Signal Processing and Renewable Energy
June 2024, (pp. 35-48)
ISSN: 2588-7327
eISSN: 2588-7335

Robust PID Optimized Load-Frequency Controller of a Two-Area Power System Considering Systems Uncertainties

Maryam Ashoory [1], Ali Naderi Saatlo [1*]

[1] Microwave and Antenna Research Center, Urmia Branch, Islamic Azad University, Urmia, Iran.

Received: 30-Jan-2024, Accepted: 12-Apr-2024.

Abstract

Load Frequency Control (LFC) has been a major subject in electric power systems and has become a more significant system in recent years. This paper aims to investigate the problem of LFC in interconnected power systems in order to obtain a robust state. In this paper, a design method for a robust controller, based on PID, has been presented to overcome the robustness against uncertainties. To achieve optimal PID, Particle Swarm Optimization (PSO) is employed to obtain coefficients of the SMC. Variations of uncertain parameters are considered between -40% and +40% of nominal values. The simulation results demonstrate that the system response with the proposed PID is better than the conventional PID controller. It is also shown that the transient response of the tie line power can be improved.

Keywords: Load Frequency Control, PID Controller, PSO Algorithm.

1. INTRODUCTION

Load-Frequency Control (LFC) is one of the problems in electric power systems because the loading in a power system is forced to change [1]. This change has affected the frequency change in power systems. Moreover, it is obvious that the operation objectives of the LFC are to preserve uniform frequency for separating the load between generators and controlling the tie-line interchange schedules [2]. There are errors in the quantities due to unforeseen load variations which cause maladjustment between the generator and load demand. One of the tasks of Automatic Generating Control (AGC) is to improve the transient state and to warrant zero steady-state errors of these two variables. Therefore, LFC is employed to preserve the system frequency and the tie-line power near to the scheduled values [3].

***Corresponding Authors Email:** ali.n.1384@gmail.com

A modified version of particle swarm optimization and innovative objective function was proposed in [4] for the optimal coordination of power system stabilizers. An innovative objective function was proposed for performing the optimization, which was a weight function of two functions.

For large scale, electric power systems are usually composed of interconnected subsystems. The connection between the subsystem or control areas (tie-line) is important to maintain system frequency [5-8]. Also, each area has its own generator and it is responsible for its own load and scheduled exchange with neighboring areas. In a power system, each area contains different uncertainties and different kinds of disturbances due to increased complexity, system modeling errors, and changing power system structure [9-11].

For multi-area power systems, cascaded controllers are applied for LFC [12, 13]. A GWO-based PI-PD controller is implemented, which has shown effective controllability [14-16], while the bat algorithm (BA)-tuned PD-PID is used for an electric vehicle to subdue frequency oscillations [17, 18]. The Harris Hawks optimization algorithm for PDPID is applied in [19- 22]. It shows promising results but the complexity of the algorithm is high. The hybrid stochastic fractal search and pattern search technique (hSFS-PS) for the PI-PD controller is designed to enhance the controlling ability of the controller in [23].

A well-designed electric power system must trade with changes in the load and with system disturbances or uncertainties, and it should prepare an appropriate high level of power quality while maintaining both voltage and frequency within tolerable limits [24-27].

During the last three decades, various control strategies for LFC have been proposed to improve frequency change in each area and tie-line. A control theory has been proposed in [28, 29] and used since the early 1970s. A proportional Integral (PI) controller based on Fuzzy logic- for LFC has been proposed in [30-32]. These controllers improve the dynamic performance of the power system in comparison with the conventional PI controller. These methods have been simulated on the decentralized design with nominal plant parameters. Therefore, they cannot be directly employed in the interconnected power systems with uncertainties. So, the important part of the design of LFC should inevitably include parameter perturbation. LFC design considering nominal system parameters is incapable of warranting both stability and the desired performance of the power system with parametric uncertainties. Therefore, modern control methods such as adaptive control have already been used to overcome this problem [21-24]. These control strategies need information on the system states. Also, adaptive methods need perfect model references to follow conditions and the complete system state information. Since the order of the power system is high, the model reference procedure may be difficult to use to design LFC.

Also, Evolutionary Algorithms such as Genetic Algorithm (GA) and other artificial intelligence methods have been proposed to design PID and PI controllers [33-38] but, linear and non-robust are weaknesses of the PID controller. All of these methods could reduce the frequency variations at nominal operating point conditions and the uncertainties cannot be considered to overcome the robustness problem, but the robust methods can tolerate uncertainties. The PID method is one of the applied robust methods utilized to improve the system response to load changes.

An innovative modified version of the cuckoo search algorithm (MCSA) with high accuracy was proposed for optimal designing of the fuzzy-based controller in [39]. Also, an innovative weighted objective function is proposed to minimize frequency and power transmission deviations.

In this paper, a decentralized robust LFC controller based on PID has been proposed to improve the system response. A novel performance metric for evaluating LFC effectiveness is introduced. These metrics may include Integral of Time-weighted Absolute Error (ITAE), settling time, and overshoot. The novelty lies in leveraging advanced optimization techniques to enhance the performance of the PID controller. The PID is extended to reduce frequency versions. To demonstrate the consequence of the proposed method, this method has been compared with a conventional PID controller. It should be noted that both, the proposed and classical methods are used in a two-area power system. The simulation results, carried out by MATLAB Simulink toolbox, show that the proposed method guarantees the robust performance of the plant for a wide range of operating conditions.

