Indonesian Journal of Electrical Engineering and Computer Science
Vol. 28, No. 3, December 2022, pp. 1239~1247
ISSN: 2502-4752, DOI: 10.11591/ijeecs.v28.i3.pp1239-1247

A novel meta-heuristic algorithm based optimized load frequency controller

Majahar Hussain Mahammad, Chekka Ravi Kumar
Department of Electrical and Electronics Engineering, University College of Engineering, Acharya Nagarjuna University, Guntur, India

Article Info

Article history:

Received Jul 3, 2022
Revised Aug 28, 2022
Accepted Sep 7, 2022

Keywords:

2-degree-of-freedom
Double-derivative
Intelligent-water drops
Load frequency control
New England
Novel-evolutionary algorithm
Proportional-integral

ABSTRACT

This work proposes a 2-degree-of-freedom proportional-integral-double-derivative (2-DOF PIDD) controller to improve frequency profiles of an IEEE 39 bus 10 generator 3 area New England interconnected power system during step load perturbations. To increase the system's dynamic response, parallel derivative components are used in the secondary controller mechanism, and comparisons are made with proportional, integral and derivative (PID) and 2-DOF PID controllers to illustrate the advantage of the proposed controller scheme. The ideal gain values of the PID, 2-DOF PID, and 2-DOF PIDD controllers are achieved using a novel evolutionary algorithm called the intelligent water drops (IWD) algorithm, which is used for the first time for the load frequency control problem for a 3-area power system. The results proved that the proposed controller is superior to the existing controllers. Simulations are done in the MATLAB-Simulink® environment.

Corresponding Author:

Majahar Hussain Mahammad
Department of Electrical and Electronics Engineering, University College of Engineering
Acharya Nagarjuna University, Guntur, Andhra Pradesh, India
Email: mazhar204@gmail.com

NOMENCLATURE

2DOF	Two-degree-of-freedom	Pw	Set point weight for proportional controller
PIDD	Proportional integral double derivative	Dw	Set point weight for derivative controller
Kp	Gain of proportional controller	N	Noise coefficient
Ki	Gain of integral controller	f	Frequency
Kd	Gain of derivative controller	Ptie	Frequency
ISE	Integral square error	IWD	Intelligent water drops

1. INTRODUCTION

The primary goal of load frequency control is to minimize the frequency oscillations and maintain the system frequency at its nominal operating value. Detailed literature survey is available in load frequency control (LFC) [1]. "During load perturbations, secondary control mechanism helps to balance the active power generation, demand and reduces the frequency deviations caused by the power imbalances". In the case of regular conventional plants, generation control is possible with secondary control action schemes [2]. Therefore, several controllers are investigated to improve the interconnected power system frequency profiles [3].

Maiden application of secondary controller design is proposed for multi-area power systems with bacterial foraging optimization algorithm (BFOA) [4]. LFC is improved by implementing different classical controllers with diverse system configurations with various optimization algorithms [5]. New performance measures were proposed and smart grid technologies were implemented. To find optimal parameter gains of the secondary controller, the fruit fly optimization (FFO) algorithm is used [6]. An analytic hierarchy process (AHP) is implemented with the JAYA algorithm for LFC studies of interconnected power systems [7]. proportional, integral and derivative (PID) with a second-order derivative filter is used instead of PID with ant lion optimizer to enhance the responses of the multi-area power system [8]. Later, "several other controller mechanisms are investigated in LFC to check suitability to achieve the frequency control and stability objectives. 2-DOF PID controller is extensively applied for the multi-area power system to minimize the frequency disturbances during load changes" [9]-[13].

A few such studies are as follows. A robust 2-DOF control mechanism is proposed in a multi-area power system environment, which minimizes the frequency oscillations better than the PID controller [9]. Further, the teaching learning-based optimization (TLBO) algorithm is used for finding optimal parameter gains of the 2-DOF PID controller [10]. Fractional order 2-DOF PID controller is proposed to improve the load frequency control [11]. 2-DOF state feedback controller is presented to enhance the performance specifications of the power system variables (frequency tie-line line power) optimized with whale optimization [12]. "Recently, combined 2-DOF PID controller strategy is applied for 2 area thermal, hydropower system to improve the frequency profiles of the interconnected power system. To tune controller parameters optimal values, invasive weed optimizer (IWO) is opted" [13]. Cascade controllers are also used in LFC studies [14]-[17]. The intelligent water drops algorithm inspired by the flow of water drops in rivers was introduced by Hamed Shah-Hosseini, a swarm-based algorithm used for optimization [18], [19]. Load frequency controllers using PID and fuzzy optimized with particle swarm optimization were also implemented [20]-[24]. The impact of renewable energy resources integration on load frequency control is investigated [25]. To improve the performance of the PID controller, its design is slightly modified, and the controller is named as PIDD controller and optimized with fitness dependent optimizer algorithm [26]. Cat swarm optimization is implemented [27]-[29]. The whale optimization algorithm (WOA) is used for optimal placement of FACTS devices [30]. Weight improved PSO (WIPSO) algorithm is used for transmission system performance improvement [31]. Weight improved PSO (WIPSO) algorithm performance is compared with whale optimization algorithm (WOA) for improvement of system performance [32].

