Lecture Notes in Electrical Engineering 870

Jitendra Kumar
Manoj Tripathy
Premalata Jena *Editors*

Control Applications in Modern Power Systems

Select Proceedings of EPREC 2021

Springer

Lecture Notes in Electrical Engineering

Volume 870

Series Editors

Leopoldo Angrisani, Department of Electrical and Information Technologies Engineering, University of Napoli Federico II, Naples, Italy
Marco Arteaga, Departament de Control y Robótica, Universidad Nacional Autónoma de México, Coyoacán, Mexico
Bijaya Ketan Panigrahi, Electrical Engineering, Indian Institute of Technology Delhi, New Delhi, Delhi, India
Samarjit Chakraborty, Fakultät für Elektrotechnik und Informationstechnik, TU München, Munich, Germany
Jiming Chen, Zhejiang University, Hangzhou, Zhejiang, China
Shanben Chen, Materials Science and Engineering, Shanghai Jiao Tong University, Shanghai, China
Tan Kay Chen, Department of Electrical and Computer Engineering, National University of Singapore, Singapore, Singapore
Rüdiger Dillmann, Humanoids and Intelligent Systems Laboratory, Karlsruhe Institute for Technology, Karlsruhe, Germany
Haibin Duan, Beijing University of Aeronautics and Astronautics, Beijing, China
Gianluigi Ferrari, Università di Parma, Parma, Italy
Manuel Ferre, Centre for Automation and Robotics CAR (UPM-CSIC), Universidad Politécnica de Madrid, Madrid, Spain
Sandra Hirche, Department of Electrical Engineering and Information Science, Technische Universität München, Munich, Germany
Faryar Jabbari, Department of Mechanical and Aerospace Engineering, University of California, Irvine, CA, USA
Limin Jia, State Key Laboratory of Rail Traffic Control and Safety, Beijing Jiaotong University, Beijing, China
Janusz Kacprzyk, Systems Research Institute, Polish Academy of Sciences, Warsaw, Poland
Alaa Khamis, German University in Egypt El Tagamoa El Khames, New Cairo City, Egypt
Torsten Kroeger, Stanford University, Stanford, CA, USA
Yong Li, Hunan University, Changsha, Hunan, China
Qilian Liang, Department of Electrical Engineering, University of Texas at Arlington, Arlington, TX, USA
Ferran Martín, Departament d'Enginyeria Electrònica, Universitat Autònoma de Barcelona, Bellaterra, Barcelona, Spain
Tan Cher Ming, College of Engineering, Nanyang Technological University, Singapore, Singapore
Wolfgang Minker, Institute of Information Technology, University of Ulm, Ulm, Germany
Pradeep Misra, Department of Electrical Engineering, Wright State University, Dayton, OH, USA
Sebastian Möller, Quality and Usability Laboratory, TU Berlin, Berlin, Germany
Subhas Mukhopadhyay, School of Engineering & Advanced Technology, Massey University, Palmerston North, Manawatu-Wanganui, New Zealand
Cun-Zheng Ning, Electrical Engineering, Arizona State University, Tempe, AZ, USA
Toyoaki Nishida, Graduate School of Informatics, Kyoto University, Kyoto, Japan
Federica Pascucci, Dipartimento di Ingegneria, Università degli Studi "Roma Tre", Rome, Italy
Yong Qin, State Key Laboratory of Rail Traffic Control and Safety, Beijing Jiaotong University, Beijing, China
Gan Woon Seng, School of Electrical & Electronic Engineering, Nanyang Technological University, Singapore, Singapore
Joachim Speidel, Institute of Telecommunications, Universität Stuttgart, Stuttgart, Germany
Germano Veiga, Campus da FEUP, INESC Porto, Porto, Portugal
Haitao Wu, Academy of Opto-electronics, Chinese Academy of Sciences, Beijing, China
Walter Zamboni, DIEM - Università degli studi di Salerno, Fisciano, Salerno, Italy
Junjie James Zhang, Charlotte, NC, USA

The book series *Lecture Notes in Electrical Engineering* (LNEE) publishes the latest developments in Electrical Engineering - quickly, informally and in high quality. While original research reported in proceedings and monographs has traditionally formed the core of LNEE, we also encourage authors to submit books devoted to supporting student education and professional training in the various fields and applications areas of electrical engineering. The series cover classical and emerging topics concerning:

- Communication Engineering, Information Theory and Networks
- Electronics Engineering and Microelectronics
- Signal, Image and Speech Processing
- Wireless and Mobile Communication
- Circuits and Systems
- Energy Systems, Power Electronics and Electrical Machines
- Electro-optical Engineering
- Instrumentation Engineering
- Avionics Engineering
- Control Systems
- Internet-of-Things and Cybersecurity
- Biomedical Devices, MEMS and NEMS

For general information about this book series, comments or suggestions, please contact leontina.dicecco@springer.com.

To submit a proposal or request further information, please contact the Publishing Editor in your country:

China

Jasmine Dou, Editor (jasmine.dou@springer.com)

India, Japan, Rest of Asia

Swati Meherishi, Editorial Director (Swati.Meherishi@springer.com)

Southeast Asia, Australia, New Zealand

Ramesh Nath Premnath, Editor (ramesh.premnath@springernature.com)

USA, Canada:

Michael Luby, Senior Editor (michael.luby@springer.com)

All other Countries:

Leontina Di Cecco, Senior Editor (leontina.dicecco@springer.com)

**** This series is indexed by EI Compendex and Scopus databases. ****

More information about this series at https://link.springer.com/bookseries/7818

Jitendra Kumar · Manoj Tripathy · Premalata Jena
Editors

Control Applications in Modern Power Systems

Select Proceedings of EPREC 2021

Springer

Editors
Jitendra Kumar
Department of Electrical Engineering
National Institute of Technology Jamshedpur
Jamshedpur, Jharkhand, India

Manoj Tripathy
Department of Electrical Engineering
Indian Institute of Technology Roorkee
Roorkee, India

Premalata Jena
Department of Electrical Engineering
Indian Institute of Technology Roorkee
Roorkee, India

ISSN 1876-1100 ISSN 1876-1119 (electronic)
Lecture Notes in Electrical Engineering
ISBN 978-981-19-0192-8 ISBN 978-981-19-0193-5 (eBook)
https://doi.org/10.1007/978-981-19-0193-5

© The Editor(s) (if applicable) and The Author(s), under exclusive license to Springer Nature Singapore Pte Ltd. 2022
This work is subject to copyright. All rights are solely and exclusively licensed by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.
The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.
The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, expressed or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

Preface

This book presents select proceedings of the Electric Power and Renewable Energy Conference 2021 (EPREC-2021). It provides rigorous discussions, case studies, and recent developments in the emerging areas of control application in power system, especially controllers of DGs, microgrid control application, operation of FACTS and HVDC, smart grid, etc. The readers would be benefited in enhancing their knowledge and skills in these domain areas. The book will be a valuable reference for beginners, researchers, and professionals interested in control applications in power system.