2. POWER SYSTEM MODEL

In this paper, two-area load frequency is considered which includes two single areas connected by a power line called the tie-line. Each area in load frequency control nourishes its user pool and the tie-line allows electric power to flow between areas. If one area has been excited the output frequencies of both areas as well as the power flow on the tie-line [40-42]. A two-area power system is shown in Figure 1. The errors of the linearization have been considered parametric uncertainties and un-modeled dynamics.

The transfer function for the turbine and governor in the load frequency is assumed as follows [3]:

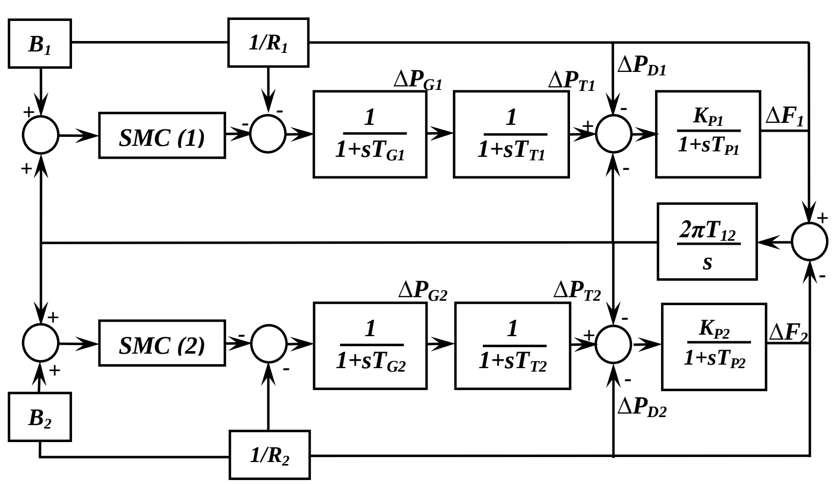


Fig.1. Block diagram of a two-area power system.

Table 1. ***Parametric uncertainties of a power system.***

P_i	$P_{i\,low}$	$P_{i\,normal}$	$P_{i\,high}$
K_{pi}	60	120	180
T_{pi}	10	20	30
T_{12}	0.0433	0.086	0.1299
R_i	1.2	2.4	3.6
T_{Ti}	0.15	0.3	0.45
T_{Gi}	0.04	0.08	0.12

$$T(S)_{Turbine} = \frac{1}{1+s.T_T} \qquad (1)$$

$$T(S)_{Governor} = \frac{1}{1+s.T_G} \qquad (2)$$

where:

T_T is the turbine Time Constant andT_G is the governor Time Constant.

Also, to model the tie-line, the power transfer equation through the tie-line is defined as follows:

$$T_{12} = \frac{|V_1|.|V_2|}{x^{12}}.\sin(\delta_1 - \delta_2) \qquad (3)$$

where δ_1 and δ_2 are the power angles of end voltages, V_1 and V_2 are the equivalent machine of the tow areas andx_{12} is reactance of tie line.

The order of the subscripts indicates that the tie line power is defined as positive in direction 1 to 2. For small deviation in the angles and the tie-line power changes with the amount i.e. small deviation in δ_1 and δ_2 changes by $\Delta\delta_1$ and $\Delta\delta_2$ respectively. Also, the Power T_{12} changes to $T_{12}+\Delta T_{12}$. Therefore, Power transferred from Area 1 to Area 2 has been obtained as given in [15]:

$$\Delta T_{12}(s) = \frac{2\pi T}{s}(\Delta F_1(s) - \Delta F_2(s)) \qquad (4)$$

where, T is the torque produced.

These transfer functions are considered linear states for load frequency that all of them are first-order transfer function [43].

The state space model of the two-area power system has been presented as follow:

$$\begin{cases} \dot{x} = Ax + Bu + Fd \\ y = Cx \end{cases} \qquad (5)$$

where x is the state variables vector, y is the output vector, u is control signals and d is the input vector, as follows:

$$X = \left[\Delta P_{T1}, \Delta P_{G1}, \Delta F_1, \Delta T_{12}, \Delta P_{T2}, \Delta P_{G2}, \Delta F_2\right]^T,$$

$$d = \left[\Delta P_{D1}, \Delta P_{D2}\right]^T,$$

$$y = \left[\Delta F_1, \Delta F_2, \Delta P_{12}\right]^T,$$

$$u = \left[\Delta u_1, \Delta u_2\right]^T$$

Also, we have:

$$A = \begin{bmatrix} -1/T_{T1} & 1/T_{T1} & 0 & 0 & 0 & 0 & 0 \\ 0 & -1/T_{G1} & -1/(R_1 T_{G1}) & 0 & 0 & 0 & 0 \\ K_{P1}/T_{P1} & 0 & -1/T_{P1} & K_{P1}/T_{P1} & 0 & 0 & 0 \\ 0 & 0 & 2\pi T_{12} & 0 & 0 & 0 & -2\pi T_{12} \\ 0 & 0 & 0 & 0 & -1/T_{T2} & 1/T_{T2} & 0 \\ 0 & 0 & 0 & 0 & 0 & -1/T_{G2} & -1/(R_2 T_{G2}) \\ 0 & 0 & 0 & K_{p2}/T_{P2} & K_{p2}/T_{P2} & 0 & -1/T_{P2} \end{bmatrix}$$