This work presents an enhanced 2-DOF PID controller named 2DOF PIDD controller for LFC of IEEE 39 bus 10 generator 3 area New England interconnected power system with an extra derivative and filter component. The intelligent waterdrops (IWD) algorithm is used to find the controller's best gain values. In LFC research, this optimization approach was used for the first time. This study compares 2-DOF PIDD controllers with PID and 2-DOF PID controllers.

2. 2-DEGREE OF FREEDOM PROPORTIONAL INTEGRAL DOUBLE DERIVATIVE CONTROLLER (2DOF PIDD)

For secondary control of LFC, PID controller is used widely in the literature survey based on the merits of stability improvement, design simplicity, and practical applicability. To enhance the frequency profiles of the interconnected power system during load perturbations, improved versions of PID controllers are also tested in LFC under different system conditions. One such controller used in earlier studies is the 2-DOF PID controller naturally has advantages over the conventional single degree of the freedom control system in control system performance specifications enhancement perspective" [4]-[16]. The schematic diagram of the 2-DOF PID controller is presented in Figure 1 with set point gains P_w and D_w. The weighted signals are processed through PID consisting of proportional, integral, and derivative with filter components whose gains are adjustable. This arrangement is modified with another derivative with a filter block to provide better control action. The schematic block diagram of the 2-DOF PIDD controller is shown in Figure 2.

Compared to the PID controller, the filter is cascaded with a derivative component used in both 2-DOF PID and PIDD controllers to yield improved performance during system uncertainties. N is the derivative filter coefficient observed in both Figures 1 and 2. With the schematic structure, the output of the 2-DOF PID controller is expressed as (1).

$$u_i(s) = k_{p_i}\left(P_{w_i}r - y\right) + \frac{k_{i_i}}{s}(r - y) + \frac{k_{d_i}s}{T_{fi}s+1}\left(D_{w_i}r - y\right) \tag{1}$$

In (1), $r\ and\ y$ are input signals (depends on the system). Reciprocal of the filter coefficient is expressed as T_{fi}, k_{p_i} is the proportional gain of the controller in i^{th} area. Integral and derivative gains of the same controller is represented by $k_{i_i}$and k_{d_i}.From the literature survey, it is observed that the multiple derivative controllers enhance the actual response over normal controllers. Therefore, the multiple derivative component concept is inserted in the PIDD controller, and the output of the controller is modified from (1) to (2) given by:

$$u_i(s) = k_{p_i}\left(P_{w_i} r - y\right) + \frac{k_{i_i}}{s}(r - y) + \left\{\prod_1^n \frac{k_{d_{ii}} s}{T_{f_{ii}} s + 1}\right\}\left(D_{w_i} r - y\right) \quad (2)$$

these additional cascade derivatives with filter components are added to reduce the effect of noise and to increase the frequency profile of the system in the case of LFC studies.

