram of single service area system

2.4 Generation Rate Constraints (GRC)

Because of substantial constraints of governor and turbine, there are some complications in generation rate which will hamper the LFC performance and can create imbalance.

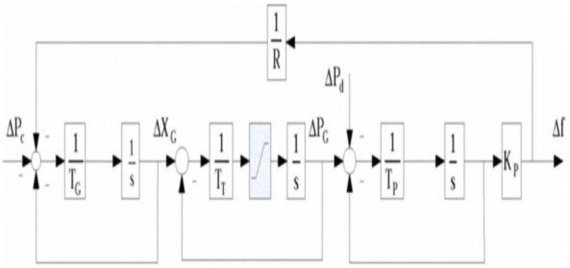

Figure 2.4 Single service area with GRC

To solve this problem, an anti-GRC structure was proposed as depicted in Figure 2.5, where K(s) is the designed controller and can be written as

$$K(s) = \frac{Ki}{s} + K_m(s) \qquad (2.9)$$

where k_i is the integral gain and

K_m (s) is the part without integral action.

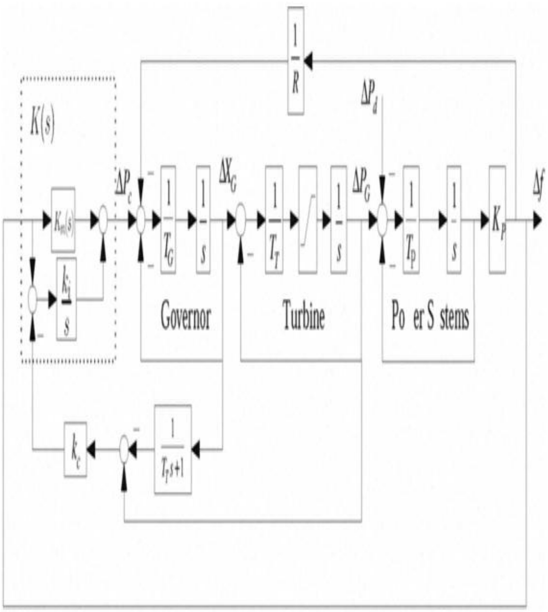

Figure 2.5 Single service area LFC with anti-GRC

If the difference between the signal which passes through the turbine and ΔP_G (t) are not identical, then is balanced by a gain k_c until both are same. So there is a need of an additional feedback when GRC exists. The same situation occurs during anti-reset configuration for PI controllers except the two conditions. Firstly the controller is not limited to PI and secondly there must be a turbine model which checks the complications directly. If these two conditions are well taken , then there will be the larger value of anti-GRC gain k_c which results in faster response on accumulated error.

3. LOAD FREQUENCY CONTROL OF TWO SERVICE AREAS

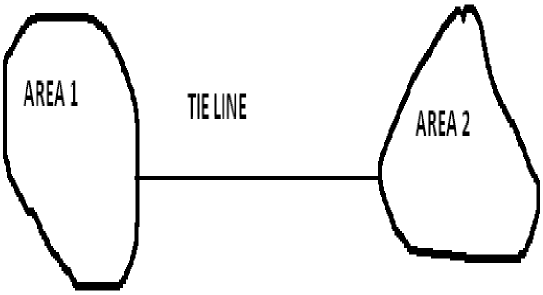

Figure 3.1 Two interconnected service areas

LFC of two service areas i.e. Area 1 and Area 2 are joined with the help of a tie line is depicted in Figure 3.1. The block diagram of similar model of given two service areas illustrated in Figure 3.1 is shown in Figure 3.2. Both service areas subsists of wind farms (WF) as well as synchronous generators (SG). Automatic Generation Control manages four synchronous generators SG1, SG2, SG5 and SG6. Governor Free (GF) manages two synchronous generators SG3 and SG7 and Load Limit (LL) operation is controlled by SG 4. The two wind farms WF1 and WF3 consists of PMSG (permanent magnet synchronous generator) and other two WF2 and WF4 consists of DFIG. P12 is flow of power between both service areas by using tie-line. Each service area of conventional power plants are expressed by turbine governor system, an equivalent inertia (M), and damping load constant (D). The difference between various outcomes obtained from synchronous and wind generators which is called deviation is further used to calculate the frequency deviation Δf_i, (i=1,2) and tie line power deviation (ΔP_{12}). The synchronous generators SG1, SG2, SG5 and SG6 are assembled by auxiliary control system whose purpose is to assure the preferred unit is appropriate.