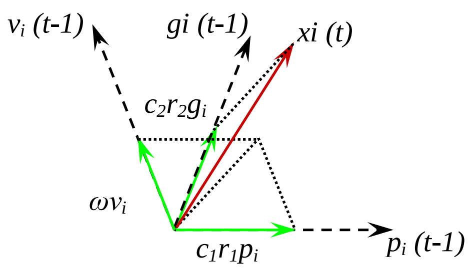


Fig. 2. Vector particle in a two-dimensional space.

$$B = \begin{bmatrix} 0 & 1/T_{G1} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & -1/T_{G1} & 0 \end{bmatrix}$$

$$F = \begin{bmatrix} 0 & 0 & -K_{P1}/T_{P1} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -K_{P2}/T_{P2} \end{bmatrix}^T$$

$$C = \begin{bmatrix} 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

The nominal value of the power system may change during a cycle due to the natural characteristics of load variation and system configuration. Therefore, the parametric uncertainties of the power system must be considered to overcome this problem. Table 1 shows the parametric uncertainties of the power system with their nominal, the lower, and upper bound values [44].

It should be noted that if the linear mode of the turbine and governor are considered, according to equation 6 for the 2-input-2 output, four transfer functions are calculated as follows [45]:

$$T(s) = C(sI - A)^{-1} B + D \qquad (6)$$

Given $T(s) = \begin{bmatrix} T_{11}(s) & T_{12}(s) \\ T_{21}(s) & T_{22}(s) \end{bmatrix}$, where:

$$T_{11} = \frac{\Delta F_1}{\Delta P_{D1}} \; T_{12} = \frac{\Delta F_1}{\Delta P_{D2}} \; T_{21} = \frac{\Delta F_2}{\Delta P_{D1}} \; T_{22} = \frac{\Delta F_2}{\Delta P_{D2}}.$$

3. PARTICLE SWARM OPTIMIZATION

The Particle Swarm Optimization (PSO) Algorithm is a kind of evolutionary algorithm in the optimization field based on a group of birds searching for food. The PSO has been successfully applied to a wide range of applications [46]. In the PSO algorithm, each bird is called a particle and each particle moves to the optimal value. Also, the PSO has been simulated by the group of birds in two-dimensional space. One of them is personal experience and another one is group experience. Figure 2 shows the personal experience (pi), global experience (gi), and initial velocity [25].

In Figure 2, x(t), v(t), c1, c2, r1, r2, and ω are position, velocity, coefficients of the PSO, random values, and coefficient of initial velocity, respectively [24, 26]. The procedure of the PSO algorithm has the following steps [25]:

- Evaluation of Cost Function.

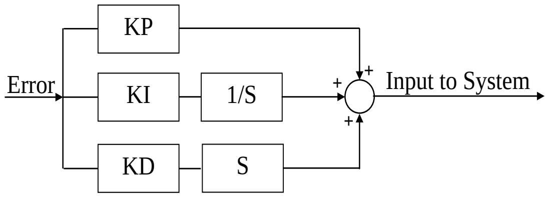


Fig. 3. Block diagram of PID.

- Evaluation of Personal and Global Experience of Each Particle.
- Evaluation of Velocities and Positions of Each Particle.

Equations (7) and (8) show the position and velocity in the PSO algorithm obtained by Newtonian mechanic laws, as follows [26]:

$$\vec{X}(t+1) = \vec{X}(t) + \vec{V}(t) \quad (7)$$

$$\vec{V}(t+1) = \vec{V}(t) + \vec{F}(t) \quad (8)$$

where, X, V, and F are the position, velocity, and force of the particle, respectively. The force of the particle is defined by the personal and global experiences, as follows [24, 26]:

$$\vec{V}(t+1) = \omega\vec{V}(t) + c_1 r_1(\vec{P}(t) - \vec{X}(t)) + c_2 r_2(\vec{g}(t) - \vec{X}(t)) \quad (9)$$

Also, the position of each particle is obtained by the equation (9). In this method, to reach the best solution the coefficients, c1 and c2 should be tuned between 0 and 2. Also, ω should be considered as $0 < \omega < 1.2$ [27].

4. COST FUNCTION

In this section, the cost function of the proposed SMC that decreases the frequency derivation (*ΔF*) of the power system due to load changes (ΔP_D) is presented based on ITAE by following equation [1-4]:

$$f_{ITAE} = \int_0^\infty t\left|e(t)\right|dt \quad (10)$$

In an *N*-area power system, the load disturbance can affect the frequency of all areas. To design the load frequency controller, all inputs and outputs should be taken into account. Therefore, in a two-area power system, the cost function has been considered as follows:

$$f = \sum_{j=1}^{N}\sum_{i=1}^{N}\int_0^\infty \left|\Delta f_i^{\,j}\right|dt \quad (11)$$

$$N = 2$$

where *N* is the number of areas in the power system and $\Delta f_i^{\,j}$ is the frequency deviation in area *i* for the step load changes in area *j*. This cost function has been evaluated for the nominal value of parameters (P%=0). To take uncertainties into account in the design stage, the cost function ought to consider the p% deviation of parameters. In this paper, it has been assumed that the deviation of the uncertain parameters is in the range of ±40%.