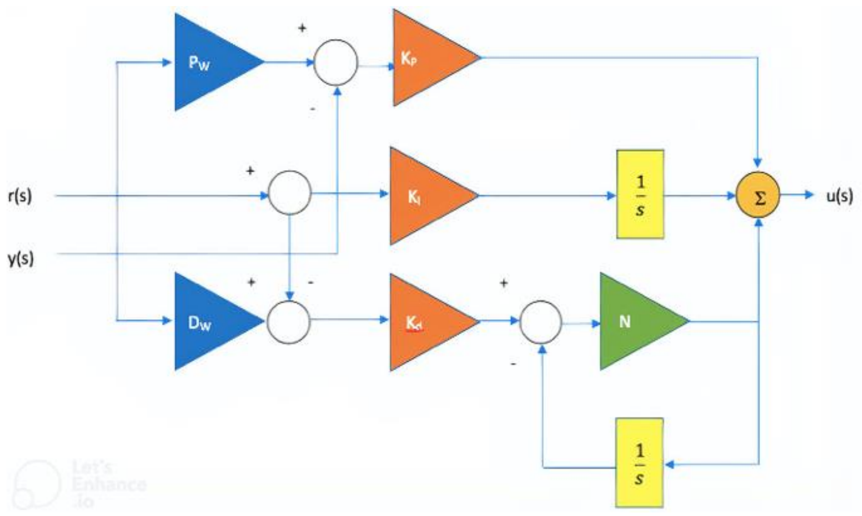

Figure 1. Schematic block diagram of 2-DOF PID controller for LFC studies

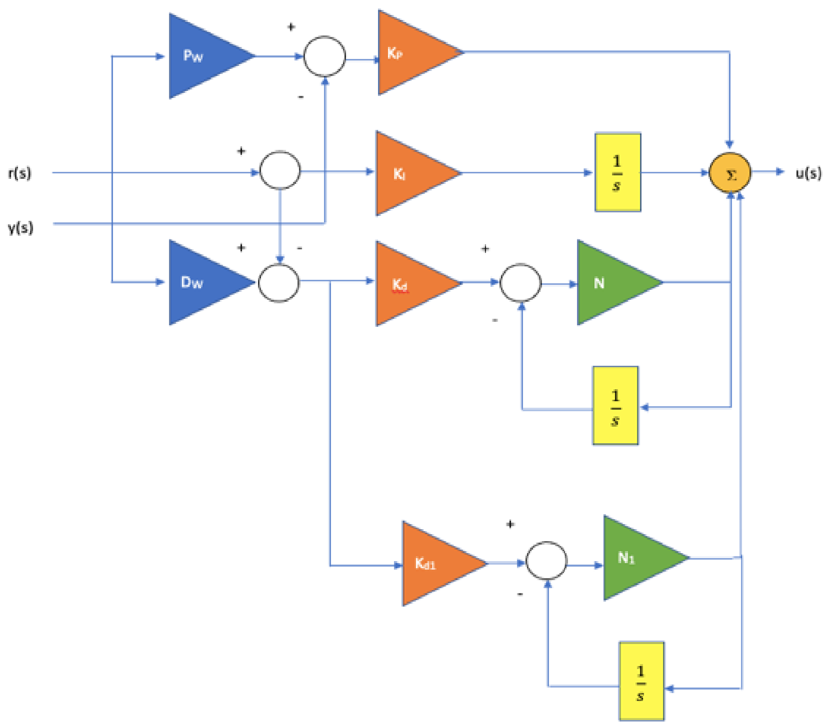

Figure 2. Schematic block diagram of 2-DOF PIDD controller for LFC studies

3. TEST SYSTEM

The performance of the proposed 2-DOF PIDD controller is tested in 3 area interconnected power system shown in Figure 3. The parameters of governor, turbine, reheater, and generator numerical values are available in [21] and given in the Appendix. Three secondary controllers are investigated in this paper, known as PID, 2-DOF PID, and 2-DOF PIDD, and comparisons are made with all these controllers. Test system areas are thermal-thermal interconnected scenario with reheat turbines. To minimize the frequency deviations, the secondary controllers' optimal parameter gains are identified using the intelligent water drops (IWD) algorithm. The flowchart of the algorithm is shown in Figure 4.