Jamshedpur, India — Jitendra Kumar
Roorkee, India — Manoj Tripathy
Roorkee, India — Premalata Jena

Contents

About the Editors

Dr. Jitendra Kumar is currently an Assistant Professor at the Department of Electrical Engineering, National Institute of Technology Jamshedpur, India. He received his B.Tech. from IMS Engineering College, Ghaziabad, India, in 2009, M.Tech. from the National Institute of Technology Kurukshetra, Kurukshetra, in 2011, and the Ph.D. degree in electrical engineering from the Indian Institute of Technology (IIT) Roorkee, in 2017. He has over 4 years of experience teaching subjects like power systems, advanced power systems, control systems, control and instrumentation, power system operation, and control, signal and system, power system protection, circuit and network theory. He has many papers in reputed journals. His major areas of research interests include power system protection and restructuring, protection algorithms design in smart grid and microgrid environment, design of protection algorithms in FACTS environment.

Dr. Manoj Tripathy received his B.E. degree in electrical engineering from Nagpur University, Nagpur, India, in 1999; M.Tech. degree in instrumentation and control from Aligarh Muslim University, Aligarh, India, in 2002; and a Ph.D. degree from the IIT Roorkee, India, in 2008. He is currently working as an Associate Professor in the Department of Electrical Engineering, IIT Roorkee, India. His fields of interest are wavelets, neural networks, optimization techniques, content-based image retrieval, digital instrumentation, digital protective relays, and digital speech processing. Dr. Tripathy is a reviewer for various international journals in the area of power systems and speech.

Dr. Premalata Jena is currently an Associate Professor at the Department of Electrical Engineering, IIT Roorkee, Uttarakhand, India. She received her B.Tech. degree in electrical engineering from the Utkal University, Bhubaneswar, India, in 2001, the M.Tech. degree in Electrical Engineering from IIT Kharagpur, in 2006, and the Ph.D. degree from the IIT Kharagpur, India, in 2011. Dr. Jena has seven years of teaching experience. She is an IEEE member and INAE, Young Associate. She received many awards such as the Women Excellence Award and Early Carrier

Research Award, SERB, DST, Government of India, New Delhi, INAE Young Engineer Award, POSOCO Power System Awards, in 2013. She has published many papers in different reputed journals and conferences. Her fields of interest are Smart Grid, Smart grid technology, and protection, Microgrid, Microgrid Protection, Signal processing application to power system relaying, Power system Protection, Protection Issues with FACTS Devices, Protection Scheme Development for a line with FACTS devices, Disturbance localization, Signal processing application for disturbance localization.

Importance of Secondary Controller and Its Parameters Optimization Using Particle Swarm Optimization Technique for AGC

Hiramani Shukla, More Raju, and Prashant Khare

Abstract The power balancing mechanism in power system is handled by automatic generation control (AGC), in which the secondary controller plays an important role. Here, in the present manuscript, we present the importance of secondary controller in single area thermal and two area thermal-thermal and thermal-hydro systems. It is observed that with secondary controller, the system dynamics do not possess any steady state error which was found without secondary controller. Various classical controllers namely proportional integral derivative (PID), proportional integral (PI) and integral (I) are used as secondary controllers and the corresponding gains are obtained by using particle swarm optimization (PSO) method and integral squared error (ISE) method. The PID controller shows superiority than I and PI controllers in the view of settling time, overshoots and oscillations. It is also observed that with PID controller the cost function value is considerably reduced. For this study, the electric governor is used for hydro generation.

Keywords Automatic generation control (AGC) · Particle swarm optimization (PSO) · PID controller · Steady state error

1 Introduction

Whenever the load demand of a control area changes, it shows the adverse effect on system steady operating point that may lead to outages of generation causing the mismatches in frequency and scheduled tie-line power flows. Automatic generation control (AGC) as the name signifies, regulates the power flow between different areas while holding the frequency constant [1].

H. Shukla (✉) · M. Raju · P. Khare
Department of Electrical Engineering, Maulana Azad National Institute of Technology Bhopal, Bhopal, India
e-mail: hs.193113004@manit.ac.in

J. Kumar et al. (eds.), *Control Applications in Modern Power Systems*, Lecture Notes in Electrical Engineering 870, https://doi.org/10.1007/978-981-19-0193-5_1

In AGC, maintaining frequency and tie-line powers within precise limits is done by selecting suitable secondary controller (SC). Ismayil et al. [2] have studied the AGC of isolated/single area system. Authors in [3] studied about the AGC of isolated and interconnected system. In [4], the authors have explained the single area AGC with thermal units. The single area AGC and automatic voltage regulator (AVR) problem is discussed in [5]. The frequency fluctuation compensation for isolated system using combination of linear quadratic regulator (LQR) and vibration compensator (VC) is described in [6]. To maintain the nominal frequency in single area power system, Fariya and Rana [7] have proposed linear quadratic Gaussian (LQG) controller for single area power system. The authors in [8], also considered the AGC for hydrothermal unit. Multi-area AGC system is implemented in [9] while the Nidhi Gupta in [10] and Anshuman Panda in [11] discussed about multi-area multi-source AGC for super conducting magnetic energy storage system (SMES) and dish-stirling solar thermal system (DSTS) respectively.

The SC used in AGC plays an important role to bring back the steady state error present in the power system outputs, i.e. frequency and tie-line power deviations. The primary governor control (PGC) mechanism is very fast whose time constant is in the order of seconds, whereas SC response is slow in nature with time constant of the order of minutes. The PGC mechanism alone is not sufficient to suppress the oscillations and requires the suitable SC. Hence, the selection of proper SC is crucial in AGC studies.

Ghoshal [1] utilized the popular proportional-integral-derivative (PID) controller as SC to multi-area AGC problem. The fractional PID (FOPID) [2], I/PID [4], PI [5] and I/PI [8], PI in [9], I in [10] and PIDF in [11] are utilized as SC for AGC studies.

The one more important thing that is required to consider for SC is the proper selection of its parameters. The parameters of SCs must be selected carefully; otherwise the system dynamics will drive the system into unstable condition. The authors in [1, 4] and [9–11] utilized particle swarm optimization (PSO) technique for retrieval of the controller parameters. The author in [1] has shown the supremacy of PSO technique when compare with popular other methods namely genetic algorithm (GA) and hybridized GA-simulated annealing (SA) methods. Authors in [12, 13] have applied the PSO in various applications like MPPT for PV grid integration and hybrid power system generation sizing. But the literature in [12, 13] does not discuss the application of PSO for AGC. This motivated the authors to consider PSO technique for the present study to optimize the parameters of SCs. [14] introduces different Inertia Weight strategies, this paper uses one of the Inertia Weight strategies i.e. constant inertia weight. Algorithm of PSO applied in this paper is inspired from [15] which was developed by Eberhart and Kennedy in 1995.