5. DESIGN OF LFC USING PID

The PID controller is well known and widely used to improve the dynamic response as well as to reduce or eliminate steady-state error.

The integral controller has added a pole at the origin, thus it has increased the type of system and it has reduced the steady state error due to a sine function to zero. The derivative controller has added a zero to the open loop plant transfer function and it has improved the transient response but the coefficient of the derivative is zero because zero is good for this system.

The proposed controller is shown in Figure 3 in this controller Uc is defined by equation (10) [1]:

$$U_c = K_p e(t) + K_i \int e(t)dt + K_d \frac{d}{dt}e(t) \qquad (12)$$

A. In this equation, U_c is the current input from the controller, K_p is the proportional gain, K_i is the integral gain and K_d is the derivative of the PID controller. The proportional value, integral gain, and derivative gain are obtained considering the minimum value of the body acceleration using the PSO algorithm.

6. SIMULATION

The PID-optimized controller is designed for dynamic frequency variation reduction (ΔF_1, ΔF_2) at the load changes in the power system (ΔP_{D1}). The parameters of the two-area decentralized power system are tabulated in Table 2 as proposed in [4]:

The implementation of the PSO, number of particles, and iteration are considered 10 and 50, respectively.

In order to show the cost function of the proposed PID clearly, the cost function of the PID is shown in Figure 4 at each iteration.

The parameters of the PID have been improved by using the mentioned algorithm. The final cost function, overshoot, and settling time are listed in Table 3.

Moreover, the results for the proposed methods in this paper and [14] entitled performance of system response are compared in Table 4.

Table 2. ***LFC Parameters.***

	T_G	T_T	K_p	T_{12}	R
Area1	0.08	0.3	120	0.0886	2.4
Area2	0.08	0.3	120		2.4

Table 3. ***Settling time (ST) and Overshoot (OV) of the response system for 0.01 pu step load variation utilizing ICA.***

Cost function	*overshoot*	*Settling Time*
0.12409	0.01	2.7 (sec)
	0.01	2 (sec)

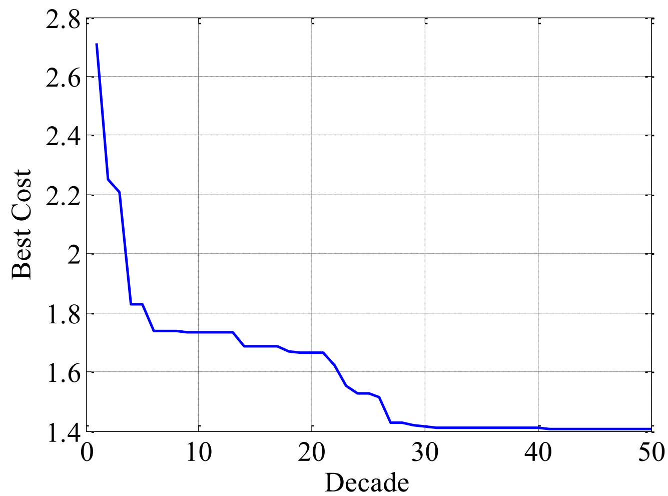
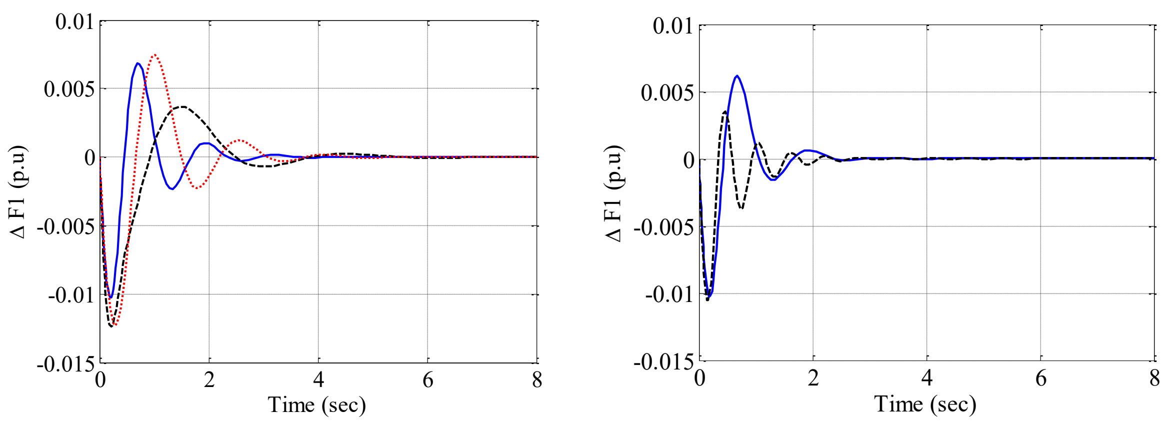


Fig. 4. Diagram of reduction of the cost function.