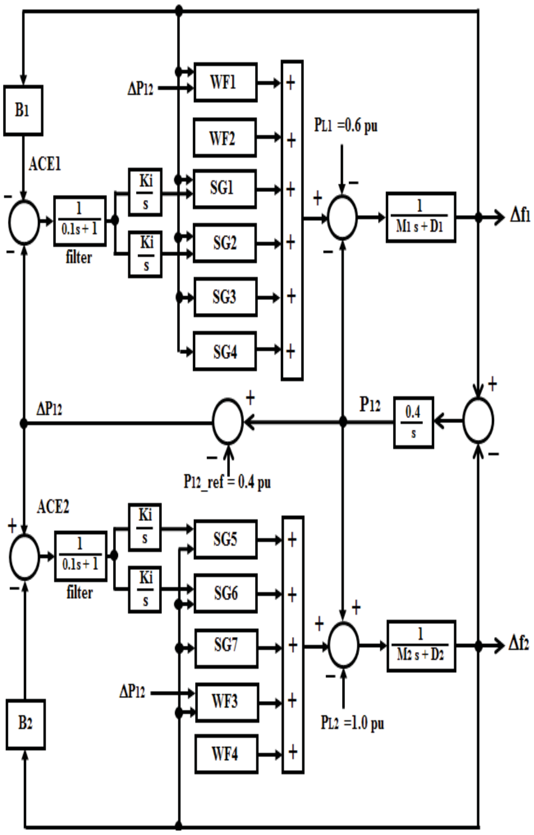

Figure 3.2 Block diagram of Two service area system

For control area 1,
$\text{ACE1} = \Delta P_{tie,\,1} + B1\, \Delta f1$ (3.1)

Eqn. (3.1) can be written using laplace transformation as
$\text{ACE1}(s) = \Delta P_{tie,\,1}(s) + B1\, \Delta f1(s)$ (3.2)

Similarly, for control area 2, ACE2 can be written as
$\text{ACE2}(s) = \Delta P_{tie,\,2}(s) + B2\, \Delta f2(s)$ (3.3)

3.1 Load Frequency Control with Generation Rate Constraints (GRCs)

LFC of interconnected power system does not considered the impact of constraints with respect to variation in power generation. In thermal power units, power generated can vary particularly at a higher described value But for reheat units rate of generation is quite lesser nearly 3%/min. If such complications are ignored then system is followed by huge momentary interruptions which leads to inappropriate damage to the controller. Various techniques have been introduced to include the effects of GRC to design load frequency control.

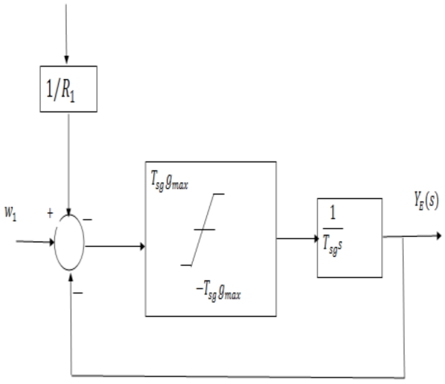

Figure 3.3 Governor model of two area with GRC

The order of the system will be varied by adding the generation rates denoted by P_{gi} into the state vector. It may be verified at each stage if GRCs are violated while solving the state equations rather than developing them. The alternate method of using GRCs for both areas is to include limiters to the governors as presented in above figure 3.3, i.e. the maximum rated speed of valve opening or closing is controlled by the limiters. Here Tsg Gmax is power rate limit levied by valve or gate control. In this model

$$|\Delta Y_E| < Gmax$$

The boundary values appointed by the limiters are preferred to regulate the generation rate by 10% per minute which results in bigger deviations in Area Control Errors. Therefore, the period for which the power needs to be carried are increased noticeably in comparison to the case where generation rate is not a big challenge. With GRCs, value of R should be optimally chosen so that it can provide the best dynamic response. In hydrothermal system, the generation rate in the hydro area normally remains below the safe limit and therefore GRCs for all the hydro plants can be ignored.