Summarizing the above discussion, the main motive of this paper is to

(a) Develop the single/isolated area thermal system.
(b) Develop the two area system with thermal-thermal generations and thermal-hydro generations separately.
(c) Obverse the system dynamics with and without various SCs.

(d) Compare the dynamics obtained in (c) to show the effect of SC for systems considered in (a) and (b) and to decide the best SC in terms of dynamics and convergence characteristics.

2 System Investigated

The isolated and two area power systems are considered for investigations. In each case, the system is studied with and without SCs. The SCs considered in this study are PID, PI and I controllers. The system capacities ratio is 1:1 for two area system. The step perturbation of 1% is considered in area-1 of two area and isolated system. The popularly known integral squared error (ISE) method is employed as cost function, J (1) with simulation time T (s).

$$J = \int_{0}^{T} \left(\Delta f_{\text{area-1}}^{2} + \Delta f_{\text{area-2}}^{2} + \Delta P_{\text{tie}}^{2}\right)\mathrm{d}t \tag{1}$$

The optimization of various controllers' parameters is subjected to (2).

$$\begin{aligned} &K_{I\text{-area-1,2}}^{\min} \le K_{I}^{*} \le K_{I\text{-area-1,2}}^{\max} \\ &K_{P\text{-area-1,2}}^{\min} \le K_{P}^{*} \le K_{P-\text{area-1,2}}^{\max} \\ &K_{D-\text{area-1,2}}^{\min} \le K_{D}^{*} \le K_{D-\text{area-1,2}}^{\max} \\ &N_{\text{area-1,2}}^{\min} \le N^{*} \le N_{D-\text{area - 1,2}}^{\max} \end{aligned} \tag{2}$$

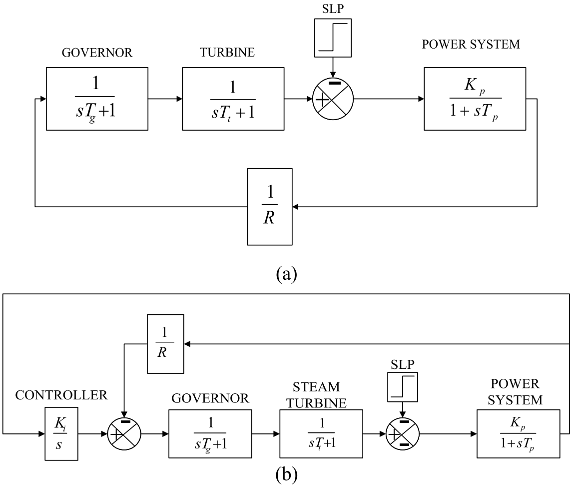

Fig. 1 Single area thermal system. **a** Without SC. **b** With SC

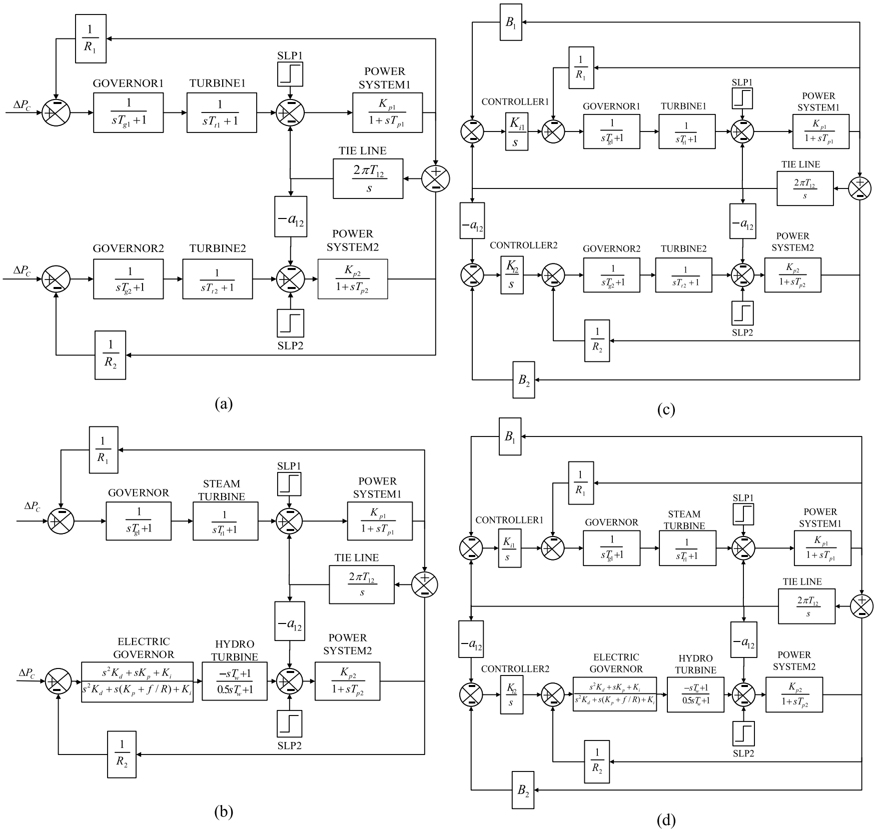

Fig. 2 Two area interconnected system. **a** Thermal-thermal without SC. **b** Thermal-hydro without SC. **c** Thermal-thermal with SC. **d** Thermal-hydro with SC

The single area thermal system with and without SC is shown in Fig. 1. Similarly, two area interconnected thermal-thermal and thermal-hydro system with and without SC is represented in Fig. 3 (Fig. 2).