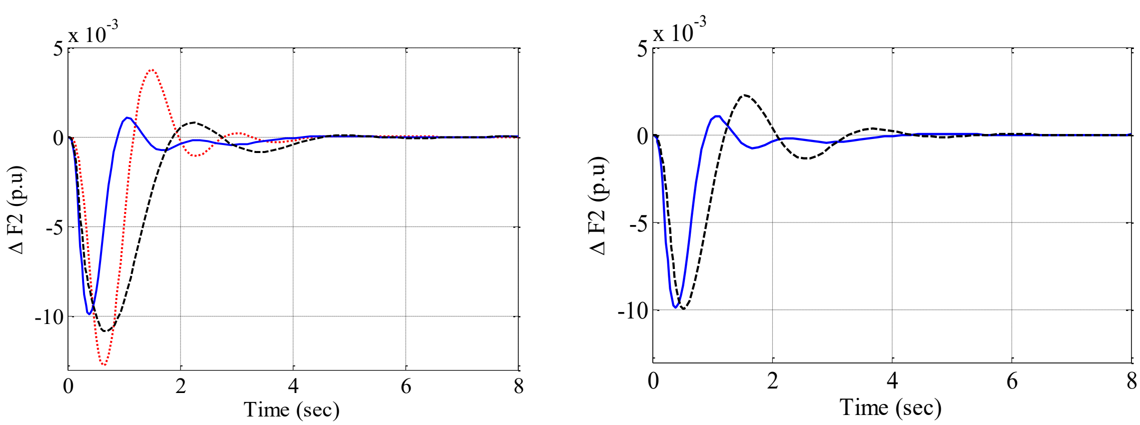
Table 4. ***Settling time (ST) and Overshoot (OV) of the response system for 0.01 pu step.***

	Proposed SMC	*PSO [14]*
Overshoot (area 1)	0.01	0.02
Settling Time(area 1)	2.7 (sec)	8 (sec)
Overshoot (area 2)	0.011	0.015
Settling Time(area 2)	2 (sec)	9 (sec)



(a) ***(b)***

Fig. 5. (a) Frequency deviations of area one for 0.01 p.u. step load change in area one due to −40% (− −), 0 %(—), and +40 %(···) uncertainties using SMC. (b) Comparison of the P-PID (—) and C-PID (− −).



(a) ***(b)***

Fig. 6. (a) Frequency deviations of area two for 0.01 p.u. step load change in area one due to −40% (− −), 0 %(—), and +40 %(···) uncertainties using SMC. (b) Comparison of the P-PID (—) and C-PID (− −).

The simulation results of the practical proposed system are done for 0.01 p.u. load changes in area one due to different uncertainties. The simulation results of frequency deviations in areas 1 and 2 by using the proposed PID due to different uncertainties are shown in Figures 5 and 6. Also, in order to compare the results of the proposed PID and conventional PID clearly, the results of the PID and proposed method due to different uncertainties are shown together in Figures 5 and 6.

According to simulation results, the proposed PID controller presents a robust performance considering parametric uncertainties. As it can be seen in Figure 5 in Area 1, the performance of the PID is less than the performance of the proposed PID. Also, according to Figure 6 in area 2, the performance of the PID is less than PID. Therefore, it can be said that the proposed PID can improve the system's dynamic performance and stability compared PID method.

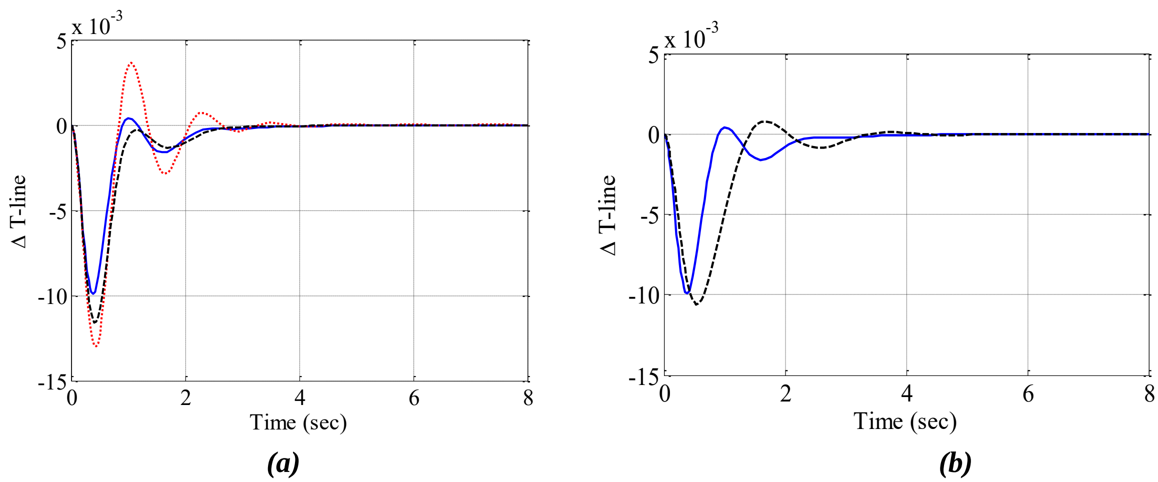


Fig. 8. (a) Transmitted power variation for 0.01 p.u. step load change due to −40% (− −), 0 %(—) and +40 %(···) uncertainties using SMC. (b) Comparison of the P-PID (—) and C-PID (− −).