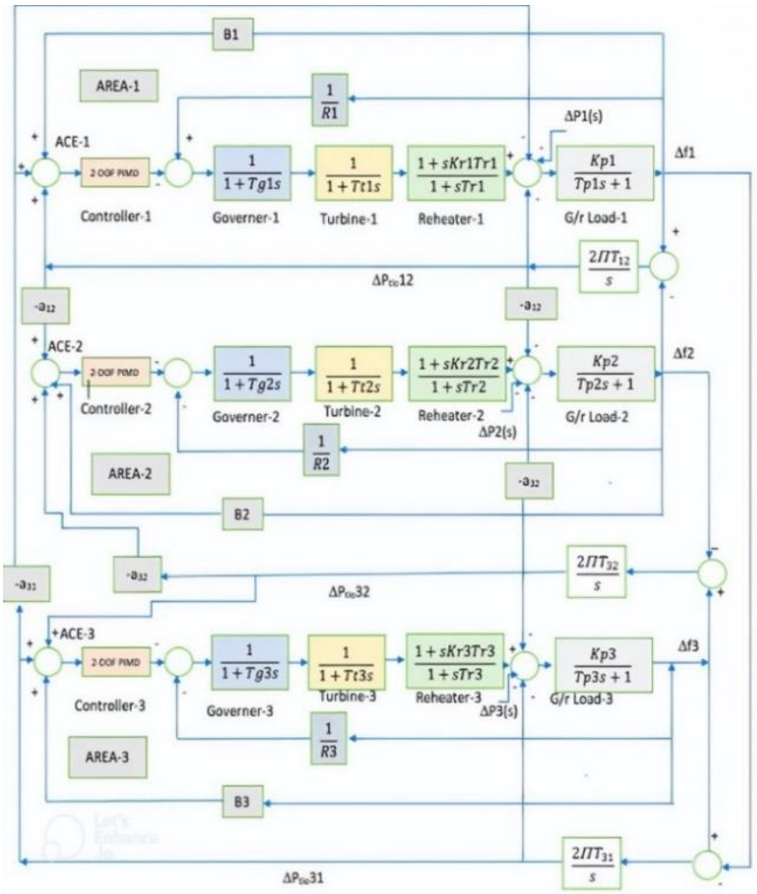

Figure 3. Block diagram of 3-area integrated power system

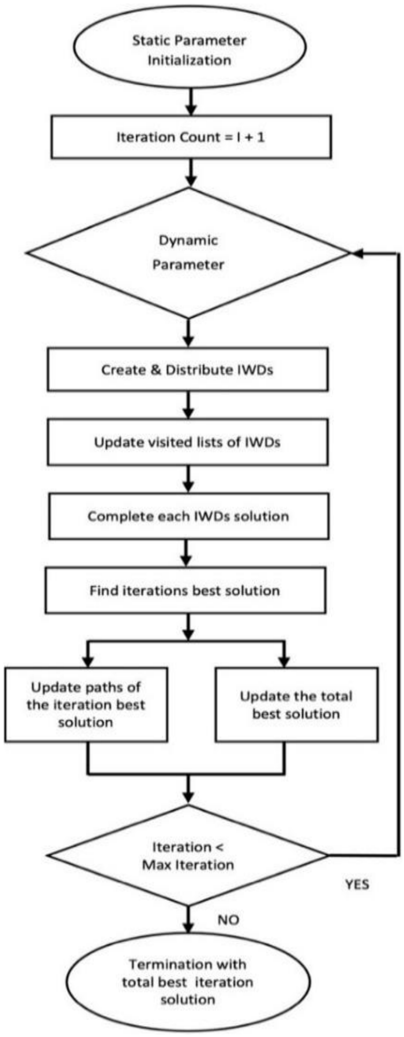

Figure 4. IWDs algorithm flow chart

4. TUNING MECHANISM FOR INTELLIGENT WATER DROPS ALGORITHM

The optimal gain parameters of the secondary PID, 2-DOF PID, and 2-DOF PIDD controllers to minimize the frequency deviations during active power disturbances must be decided using optimization algorithms. For this purpose, this paper has opted for an intelligent water drop algorithm (IWD). Based on the waterdrops mechanism in the river flow, an intelligent waterdrops algorithm was proposed in the year 2009 by Hamed shah-Hosseini. This algorithm is implemented with two key factors: velocity and soil [18], [19]. The IWD flow starts at initial velocity and zero soil. During the river process, these factors may change. Further, the elements used in IWD are classified into two categories known as static and dynamic. The static parameters are constant during the lifetime of the algorithm, whereas the dynamic parameter changes for every iteration/update. The algorithm of IWD is started with the initialization process. In this step, the first static parameters are initialized. Node set 'N' and edge set 'E' and graph (N, E) also need to define for the algorithm. Like swarm intelligence algorithms, the number of iterations also needs to be defined. For particle T^{TB}, the quality of the solution set is at its worst value -∞. For updating velocity and soil parameters, a_v, b_v, c_v, a_s, b_s and $c_s$values need to be addressed. After initialization, IWDs spread randomly and visited nodes and updated nodes.

The next node 'j' may add in the visited node list with the probability $p_i^{IWD}(j)$ given by (3).

$$p_i^{IWD}(j) = \frac{f(soil(i,j)}{\sum_{k\notin vc(IWD)} f(soil(i,k))} \tag{3}$$

The velocity for each IWD moving from i node to j node is given by (4).

$$vel^{IWD}(t+1) = vel^{IWD}(t) + \frac{a_v}{b_v + c_v.soil^2(i,j)} \tag{4}$$

Further, change in function is calculated using (5).

$$\Delta soil(i,j) = \frac{a_s}{b_s + c_s time^2(i,j;vel^{IWD}(t+1))} \tag{5}$$

Finally, the soil is updated using the equation given by:

$$soil^{IWD} = soil^{IWD} + \Delta soil(i,j) \tag{6}$$

from all updating solutions, the best solution is identified based on the quality of the solution and update the soils on the paths that form the current iteration to the best solution (T^{IB}) is:

$$soil(i,j) = (1+\rho_{IWD})soil(i,j) - \rho_{IWD}\frac{1}{N_{IB}-1}soil_{IB}^{IWD} \tag{7}$$

once these solutions and paths are updated, the next iteration will start, and this procedure will continue until the maximum number of iterations are completed. Using IWD, secondary controller parameter gains are treated as decision variables to improve the frequency profile. In this case, the primary regulation gains are constants. Further, primary regulation gains are also considered as decision variables, along with secondary controller parameter gains as an additional case. The identification of optimal gains totally depends on the fitness function of the problem calculated using (8).

$$J = \int_0^t \sum_{\substack{i=1 \\ j=1 \\ i\neq j}}^{n} [(\Delta f_i)^2 + \left(\Delta P_{ij}\right)^2 dt \tag{8}$$

The solution space of the IWD is based on the limits of the decision variables provided in the system. The upper and lower bounds of the primary and secondary control loop variables are given by:

$$k_{min} \leq k_{p_i}, k_{i_i}, k_{d_i} \leq k_{max} \tag{9}$$

$$0 \leq N \leq N_{max} \tag{10}$$

$$P_{min} \leq P_w \leq P_{max} \tag{11}$$

$$D_{min} \leq D_w \leq D_{max} \tag{12}$$

$$R_{min} \leq R \leq R_{max} \tag{13}$$

these limits are fixed from the stability criteria of the test system. In the case of PID, 2-DOF PID controllers also, the same limits are used to provide straightforward comparisons.

5. SIMULATION RESULTS

To enhance the system performance in terms of frequency profile improvement, the proposed 2-DOF PIDD controller is placed in the secondary control loop of LFC, and comparisons are provided with both PID and 2-DOF PID controllers. Investigations are carried out in the presence of single load disturbances. IWD produced the optimal gain parameters for the three controllers. Using the IWD optimizer, the optimal values of the controller parameters for simple load changes are reported in Table 1.