3 Particle Swarm Optimization (PSO)

The PSO technique was introduced by Kennedy and Eberhart [15]. The various steps in the PSO are explained by the authors in [4, 9]. Here, for optimization of various SCs parameters PSO technique is utilized with the algorithm parameters mentioned below. The flow chart of PSO technique is given in Fig. 3.

where,

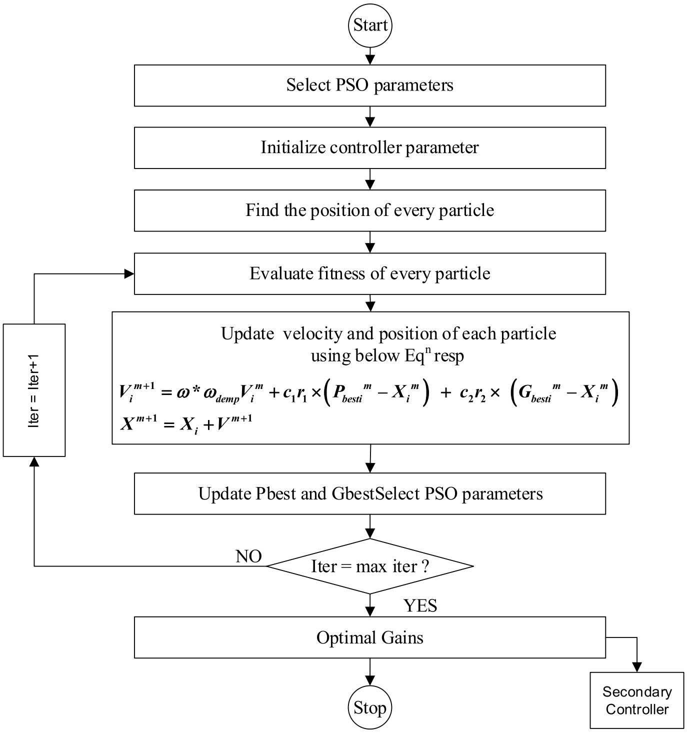

Fig. 3 Flowchart of PSO technique

$i = 1, \ldots\ldots Z,$

Z	is total number of particles,
M	is the current iteration number,
c_1	and c_2 are acceleration constants,
r_1 and r_2	are random numbers range (0 1),
$V_i{}^m$	is velocity of particle i at mth iteration,
(ω)	is inertia weight and (ω_{damp}) is damping factor,
$X_i{}^m$	is current position of the particle i of iteration m,
$P_{\text{best}i}{}^m$	is previous best position of particle i,
$G_{\text{best}i}{}^m$	is global best position of particles.

The PSO technique is utilized to extract the various controllers' parameters. The PSO parameters considered are: learning rates $c_1 = c_2 = 2$, damping factor (ω_{damp}) = 0.99, inertia weight (ω) = 1, population size (n) = 10 and iterations (iter) = 100.

4 Results and Discussion

4.1 Single Area System

Initially, the single area thermal system is considered for study. The system dynamics are compared for with and without controllers. The various controllers used are PID, PI and I (Fig. 4.). The transfer function models of these controllers are represented as in Eqs. (3)–(5).

$$G(s)_{\text{PI-controller}} = \frac{K_I}{s} \tag{3}$$

$$G(s)_{\text{PI-controller}} = K_P + \frac{K_I}{s} \tag{4}$$

$$G(s)_{\text{PID-controller}} = K_P + \frac{K_I}{s} + K_D \frac{N}{1 + \frac{N}{s}} \tag{5}$$

where, K_I, K_P, K_D and N are respective controller gains and filter coefficient.

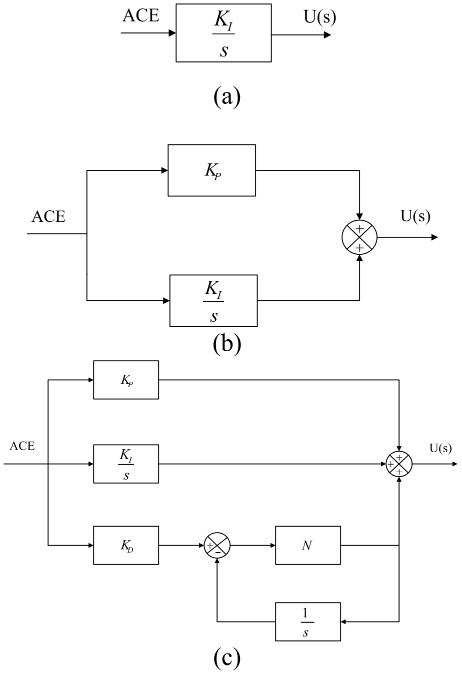

Fig. 4 I, PI and PID controllers

The system dynamics without controller are shown in Fig. 5. From Fig. 5, clearly we can see the steady state error of 0.0235 Hz in the frequency response with an undershoot of 0.0306 Hz.

Similarly, when the system is supplied with various SCs (Eqs. (6)–(8)), the comparative frequency response is shown among them in Fig. 6.

The optimized controllers obtained are (6)–(8).

$$G(s)_{\text{I - controller}} = \frac{0.4176}{s} \tag{6}$$

$$G(s)_{\text{PI - controller}} = \frac{1}{s} + 0.6305 \tag{7}$$

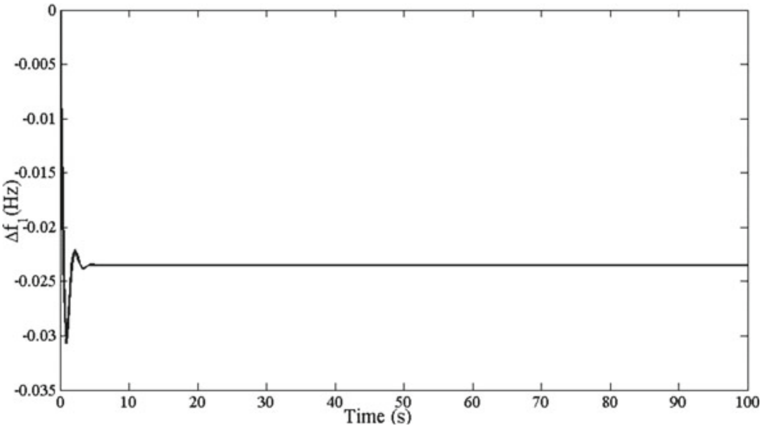

Fig. 5 Dynamic response of frequency without SCs

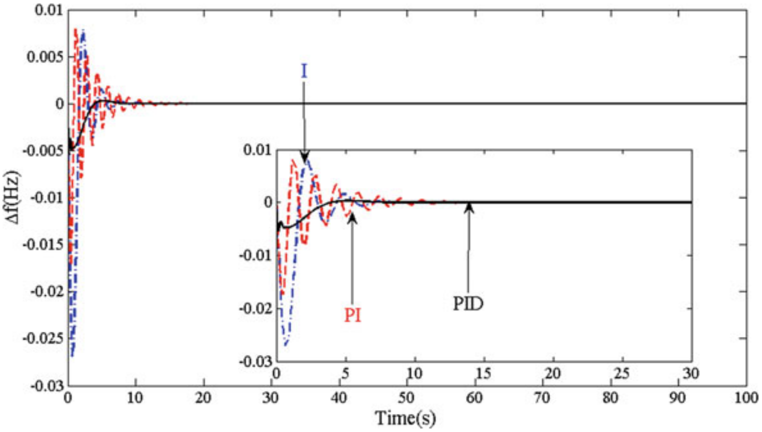

Fig. 6 Comparison of dynamic response of frequency for I, PI and PID controllers

$$G(s)_{\text{PID - controller}} = \frac{1}{s} + 1 + \frac{60.6414}{1 + \frac{60.6414}{s}} \tag{8}$$

The settling time of frequency with PID, PI and I are 10.78 s and 27.63 s and 9.097 s respectively. The peak overshoots are 0.0079 Hz, 0.0079 Hz, 0.0003 Hz and the peak undershoots are 0.0271 Hz, 0.0172 Hz, 0.0054 Hz and the cost functions obtained are 6.4585×10^{-4}, 1.5860×10^{-4}, 4.0178×10^{-5} for I, PI and PID controllers respectively. The convergence curve for PID controller is shown in Fig. 7. Also the cost comparison is shown in Fig. 8 for various controllers.