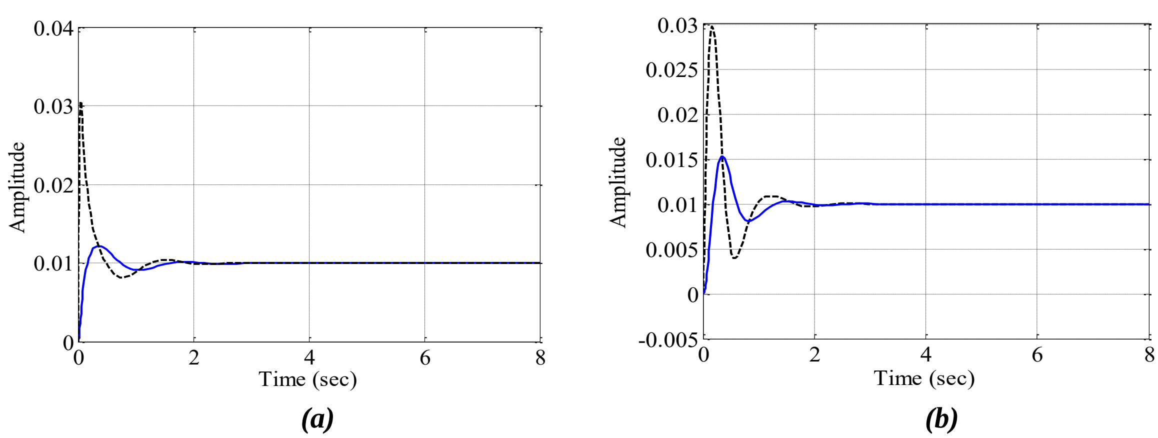
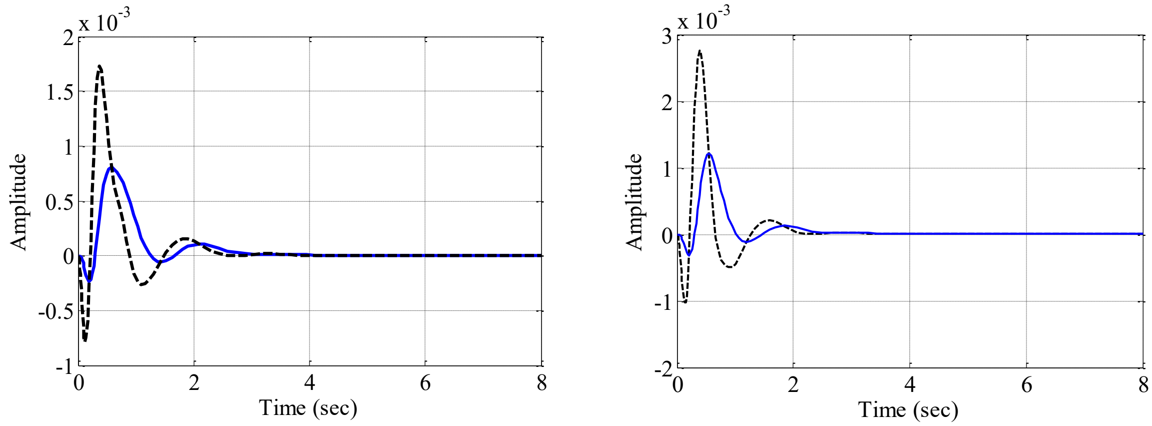


Fig. 9. Governor (—) and Turbine (− −) area 1 power system for 0.01 p.u. step load change (a) P-PID, (b) C-PID.



(a) ***(b)***

Fig. 10. Governor (—) and Turbine (− −) area 2 power system for 0.01 p.u. step load change in area 1 (a) P-PID, (b) C-PID.

The performance of the tie-line has been determined by using the proposed PID due to different uncertainties in Figure 7. According to this figure, the proposed PID can improve the changes in the power of the tie-line.

The performance of the governor and turbine has been shown in Figures 8 and 9. According to Figure 8, in area 1, the 0.01 step response of the governor and turbine tracks the 0.01 because area 1 has been excited to simulate the proposed control method (ΔF_{D1}=0.01).

As can be seen, the performance of the proposed PID is better than the conventional PID method. According to Figure 8, character ties of the transmit state (overshoot, settling time, and rise time) have been improved by considering the proposed PID.

Figure 9 shows the performance of the Governor and turbine in Area 2. This performance tracks the zero line because Area 2 has not been excited (ΔF_{D2}=0). Also, it can be seen that the characterizes of the transmit state (overshoot, settling time, and rise time) of the proposed PID are better than the conventional PID method. Therefore, it can be said that the proposed PID can be improved and reduce the transmit state.

7. CONCLUSION

In this paper, the decentralized robust controller design method of LFC which was proposed based on the PID controller. A two-area power system with proposed PID based on controllers was considered to simulate of the LFC. The simulation results determined that the proposed PID improved the performance of LFC. Also, the simulation results show that the responses of the proposed PID are significantly better than the conventional PID controller. It must be noted that the proposed PID can present a robust performance.

The future work can be listed as follows:

1. Adaptive Tuning Strategies: Explore adaptive tuning methods for cascaded PID and PI-PDN controllers. These strategies can dynamically adjust controller gains based on real-time system conditions, including changes in RES output and load demand.
2. Hybrid optimization techniques: combine BOA with other optimization algorithms to

increase convergence speed and robustness. Hybrid approaches may take advantage of the strengths of different algorithms while mitigating their individual weaknesses.

3. Practical Implementation: Transition from simulations to real-world deployment and addressing the hardware constraints and communication delays.