Table 1. IWD algorithm tuned controller's optimal gains

Controller	Area-1			Area-2			Area-3		
Parameter	PID	2DOF PID	2DOF PIDD	PID	2DOF PID	2DOF PIDD	PID	2DOF PID	2DOF PIDD
k_p	-1.87	-1	-0.94	-1.16	-1.12	-1.14	-1.41	-1.26	-1.24
k_i	-1.2	-1.14	-1.45	-0.86	-1.96	-1.84	-1.13	-1.78	-1.89
k_d	-0.94	-1.34	-1.93	-0.74	-1.54	-1.65	-1.96	-1.124	-1.28
P_w	-	1	1	-	0.92	1	-	1	0.98
D_w	-	1	1	-	0.98	1	-	0.89	1
N	-	200	200	-	200	200	-	200	200
k_{d1}	-	-	-1.84	-	-	-1.87	-	-	-1.86
N_1	-	-	200	-	-	200	-	-	200

6. PERFORMANCE EVALUATION

For a load change of 10% (decrease), the change in area-1, area-2, and area-3 frequencies are presented in Figures 5-7, and tie line power flow variations in between area-1, 2 and 3 are presented in Figures 8-10. The peak value of change in frequencies and settling time values are reported in Table 2. Based on the fitness values (ISE) obtained in the IWD algorithm assessment, the rank-wise selection is provided for the secondary PID, 2-DOF PID, and PIDD controllers in Table 2. From both performance specifications and measures, the proposed 2-DOF PIDD controller yields superior results over PID and 2-DOF PID controller.