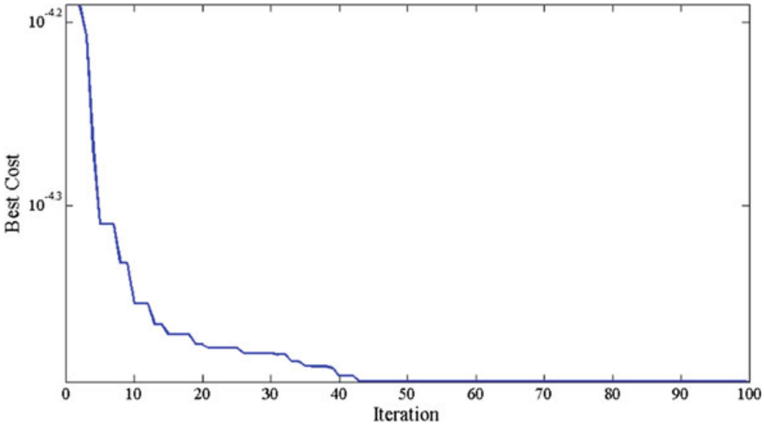

Fig. 7 Convergence curve of PID controller

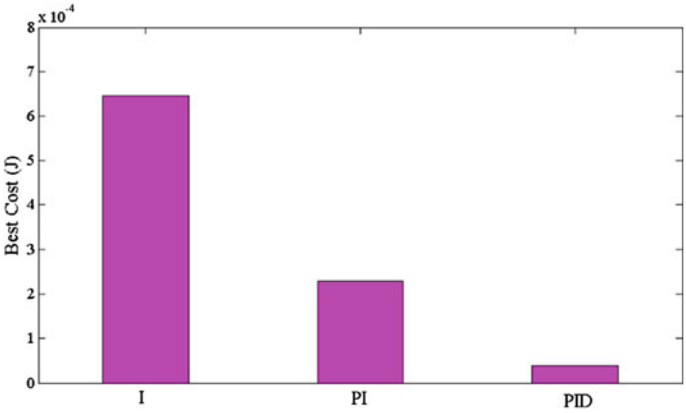

Fig. 8 Comparison of cost function (J) for I, PI and PID controllers

From Figs. 5, 6, 7 and 8 the following observations are made. From Fig. 5 the settling time (s) for PID controller 9.097 s which is lesser than settling times of PI and I controllers. Similarly, the peak overshoot and peak under shoots are also lesser in magnitudes as compared to that of I and PI controllers. This shows the superiority of PID over the remaining controllers studied in the system. Further the cost value of PID is lesser than other controllers.

4.2 Two Area System

In this case, the two different systems have been considered for study.

(a) Two area thermal-thermal system.
(b) Two area hydro-thermal system.

(a) **Two area thermal-thermal system**. The two equal capacities thermal areas are interconnected via tie-line is considered for study. Here also the PID, PI and I controllers are treated as SCs whose parameters are optimized with PSO and the corresponding transfer functions are given below in Eqs. (9)–(11).

$$\begin{aligned} G(s)_{\substack{\text{I - controller}\\ \text{AREA - 1}}} &= \frac{0.7855}{s} \\ G(s)_{\substack{\text{I - controller}\\ \text{AREA - 2}}} &= \frac{0.1000}{s} \end{aligned} \tag{9}$$

$$\begin{aligned} G(s)_{\substack{\text{PI - controller}\\ \text{AREA - 1}}} &= \frac{0.8136}{s} + 0.2790 \\ G(s)_{\substack{\text{PI - controller}\\ \text{AREA - 2}}} &= \frac{0.1000}{s} + 1 \end{aligned} \tag{10}$$

$$\begin{aligned} G(s)_{\substack{\text{PID - controller}\\ \text{AREA - 1}}} &= \frac{1}{s} + 0.9999 + 0.9999\frac{73.4556}{1 + \frac{73.4556}{s}} \\ G(s)_{\substack{\text{PID - controller}\\ \text{AREA - 2}}} &= \frac{0.1002}{s} + 0.2016 + 0.9966\frac{58.5712}{1 + \frac{58.5712}{s}} \end{aligned} \tag{11}$$

With the above controllers, the frequency and tie-line power dynamics are plotted and compared in Fig. 9 for two area thermal-thermal system. The cost curves and cost function values are compared in Figs. 10, 11. The dynamic parameters such as settling time (ST), peal overshoots (POs) and undershoots (PUs) are noted in Table 1. In all parameters the PID controller is outperforming I and PI controllers. The convergence characteristics are also better for PID controller.