4. LOAD FREQUENCY CONTROL OF THREE SERVICE AREAS/ MULTI AREA POWER SYSTEM

A system of a single generator which provides input to a huge and complicated area is hardly existed in the power system. Therefore generators in large quantity are interconnected in parallel which may be at one position or at variant positions for the attainment of huge area load demand. For achieving the load demand, large load areas are splitted within various minor areas. The power is transferred between different areas is done with the help of tie lines. Following Figure 4.1 refers to three or multi service area interconnected power system in which circles represents area where thermal power plant is referred by Area 1 and Area 2 but Hydro power plant is Area 3 and all are interconnected via tie lines.

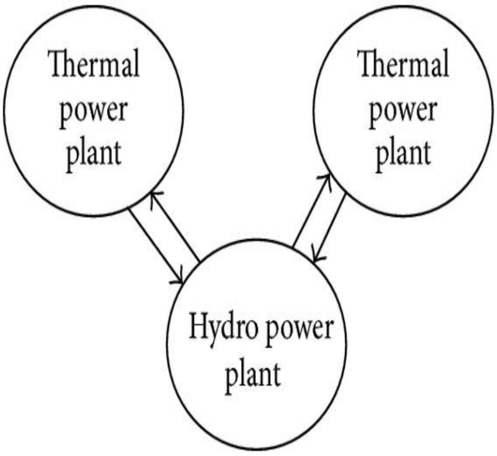

Figure 4.1 Three service area Interconnection

The control system's main aim is to manage the frequency of every unit and govern power of tie line at equal instants. As in the situation of frequency, various controllers are installed to yield zero steady state error. Area Control error of the ith area (ACE_i) is the input given to the supplementary controller of the ith area, which can be expressed as

$$ACE_i = \sum_{j=1}^{n} \Delta P_{tie,Ij} + B_i \Delta f_i \qquad (4.1)$$

Where ACE_I = area control error of the ith area
Δf_i = deviation in frequency of ith area
$\Delta P_{tie,Ij}$ = deviation in tie line power flow between ith and jth area.
B_i = frequency bias coefficient of ith area.

5. VARIOUS PROBLEMS AND THEIR SOLUTIONS

Decentralized Control

Due to rise in scope and complications of an interconnected power system, Load Frequency Control plays very meaningful aspect today. Multivariable control approaches are used to study centralized LFC but decentralized load frequency control is mostly used due to its simple design and easy to execute. Majority of techniques advice convoluted state-feedback or high-order dynamic controllers, which are practically not possible for commercial usage. A decentralized controller design method was proposed in [13, 14]. It first ignores the tie-line power flows, i.e., assume $\Delta P_{tiei} = O$ (i = 1…, n). In this situation, the local feedback control is expressed as

$$u_i = -K_i(s)\, B_i\, \Delta f_i$$

The transfer function of generator for Area #i which is represented by $G_{gi}(s)$, $G_{ti}(s)$, and $G_{pJ}(s)$ is expressed as

$$G_i(s) = \frac{G_{gi}G_{ti}G_{pj}}{1 + G_{gi}G_{ti}G_{pj}/R_i}$$

Now, multiply the plant model by the local bias coefficient B_i in order to get decentralized load frequency controller, and further persue the equal practice same as in single-area LFC for Area #i.

P_i (s) = G_i(s) B_i

Therefore LFC can be designed independently for every area. So, the design for every area should consider the coupling among areas since there is coupling among areas.

Stability of Decentralized Control

The stability of various multiple service areas within decentralized LFC controller can be verified with the help of Multivariable stability theories. However, the multiple service areas have its own unique pattern, so that a straightforward approach can be used for stability study.

Robustness

Firstly, the stability of local-area power systems with fluctuation of specifications are assured for local LFC via SSV. Secondly to investigate the designed decentralized LFC is robust against tie-line operation. Furthermore, the significance of each tie-line power flow is divergent. However it’s problematic to regulate when the decentralized Load Frequency Control is suitably robust for structural unpredictabilities in tie-line activities. Therefore, before the assurance of tie-line strategies, the stability of the full power system can be verified with standard Theorem of robustness. The intricacy propelled on calculating the solution of tie-line process, not the mechanism to check authenticity of the stability.