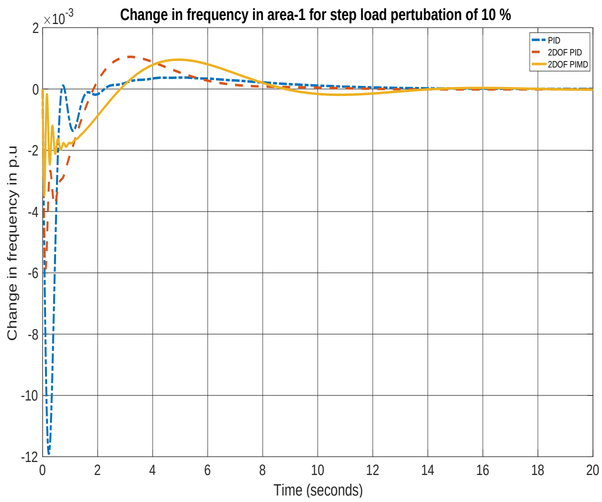

Figure 5. Frequency changes in area 1

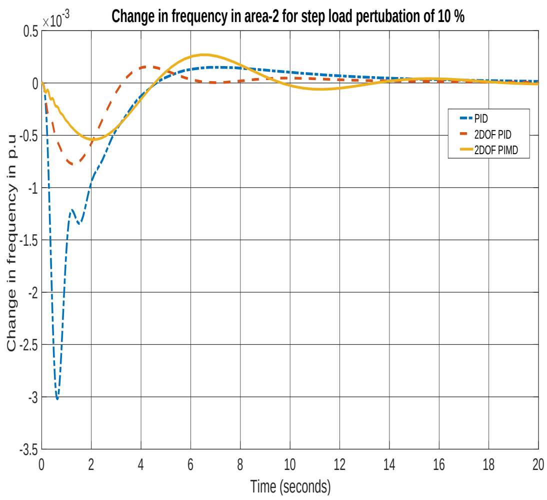

Figure 6. Frequency changes in area 2

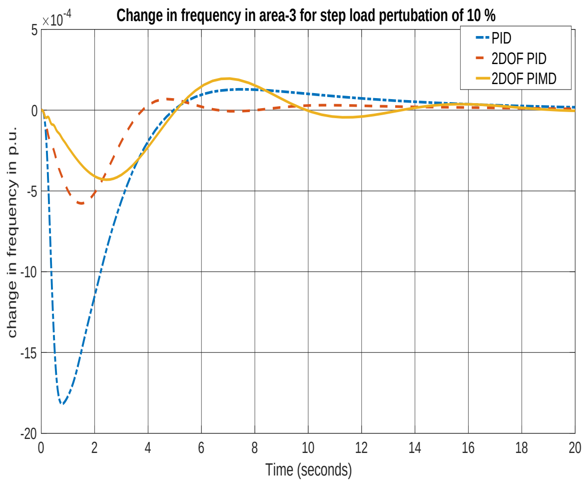

Figure 7. Frequency changes in area 3

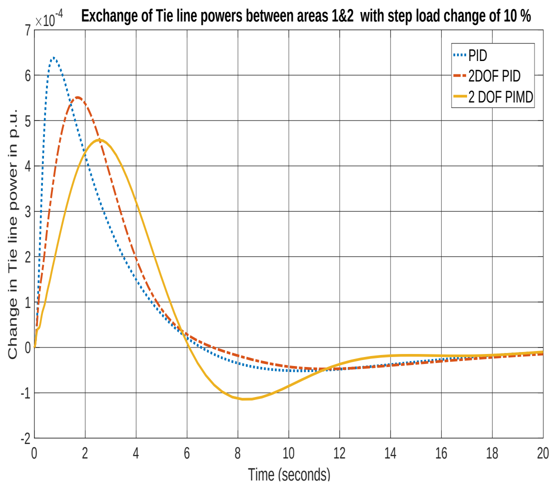

Figure 8. Exchange of Tie line powers between areas 1&2

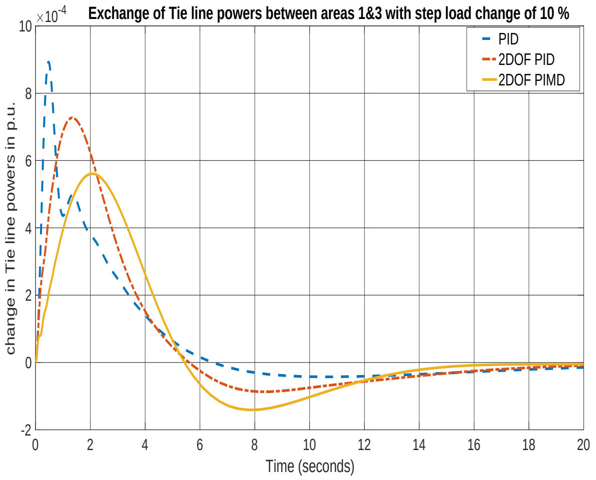

Figure 9. Exchange of Tie line powers areas 1&3

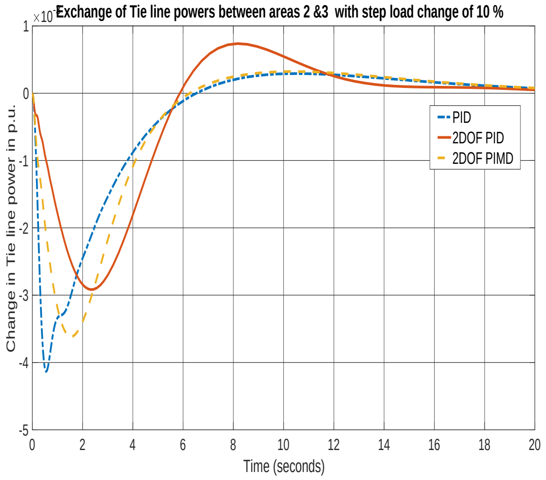

Figure 10. Exchange of Tie line powers between areas 2&3

Table 2. System response specifications for all controllers during step load change

Controller	$\Delta f1$		$\Delta f2$		$\Delta f3$		$\Delta Tie1\&2$	$\Delta Tie\ 2\&3$	$\Delta Tie\ 1\&3$	Rank
	Peak	Ts	Peak	Ts	Peak	Ts	Peak	Peak	Peak	Based on ISE
PID	-0.0119	15	-0.0034	14	-0.0018	14.5	0.00063	-0.004133	0.000892	3
2-DOF PID	-0.0058	12	-0.0007	6.5	-0.00057	6.5	0.00055	-0.003615	0.000727	2
2-DOF PIDD	-0.0034	14	-0.00054	8.5	-0.00043	10	0.00045	-0.002917	0.0005608	1

7. COMPARISION WITH OTHER ALGORITHMS

To show the superiority of the proposed algorithm, the system response with the IWDs algorithm is compared with the system responses with PSO, IPSO, and DE algorithms. These tuning algorithms are considered for comparison since these algorithms are extensively used in earlier LFC studies. The comparison results are presented in Table 3.

Table 3. Comparison of system performance with different algorithms

Change in parameter	$\Delta f1$		$\Delta f2$		$\Delta f3$		$\Delta Tie1\&2$	$\Delta Tie\ 2\&3$	$\Delta Tie\ 1\&3$
Algorithm	Peak	Ts	Peak	Ts	Peak	Ts	Peak	Peak	Peak
PSO	-0.0091	16.7	-0.00081	10.4	-0.00072	12.3	0.00071	-0.00453	0.000761
IPSO	-0.0072	15.6	-0.00075	9.6	-0.00062	11.8	0.00064	-0.00335	0.000712
DE	-0.0054	15	-0.00064	8.9	-0.00051	10.6	0.00053	-0.00312	0.000612
IWDs	-0.0034	14	-0.00054	8.5	-0.00043	10	0.00045	-0.00291	0.000560

8. CONCLUSIONS

This paper presents a modified 2-DOF PID (2DOF-PIDD) controller to improve the frequency profiles of the interconnected power system during step load perturbations. To achieve quality results, the IWDs optimizer is used for identifying optimal parameter gains of the 2-DOF PIDD controller. Comparisons with IWDs tuned PID and 2-DOF PID controllers provided the superiorities of the proposed controller in terms of performance specifications and measures.