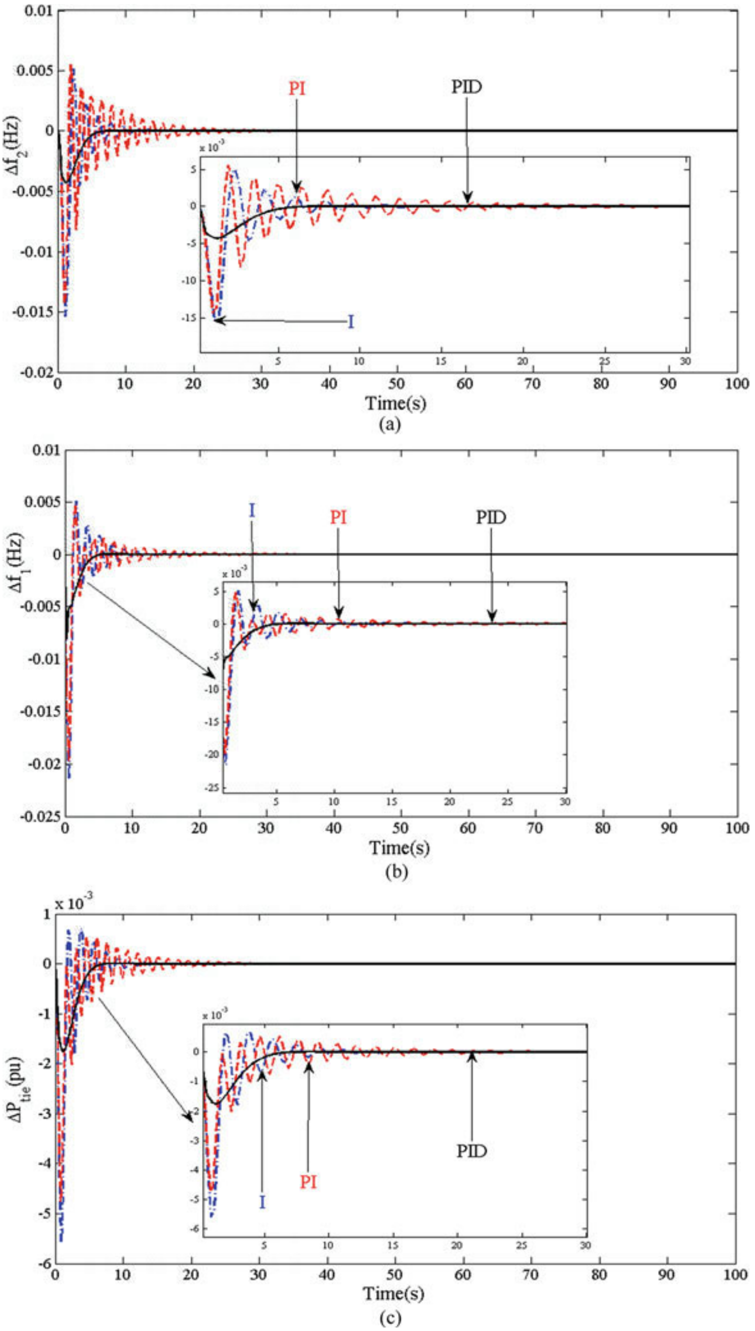

Fig. 9 Comparison of dynamic responses for I, PI and PID controllers for two area thermal system. **a** Frquency variation in 1st area. **b** Frquency variation in 2nd area. **c** Tie-line power variation

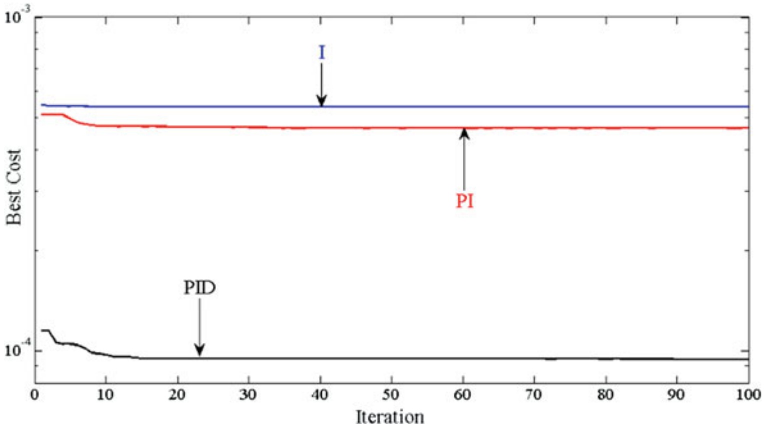

Fig. 10 Convergence curves of I, PI, PID controller

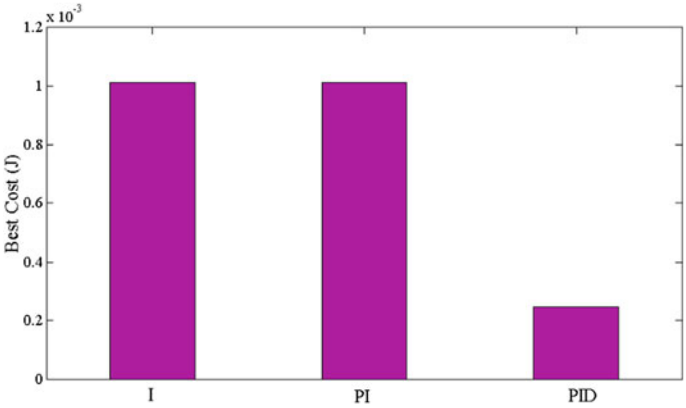

Fig. 11 Cost function comparision for thermal-thermal system

Table 1 The ST (s), POs and PUs comparison for two area thermal-thermal system

Dynamic response	Δf_1			Δf_2			ΔP_{tie}		
Controller	ST	PO	PU	ST	PO	PU	ST	PO	PU
I	17.94	0.00511	0.02148	23.96	0.00512	0.01539	16.44	0.00070	0.00558
PI	28.65	0.00486	0.01975	38.94	0.00551	0.01433	32.91	0.00055	0.00475
PID	8.792	NIL	0.00800	10.38	NIL	0.004278	10.12	NIL	0.00174

(b) **Two area thermal-hydro system**: The two equal capacities thermal and hydro areas are interconnected in this case. Similar to case (a), the I, PI and PID are utilized as SC and the optimal parameters are obtained using PSO technique. The obtained controller transfer functions are given below in Eqs. (12)–(14).

$$\begin{aligned} G(s)_{\text{I - controller,AREA - 1}} &= \frac{1}{s} \\ G(s)_{\text{I - controller,AREA - 2}} &= \frac{0.1}{s} \end{aligned} \tag{12}$$

$$\begin{aligned} G(s)_{\text{PI - controller,AREA - 1}} &= 0.1927 + \frac{0.9499}{s} \\ G(s)_{\text{PI - controller,AREA - 2}} &= 0.1 + \frac{0.1000}{s} \end{aligned} \tag{13}$$

$$\begin{aligned} G(s)_{\substack{\text{PID - controller} \\ \text{AREA - 1}}} &= \frac{1}{s} + 0.9997 + 1\frac{97.8607}{1 + \frac{97.8607}{s}} \\ G(s)_{\substack{\text{PID - controller} \\ \text{AREA - 2}}} &= \frac{0.01}{s} + 0.1932 + 0.1665\frac{108.9545}{1 + \frac{108.9545}{s}} \end{aligned} \tag{14}$$

The observation of Figs. 12, 13 and 14 and Table 2 shows that with PID controller the dynamic parameters are lesser and also converge quickly. Hence PID controller is superior to I and PI controllers.

5 Conclusion

This paper describes the importance of the secondary controller in isolated power system. Without controller, it is seen that there exists steady state error. The studies in two area thermal-thermal and thermal-hydro revealed that PID is outperforming I and PI controllers in terms of dynamic parameters such as settling time, peak overshoots and peak undershoots as per values obtained from the simulation results. It is clearly observed from the bar graph that the cost function value obtained for PID controller is approximately five times lesser as compared to I and PI controllers.