REFERENCES

[1] Yang, Ting, et al. "Decentralized networked load frequency control in interconnected power systems based on stochastic jump system theory." IEEE Transactions on Smart Grid 11.5 (2020): 4427-4439.

[2] P. Kundur, "Power System Stability and Control" McGraw-Hill, 1994

[3] Zhao, Xin, Suli Zou, and Zhongjing Ma. "Decentralized Resilient $ H_ {\infty} $ Load Frequency Control for Cyber-Physical Power Systems Under DoS Attacks." IEEE/CAA Journal of Automatica Sinica 8.11 (2021): 1737-1751.

[4] Latif, S., Irshad, S., Ahmadi Kamarposhti, M., Shokouhandeh, H., Colak, I., & Eguchi, K. (2022). Intelligent design of multi-machine power system stabilizers (PSSs) using improved particle swarm optimization. electronics, 11(6), 946.

[5] Al-Majidi, Sadeq D., et al. "Design of a load frequency controller based on an optimal neural network." Energies 15.17 (2022): 6223.

[6] Tripathi, Santosh K., Vijay P. Singh, and A. S. Pandey. "Robust load frequency control of interconnected power system in smart grid." IETE Journal of Research 69.8 (2023): 5351-5363.

[7] S. A. Taher, R. Hematti, A. Abdolalipour and S. H. Tabei, "Optimal Decentralized Load Frequency Control Using HPSO Algorithms in Deregulated Power Systems", American Journal of Applied Sciences. Vol. 5 (9), pp. 1167-1174, 2022.

[8] El-Ela, A., Adel, A., El-Sehiemy, R. A., Shheen, A. M., & Diab, A.E.-G. (2021). Enhanced coyote optimizer-based cascade load frequency controllers in multi-area power systems with renewable. Neural Computing and Applications, 33, 8459–8477.

[9] Padhy, S., Panda, S., & Mahapatra, S. (2017). A modified GWO techniquebased cascade PI-PD controller for AGC of power systems in presence of plug-in electric vehicles. Engineering Science and Technology, an International Journal, 20(2), 427–442.

[10] Dash, P., Saikia, L. C., & Sinha, N. (2015). Automatic generation control of multi area thermal system using Bat algrithm optimized PD–PID cascade controller. International Journal of Electrical Power & Energy Systems, 68, 364–372.

[11] Barakat, M., Donkol, A., Hamed, H. F. A., & Salama, G. M. (2021). Harris hawks-based optimization algorithm for a tomatic LFC of the interconnected power system using PD-PI cascade control. Journal of Electrical Engineering and Technology, 16(4), 1845 1865.

[12] Padhy, S., & Panda, S. (2017). A hybrid stochastic fractal search and pattern search technique based cascade PI-PD controller for automatic generation control of multi-source power systems in presence of plug in electric vehicles. CAAI Transactions on Intelligence Technology, 2(1), 12–25.

[13] Shangguan, Xing-Chen, et al. "Robust load frequency control for power system considering transmission delay and sampling period." IEEE Transactions on Industrial Informatics 17.8 (2020): 5292-5303.

[14] C.F Juang, C.F Lu, “Power System Load Frequency Control by Evolutionary Fuzzy PI Controller”, Proc. of IEEE International Conf. on Fuzzy Syst., Vol. 2, pp. 715–719, Budapest, Hungary, 25-29 July 2004.

[15] Alhelou, Hassan Haes, et al. "Challenges and opportunities of load frequency control in conventional, modern and future smart power systems: A comprehensive review." Energies 11.10 (2018): 2497.

[16] I. Valk, M. Vajta, L. Keviczky, R. Haber, J. Hettessy, “Adaptive Load-Frequency Control of Hungrian power system”, Automatica, Vol. 21, pp. 129–137, 1985.

[17] J. Kanniah, S. C. Tripathy, O. P. Malik, G. S. Hope, “Microprocessor-Based Adaptive Load- Frequency Control”, IEEE Proc. Part C, Vol. 131, pp. 121–128, 2021.

[18] Hasan, Naimul, Ibraheem Nasirudin, and Shuaib Farooq. "Hybrid Taguchi genetic algorithm-based AGC controller for multisource interconnected power system." Electric Power Components and Systems 47.1-2 (2019): 101-112.

[19] Nayak, Jyoti Ranjan, et al. "Application of optimized adaptive crow search algorithm based two degree of freedom optimal fuzzy PID controller for AGC system." Engineering Science and Technology, an International Journal 32 (2022): 101061.

[20] Gen, Mitsuo, and Lin Lin. "Genetic algorithms and their applications." Springer handbook of engineering statistics. London: Springer London, 2023. 635-674.

[21] Y. John, Hung, “Variable Structure Control”, a Survey, IEEE Transaction on Industrial Electronics, Vol. 40, No.1. 1993

[22] C. F. Lu, C. C, Liu, C. J. Wu, “Effect of Battery Energy Storage System on Load Frequency Control Considering Governor Dead Band and Generation Rate Constant” IEEE Trans. On Energy Conversion, Vol. 10, No. 3, pp. 555-561, Sep., 1995.

[23] A. Khodabakhshian and N. Golban, “Unified PID Design for Load Frequency Control,” Proc. Inter.Conf. on Control Applications, Vol. 2, pp. 1627-1632, 2021.

[24] Alotaibi, Ibrahim M., et al. "Nonlinear Power System Stabilizer Design for Small Signal Stability Enhancement." Arabian Journal for Science and Engineering 47.11 (2022): 13893-13905.