APPENDIX

Parameters of the system considered for study:

Governor time constant:	Generator Gain constant:
Tg1=Tg2=Tg3=0.08 s;	KP1=KP2=KP3=120.83 Hz/p.u MW;
Turbine time constant:	Generator time constant:
Tt1=Tt2=Tt3=0.3 s;	TP1=13.325 s; TP2=12.669 s; TP3=14.506 s;
Reheater time constant:	Synchronizing power coefficient:
Tr1=Tr2=Tr3=10 s;	T12=T23=T31=0.545 p.u;

Reheater gain constant: Kr1=Kr2=Kr3=0.5 p.u MW.

Area Capacity Ratio: a12=a23=0.5.

Frequency bias constant: B1=B2=B3=0.425 p.u MW/Hz;

Speed governor regulation parameter: R1=2.4545 Hz/p.u MW; R2=2.0712 Hz/p.u MW; R3=1.8912 Hz/p.u MW;

REFERENCES

[1] P. Kumar, and D. P. Kothari, "Recent philosophies of automatic generation control strategies in power systems," *IEEE Transactions on Power Systems*, vol. 20, no. 1, 346-357, 2005, doi: 10.1109/TPWRS.2004.840438.

[2] P. Chilukuri *et al.* "Introduction of secondary frequency control in Indian power system," In *2018 20th National Power Systems Conference (NPSC)*, IEEE, 2018, pp. 1-6, doi: 10.1109/NPSC.2018.8771767.

[3] L. C. Saikia, J. Nanda, and S. Mishra. "Performance comparison of several classical controllers in AGC for multi-area interconnected thermal system," *International Journal of Electrical Power & Energy Systems*, vol. 33, no. 3, pp. 394-401, 2011, doi: 10.1016/j.ijepes.2010.08.036.

[4] J. Nanda, S. Mishra, and L. C. Saikia, "Maiden application of bacterial foraging-based optimization technique in multiarea automatic generation control," *IEEE Transactions on power systems*, vol. 24, no. 2, pp. 602-609, 2009, doi: 10.1109/TPWRS.2009.2016588.

[5] D. Guha, P. K. Roy, and S. Banerjee, "Study of differential search algorithm based automatic generation control of an interconnected thermal-thermal system with governor dead-band," *Applied Soft Computing*, vol. 52, pp. 160-175, 2017, doi: 10.1016/j.asoc.2016.12.012.

[6] B. Mohanty, and P. K. Hota, "Comparative performance analysis of fruit fly optimisation algorithm for multi-area multi-source automatic generation control under deregulated environment," *IET Generation, Transmission & Distribution*, vol. 9, no. 14, pp. 1845-1855, 2015, doi: 10.1049/iet-gtd.2015.0284.

[7] S, P. Singh, T, Prakash, V. P. Singh, and M. G, Babu, "Analytic hierarchy process based automatic generation control of multi-area interconnected power system using Jaya algorithm," *Engineering Applications of Artificial Intelligence*, vol. 60, pp. 35-44, 2017, doi: 10.1016/j.engappai.2017.01.008.

[8] M. Raju, L. C. Saikia, and N. Sinha, "Automatic generation control of a multi-area system using ant lion optimizer algorithm based PID plus second order derivative controller," *International Journal of Electrical Power & Energy Systems*, vol. 80, pp. 52-63, 2016, doi: 10.1016/j.ijepes.2016.01.037.

[9] S. Debbarma, L. C. Saikia, and N. Sinha, "Robust 2-degree-of-freedom controller for automatic generation control of multi-area system," *International Journal of Electrical Power & Energy Systems*, vol. 63, pp. 878-886, 2014, doi: 10.1016/j.ijepes.2014.06.053.

[10] R. K. Sahu, S. Panda, U. K. Rout, and D. K.Sahoo, "Teaching learning based optimization algorithm for automatic generation control of power system using 2-DOF PID controller," *International Journal of Electrical Power & Energy Systems*, vol. 77, pp. 287-301, 2016, doi: 10.1016/j.ijepes.2015.11.082.

[11] S. Debbarma, L. C. Saikia, and N. Sinha, "Automatic generation control using 2 degree of freedom fractional order PID controller," *International Journal of Electrical Power & Energy Systems,* vol. 58, pp. 120-12, 2014, doi: 10.1016/j.ijepes.2014.01.011.

[12] K. S. Simhadri, B. Mohanty, and S. K. Panda, "Comparative performance analysis 2DOF state feedback controller for automatic generation control using whale optimization algorithm," *Optimal Control Applications and Methods*, vol. 40, no. 1, pp. 24-42, 2019, doi: 10.1002/oca.2462.

[13] M. Azaharahmed, K. Raja, M. K. Patan, C. D. Prasad, and P. Ganeshan, "Invasive weedoptimized area centralized 2 degree of freedom combined PID controller scheme for automatic generation control," *Journal of Electrical Engineering & Technology*, vol. 16, no. 1, pp. 31-42, 2021, doi: 10.1007/s42835-020-00565-9.