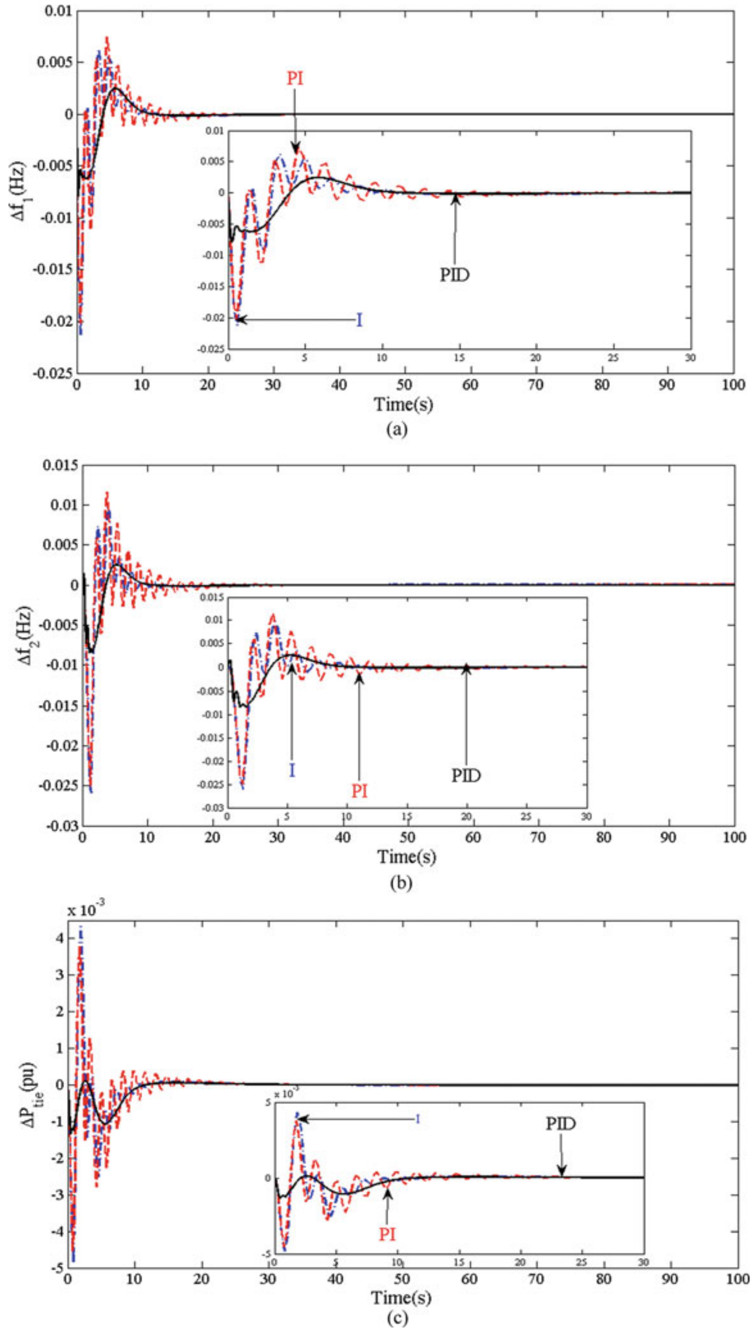

Fig. 12 The comparison of dynamic responses for I, PI and PID controllers for two area thermal system. **a** Frquency variation in 1st area. **b** Frquency variation in 2nd area. **c** Tie-line power variation

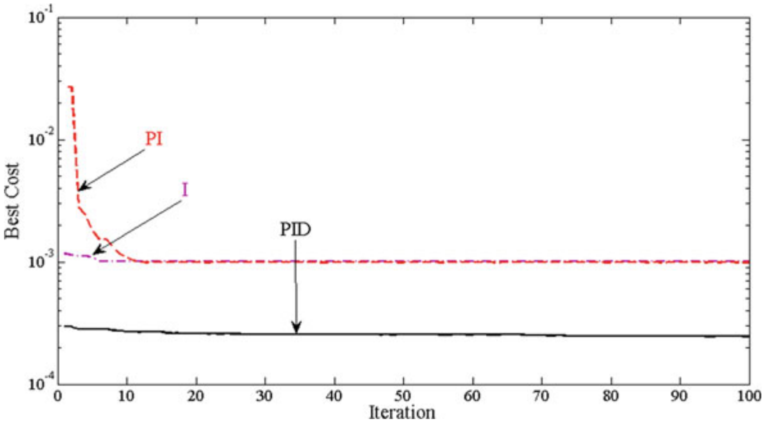

Fig. 13 The comparison of convergence curves for I, PI and PID controllers for two area thermal-hydro system

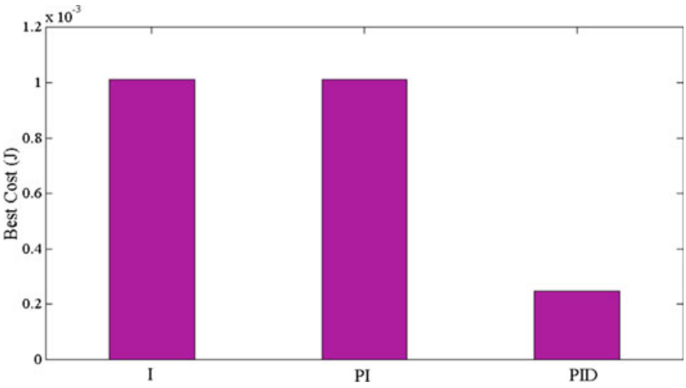

Fig. 14 Cost function comparision for thernal-hydro systems

Table 2 The ST (s), POs and PUs comparison for two area thermal-hydro system

Dynamic response	Δf_1			Δf_2			ΔP_{tie}		
Controller	ST	PO	PU	ST	PO	PU	ST	PO	PU
I	20.74	0.006238	0.02136	25.17	0.009737	0.02596	31.19	0.00433	0.004842
PI	28.85	0.00742	0.02016	29.09	0.0116	0.0295	32.63	0.003778	0.004533
PID	14.14	0.002457	0.007804	12.94	0.00248	0.00799	17.16	0.0001131	0.001263