[25] [E. Nasab, M. Khezri, M. Khodamoradi, E. A. Gargari, “An application of Imperialist Competitive

Algorithm to Simulation of Energy Demand Based on Economic Indicators," European Journal of Scientific Research Vol.43 No.4, pp.495-506, 2010, ISSN 1450-216X http://www.eurojournals.com/ejsr.htm

[26] E. Atashpaz-Gargari and C. Lucas, "Imperialist Competitive Algorithm: An Algorithm for Optimization Inspired by Imperialistic Competition," IEEE Congress on Evolutionary Computation (CEC 2007), pp. 4661-4667, 2007.

[27] Liu, Xiangjun, et al. "Microscopic 3D reconstruction based on point cloud data generated using defocused images." Measurement and Control 54.9-10 (2021): 1309-1318.

[28] M. Ghanavati, M. R. Gholamian, B. Minael, M. Davoudi, "An Efficient Cost Function For Imperalist Competitive Algorithm To Find Best Clusters," Journal of Theoretical and Applied Information Technology, Vol. 29 No.1. pp. 22-31, 2011

[29] Ahad Mirlo, M. B. B Sharifian, "Speed Observer Based on ICA Trained Neural Network in DTC drive of IPMSM," International Power System Conference, Thehran, iran, Nov, 2011

[30] L. K. Shahvandi, Prof. M. Teshnehlab, Dr. A. Haroonabadi, "Multi-Level Clustering by Imperialist Competitive Algorithm in Wireless Sensor Networks," International Journal of Advanced Engineering Sciences and Technologies, Vol. 9, No. 2, pp. 327 – 332.

[31] Shokouhandeh, Hassan, and Mostafa Jazaeri. "Robust design of fuzzy-based power system stabiliser considering uncertainties of loading conditions and transmission line parameters." IET Generation, Transmission & Distribution 13.19 (2019): 4287-4300.

[32] P. Farzin, J. Amin, N. Sulaiman, "Novel Artificial Control of Nonlinear Uncertain System Design a Novel Modified PSO SISO Lyapunov Based Fuzzy Sliding Mode" International of Robotic and Automation J. Vol. 2, 2022.

[33] A. Fouad, B. Fares, "A PSO Based Decentralized Neuro-Fuzzy-Sliding Mode Controller for the Twin Rotor MIMO system" Automation & Systems Engineering J, Vol. 10, pp. 133-148, 2021.

[34] Liu, Senyi, et al. "Direct modulation pattern control for dual three-phase PMSM drive system." IEEE Transactions on Industrial Electronics 69.1 (2021): 110-120.

[35] Razmjooy, Navid, et al. "A new design for robust control of power system stabilizer based on Moth search algorithm." Metaheuristics and Optimization in Computer and Electrical Engineering (2021): 187-202.

[36] YA. Nurkan, Y. Ismail, "Robust Control of Active Suspensions Using Sliding Modes" Turkish J, Vol. 25, pp. 74-87, 2022.

[37] Gardeshkhah, Rasool, and Ali Naderi Saatlo. "A New Tunable Gyrator-C-Based Active Inductor Circuit for Low Power Applications." Journal of Circuits, Systems and Computers (2023).

[38] M. Rafiq, S. Rehman, “Performance Comparison of PI and Sliding Mode for Speed Control Applications of SR Motor” European Scientific Research J, Vol. 50, 2023; pp. 363-380.

[39] Kamarposhti, M. A., Shokouhandeh, H., Alipur, M., Colak, I., Zare, H., & Eguchi, K. (2022). Optimal designing of fuzzy-PID controller in the load-frequency control loop of hydro-thermal power system connected to wind farm by HVDC lines. IEEE Access, 10, 63812-63822.

[40] Saatlo, Ali Naderi. "Systematic design of stable high-order delta sigma modulators using genetic algorithm." Analog Integrated Circuits and Signal Processing (2023): 1-10.

[41] Mavali, Amin, and Ali Naderi Saatlo. "Coordinated Control and Energy Management of Distributed Generation Inverter Using Robust Control in Microgrid." Signal Processing and Renewable Energy 7.3 (2023): 53-76.

[42] Aghaei, Tohid, and Ali Naderi Saatlo. "An efficient architecture for accurate and low power CMOS analog multiplier." Journal of Circuits, Systems and Computers 30.03 (2021): 2150045.

[43] Naderi Saatlo, Ali, and Serdar Ozoguz. "Wide Range High Precision CMOS Exponential Circuit Based on Linear Least Squares Approach." Radioengineering 27.4 (2018).

[44] K. Vrdoljak. N. Perić. M. Mehmedović, “Optimal Parameters for Sliding Mode Based Load-Frequency Control in Power Systems” Proceeding of Variable Structure Systems, (VSS '08)”, Antalya, Turkey, pp. 331-336, 2020.

[45] Guo, Libang, et al. "Allocation of centrally switched fault current limiters enabled by 5G in transmission system." IEEE Transactions on Power Delivery 36.5 (2020): 3231-3241.

[46] Bartoszewicz, Andrzej, and Katarzyna Adamiak. "Discrete-time sliding-mode control with a desired switching variable generator." IEEE Transactions on Automatic Control 65.4 (2019): 1807-1814.