Communication Delays

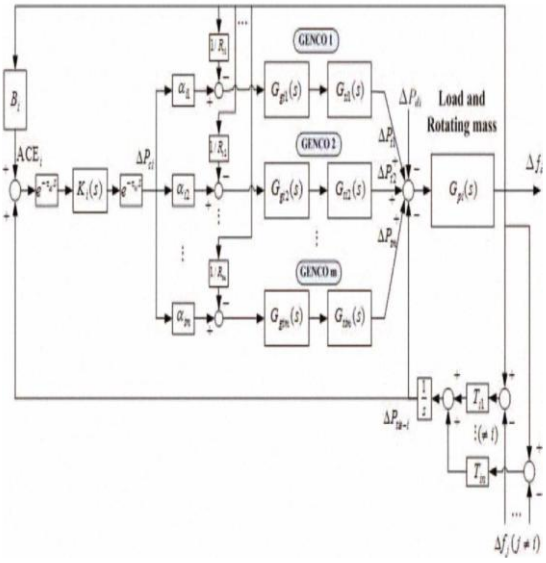

Figure 4.2 Control areas with communication delays

Mostly multi-generation systems are supposed to be in a control service area rather than in one individual assembled generator unit. This position is highly reasonable for LFC in a reconstructed power system. Communication delays are affected by the control input, the deliberated frequency and the consistent flow of tie line power.

CONCLUSION

It is obvious that the load frequency control problem is an exemplary disturbance rejection obstacle with Generation rate boundaries, criterion alterations, unpredictability of structural behavior and communication gaps. Some serious unpredictabilities and interruptions in the operation of power system are made known with the increase in scope and intricacy of power system. It becomes devotion towards the innovative control techniques to be refined with focus to obtain the basic LFC objectives and manage authenticity of the electric power system in sufficient amount. Though many modern soft computing techniques have been tried to improve the control performance, some issues are still unsolved. For example, Firstly Random communication delays among control areas. Currently the communication delays among control areas are supposed to be fixed but unknown. However, in practice they should be random. Efficient methods to deal with the random delays have not been proposed for LFC. Secondly Structural robustness for tie-line operation. Theoretical results are currently unavailable to check the issue for LFC

REFERENCES

[1]. P. Kundur. Power System Stability and Control. McGraw Hill, 1994.

[2]. P. K. Ibrabeem and D. P. Kothari. Recent philosophies of automatic generation control strategies in power systems. IEEE Trans. Power Systems, 20(1):346-357, 2005.

[3]. H. Shayeghi, H. A. Shayanfar, and A. Jalili. Load frequency control strategies: A state-of-the-art survey for the researcher. Energy Conversion and Management, 50(2):344-353, 2009.

[4]. G. J. Balas, J. C. Doyle, K. Glover, A. Packard, and R. Smith. J-L-Analysis and Synthesis Toolbox. For use with MATLAB. MUSY N and The MathWorks, Inc., 1993.

[5]. W. C. Chan and Y. Y. Hsu. Automatic generation control of interconnected power systems using variable-structure controller. lEE Proc., Part C, 128:269-279, 1981.

[6]. W. Tan and Z. Xu. Robust analysis and design of load frequency controller for power systems. Electric Power Systems Research, 79(5):846-853, 2009.

[7]. K. Y. Lim, Y. Wang, and R. Zhou. Robust decentralized load frequency control of multi-area power systems. lEE P roc. Part C, 143: 377-386, 1996.

[8]. H. L. Zeynelgil, A. Demiroren, and N. S. Sengor. The application of ANN technique to automatic generation control for multi-area power system. Int. 1. Electrical Power and Energy Systems, 24: 345-354, 2002.

[9]. T. C. Yang, Z. T. Ding, and H. Yu. Decentralized power system load-frequency control beyond the limit of diagonal dominance. Int. 1. Electrical Power and Energy Systems, 24(3): 173-184, 2002.

[10]. H. Bevrani, Y. Mitani, and K. Tsuji. Sequential design of decentralized load frequency controllers using J-L synthesis and analysis. Energy Conversion and Management, 45:865-881, 2004.

[11]. M. Zribi, M. AI-Rashed, and M. Alrifai. Adaptive decentralized load frequency control of multi-area power

systems. Int. 1. Electrical Power and Energy Systems, 27:575-583, 2005.

[12]. P. Subbaraj and K. Manickavasagam. Automatic generation control of multi-area power system using fuzzy controller. European Transactions on Electrical Power, 18:266- 280, 2008.