References

1. Ghoshal SP (2004) Optimizations of PID gains by particle swarm optimizations in fuzzy based automatic generation control. Electr Power Syst Res 72(3):203–212
2. Ismayil C, Sreerama Kumar R, Sindhu TK (2014) Automatic generation control of single area thermal power system with fractional order PID (PIλDμ) controllers. In: 3rd international conference on advances in control and optimization of dynamical systems (2014), vol 47, pp 552–557
3. Usman A, Divakar BP (2012) Simulation study of load frequency control of single and two area systems. In: 2012 IEEE global humanitarian technology conference. Seattle, WA, pp 214–219
4. Prasad B, Prasad CD, Kumar GP (2015) Effect of load parameters variations on AGC of single area thermal power system in presence of integral and PSO-PID controllers. In: 2015 conference on power, control, communication and computational technologies for sustainable growth (PCCCTSG), Kurnool, pp 64–68
5. Grover H, Verma A, Bhatti TS (2020) Load frequency control & automatic voltage regulation for a single area power system. In: 2020 IEEE 9th power india international conference (PIICON), SONEPAT, India, pp 1–5 (2020)
6. Tabassum F, Rana MS (2019) Compensation of frequency fluctuation in a single area power system using LQR-VC. In: 2019 1st international conference on advances in science, engineering and robotics technology (ICASERT), Dhaka, Bangladesh, pp 1–4
7. Tabassum F, Rana MS (2019) Design an optimal LQG control for maintaining nominal frequency of a single area power system. In: 2019 international conference on computer, communication, chemical, materials and electronic engineering (IC4ME2), Rajshahi, Bangladesh, pp 1–4
8. Nanda J et al (2006) Some new findings on automatic generation control of an interconnected hydrothermal system with conventional controllers. IEEE Trans Energy Convers 21(1):187–194
9. Yinsha W, Wenyi L, Zhiwen L (2019) Research on PSO-fuzzy algorithm optimized control for multi-area AGC system with DFIG wind turbine. In: 14th IEEE conference on industrial electronics and applications (ICIEA), pp 877–881
10. Gupta N, Kumar N, Singh N (2018) PSO tuned AGC strategy of multi area multi-source power system incorporating SMES. In: 2nd IEEE international conference on power electronics, intelligent control and energy systems (ICPEICES), pp 273–279
11. Panda A, Das A, Pati, S.S., Mishra, S.K.: A PSO based PIDF controller for multiarea multi-source system incorporating dish stirling solar system. In 2019 International Conference on Intelligent Computing and Control Systems (ICCS) pp. 1458–1462 (2019).
12. Priyadarshi N, Padmanaban S, Holm-Nielsen JB, Blaabjerg F, Bhaskar MS (2019) An experimental estimation of hybrid ANFIS–PSO-based MPPT for PV grid integration under fluctuating sun irradiance. IEEE Syst J 14(1):1218–1229
13. Llerena-Pizarro O, Proenza-Perez N, Tuna CE, Silveira JL (2020) A PSO-BPSO technique for hybrid power generation system sizing. IEEE Lat Am Trans 18(08):1362–1370
14. Bansal et al (2011) Inertia weight strategies in particle swarm optimization. In: 2011 third world congress on nature and biologically inspired computing, Salamanca, pp 633–640
15. Kennedy J, Eberhart RC (1995) Particle swarm optimization. In: Proceedings of IEEE international conference on neutral networks. IEEE Press, Perth, pp 1942–1948

Section of Suitable GRC Structure for Dual Area Thermal System Under 2DOF-PID Controller

CH. Naga Sai Kalyan and Chintalapudi V. Suresh

Abstract In this paper, selection of suitable generation rate constraint (GRC) structure for optimal control of dual area thermal system is presented. Two different GRC models of open loop and closed loop structures are investigated in this work to find the one which suits better for the study of automatic generation control (AGC). Two-degree of freedom-PID (2DOF-PID) is enacted as regulator optimized with a hybridized soft computing mechanism of artificial electric field (HAEFA) algorithm. Controller parameter optimization procedure is laid with respective of minimizing the error squared over integral (ISE) function. Simulation results reveal the best suitable model of GRC for thermal system to obtain better functioning in AGC design.

Keywords AGC · 2DOF-PID · GRC · HAEFA · ISE

1 Introduction

AGC is performing an essential role in regulating the dynamical behavior of interconnected modern day power systems. To acquire the accurate realistic essence and exact insight of AGC study, it is necessary to consider the inherited physical constraints of the generation units in to account which adversely affects the dynamical behavior of the power system. One such constraints is GRC which influences the generation units in altering the power generation within stipulated time duration by laying physical constraints on the turbine unit. The nonlinearity features of the GRC greatly influences the generation characteristics of generation unit. Thus, AGC design without GRC consideration may not be recommended and no way closes to the practical one [1]. The key idea behind the consideration of GRC is to eliminate the excessive drop out of steam from the boiler during rapid power change which cause steam to condensate because of adiabatic expansion. The GRC effect will more noticeable in case of system subjugated to large step load variations. In this event, the generation unit tries to increase the generation rapidly but the GRC limits the generation simply by rejecting the disturbances. These consequences of GRC will get toughened

---

CH. N. S. Kalyan (✉) · C. V. Suresh
EEE Department, Vasireddy Venkatadri Institute of Technology, Guntur, Andhra Pradesh, India

J. Kumar et al. (eds.), *Control Applications in Modern Power Systems*, Lecture Notes in Electrical Engineering 870, https://doi.org/10.1007/978-981-19-0193-5_2

by employing another nonlinearity of governor dead band (GDB). When the GRC will get combined with GDB, the frequency may not reach the nominal value within prescribed time. But, the study of AGC may not in a realistic one when nonlinearities are not perceived.

Literature survey reveals that researchers had perceived different test system models include combination of various conventional units and also considering renewable integration for AGC study [2]. A conventional thermal unit of dual area system is investigated without [3] and with [4] considering GRC. In [5], GRC and GDB are perceived for the investigation of same test system model. A GRC of open loop modeling had been investigated by the researchers in [6] for three area thermal system. In [7], closed loop GRC modeling is presented and its effect on system performance is monitored. In [8], adopted both GRC and GDB for thermal units to disclose its impact on performance simultaneously. Anti-GRC structure was proposed in [9], to eliminate the consequences exhibiting on frequency stability.

From the above review, it is come to know that the modeling of GRC for AGC study is a major concern. In this present work, GRC modeling of open loop and closed loop structures is adopted for thermal unit to deliberate the best suitable model to achieve optimal AGC. Similar type of research had been reported in [10], but limited to usage of particle swarm optimization (PSO) tuned traditional PID regulator. So, in this paper a higher order controller of 2DOF-PID is employed which is fine tuned with a new HAEFA approach.

2 Investigative Model

Dual area thermal system with the structure of reheat turbines including the constraints of GDB and GRC is shown in Fig. 1 [10]. However, the modeling of GRC can be done either in open loop or in closed loop and is rendered in Fig. 2. The value of 10%/min is taken as GRC for both open loop and closed loop models. The parameters of the dual area system including the GDB that are considered to accomplish this work are given in Table 1 and are taken from [10].

3 Controller and Optimization

3.1 2DOF-PID Controller

Aiming to damp out the oscillations in an effective manner, higher order controller of 2DOF-PID shown in Fig. 3, [11] is acted as secondary regulator in both areas. In this present work, error squared over integral (ISE) function is taken as objective function to find the gains of 2DOF-PID controller using HAEFA optimization. As the objective function, ISE is very effective in maintaining the average momentum with