[13]. W. Tan. Tuning of PID load frequency controller for power systems. Energy Conversion and Management, 50(6): 1465- 1472, 2009.

[14]. W. Tan. Unified tuning of PID load frequency controller for power systems via IMC. IEEE Trans. Power Syst., 25(1):341- 350, 2010.

[15]. W. Tan. Decentralized load frequency controller analysis and tuning for multi-area power systems. Energy Conversion and Management, 52(5):2015-2023, 2011.

[16]. S. Bhowmik, K. Tomsovic, and A. Bose. Communication model for third party load freqeuncy control. IEEE Trans. Power Systems, 19(1):543-548, 2004.

[17]. X. F. Yu and K. Tomsovic. Application of linear matrix inequalities for load frequency control with communication delays. IEEE Trans. Power Systems, 19(3): 1508-1519, 2004.

[18]. H. Bevrani and T. Hiyama. Robust decentralised PI based LFC design for time delay power systems. Energy Conversion and Management, 49: 193-204, 2008.

[19]. H. Bevrani and T. Hiyama. On load-frequency regulation with time delays: design and real-time implementation. IEEE Trans. Energy Conversion, 24(1):292-300, 2009.

[20]. H. Bevrani, Y. Mitani, K. Tsuji, and H. Bevrani. Bilateral based robust load frequency control. Energy Conversion and Management, 46(7-8): 1129-1146, 2005.

[21]. H. Saadat. Power System Analysis. McGraw-Hill, 1999.

[22]. C. E. Fosha and O. I. Elgerd. The megawatt-frequency control problem: a new approach via optimal control theory. IEEE Trans. Power App. Syst., PAS-89(4):563-567, 1970.

[23]. M. Calovic. Linear regulator design for a load and frequency control theory. IEEE Trans. Power App. Syst., PAS- 91(6):2271-2285, 1972.

[24]. C. T. Pan and C. M. Liaw. An adaptive controller for power system load-frequency control. IEEE Trans. Power Systems, 4(1):122-128, 1989.

[25]. Y. Wang, R. Zhou, and C. Wen. Robust load-frequency controller design for power systems. lEE P roc.Part C, 140(1): 11-16, 1993.

[26]. Z. Q. Wang and M. Sznaier. Robust control design for load frequency control using J-L-synthesis. In Southconl94, Conference Record, pages 186-190, Orlando, FL, USA, March 1994.

[27]. G. Ray, A. N. Prasad, and G. D. Prasad. A new approach to the design of robust load-frequency controller for large scale power systems. Electric Power Systems Research, 51(1):13- 22, 1999.

[28]. Y. H. Moon, H. S. Ryu, J. G. Lee, K. B. Song, and M. C. Shin. Extended integral control for load frequency control with the consideration of generation-rate constraints. Int. 1. Electrical Power and Energy Systems, 24:263-269, 2002.

[29]. J. Talaq and F. Al-Basri. Adaptive fuzzy gain scheduling for load frequency control. IEEE Trans. Power Systems, 14(1): 145-150, 1999.

[30]. M. F. Hossain, T. Takahashi, M. G. Rabbani, M. R. I. Sheikh, and M.S. Anower. Fuzzy-proportional integral controller for an AGC in a single area power system. In Proc. 4th Int. Con! on Electrical and Computer Engineering (ICECE), pages 120-123, Dhaka, Bangladesh, December 2006.

[31]. Y. H. Moon, H. S. Ryu, B. K. Choi, and H. J. Kook. Improvement of system damping by using the differential feedback in the load frequency control. In Proc. of the IEEE P ES 1999 Winter Meeting, pages 683-688, Feb. 1999.

[32]. Y. H. Moon, H. S. Ryu, J. G. Lee, and S. Kim. Power system load frequency control using noise-tolerable PID feedback. In Proc. IEEE Int. Symposium on Industrial Electronics (ISlE), volume 3, pages 1714-1718, June 2001.

[33]. A. Khodabakhshian and N. Golbon. Unified PID design for load frequency control. In Proc. 2004 IEEE Int. Con! On Control Applications (CCA), pages 1627-1632, Taipei, Taiwan, September 2004.

[34]. A. Khodabakhshian and M. Edrisi. A new robust PID load frequency controller. Control Engineering Practice, 16: 1069-1080, 2008.