[14] A. Behera, T. K. Panigrahi, P. K. Ray, and A. K. Sahoo, "A novel cascaded PID controller for automatic generation control analysis with renewable sources," *IEEE/CAA Journal of Automatica Sinica*, vol. 6, no. 6, pp. 1438-1451, 2019, doi: 10.1109/JAS.2019.1911666.

[15] S. Padhy, S. Panda, and S. Mahapatra, "A modified GWO technique based cascade PI-PD controller for AGC of power systems in presence of plug in electric vehicles," *Engineering Science and Technology, an International Journal*, vol. 20, no. 2, pp. 427-442, 2017, doi: 10.1016/j.jestch.2017.03.004.

[16] M. Barakat, A. Donkol, H. F. A. Hamed, and G. M. Salama, "Harris hawks-based optimization algorithm for automatic LFC of the interconnected power system using PD-PI cascade control," *Journal of Electrical Engineering & Technology*, pp. 1-21, 2021, doi: 10.1007/s42835-021-00729-1.

[17] N. Pathak, T. S. Bhatti, and A. Verma, "New performance indices for the optimization of controller gains of automatic generation control of an interconnected thermal power system," *Sustainable Energy, Grids and Ne2rks*, vol. 9, pp. 27-37, 2017, doi: 10.1016/j.segan.2016.11.003.

[18] H. Shah-Hosseini, "The intelligent water drops algorithm: a nature-inspired swarm-based optimization algorithm," *International Journal of Bio-inspired computation*, vol. 1, no. 1-2, pp. 71-79, 2009, doi: 10.1504/IJBIC.2009.022775.

[19] H. Shah-Hosseini, "An approach to continuous optimization by the intelligent water drops algorithm," *Procedia-Social and Behavioral Sciences*, vol. 32, pp. 224-229, 2012, doi: 10.1016/j.sbspro.2012.01.033.

[20] M. K. Patan, K. Raja, M. Azaharahmed, C. D. Prasad, and P. Ganeshan, "Influence of primary regulation on frequency control of an isolated microgrid equipped with crow search algorithm tuned classical controllers," *Journal of Electrical Engineering & Technology*, vol. 16, no. 2, pp. 681-695, 2021, doi: 10.1007/s42835-020-00614-3.

[21] T. K. Pati, J. R. Nayak, B. K. Sahu, and B. Gantayat, "Load frequency control of an interconnected three-area thermal power system using conventional PID & Fuzzy-logic controller," *2015 International Conference on Energy, Power and Environment: Towards Sustainable Growth (ICEPE)*, 2015, pp. 1-6, doi: 10.1109/EPETSG.2015.7510137.

[22] S, S. Dhillon, J. S. Lather, and S. Marwaha, "Multi area load frequency control using particle swarm optimization and fuzzy rules," *Procedia Computer Science*, vol. 57, pp. 460-472, 2015, doi: 10.1016/j.procs.2015.07.363.

[23] D. V. Doan, K. Nguyen, and Q. V. Thai, "Load-frequency control of three-area interconnected power systems with renewable energy sources using novel PSO-PID-like fuzzy logic controllers," *Engineering, Technology & Applied Science Research*, vol. 12, no. 3, pp. 8597–8604, 2022, doi: 10.48084/etasr.4924.

[24] U. U. Rehman, A. Jameel, A. Khan, M. M. Gulzar, and S. Murawwat, "Load frequency management for a two-area system (ThermalPV & Hydel-PV) by swarm optimization based intelligent algorithms," *In Proceedings of the 2021 International Conference on Emerging Power Technologies (ICEPT)*, Topi, Pakistan, 2021, pp. 1–6, doi: 10.1109/ICEPT51706.2021.9435527.

[25] K. Arora, A. Kumar, V. K. Kamboj, D. Prashar, B. Shrestha, and G. P. Joshi, "Impact of renewable energy sources into multi area multi-source load frequency control of interrelated power system," *Mathematics*, vol. 9, p. 186, 2021, doi: 10.3390/math9020186.

[26] A. Daraz, S. A. Malik, I. U. Haq, K. B. Khan, G. F. Laghari, and F. Zafar, "Modified PID controller for automatic generation control of multi-source interconnected power system using fitness dependent optimizer algorithm," *PLoS ONE*, vol. 15, no. 11, 2020, doi: 10.1371/journal.pone.0242428.

[27] C. R. Kumar and P. V. R. Rao, "Cat swarm optimization (CSO) based fractional order automatic generation controller for a multi area interconnected system," *Asia Modelling Symposium 2015 9th International Conference on Mathematical Modelling and Computer Simulation*, 2015, pp. 11-20.

[28] R. K. Chekka, and P. V. R. Rao, "Fractional order automatic generation controller for a multi area interconnected system using evolutionary algorithms," *International Journal of Applied Engineering Research*, vol. 11, no. 4, pp. 2199-2205, 2016.

[29] C. R. Kumar and P. V. R. Rao, "PSO based fractional order automatic generation controller for a three area interconnected system," 2015 *International Conference on Electrical, Electronics, Signals, Communication and Optimization (EESCO)*, 2015, pp. 1-6, doi: 10.1109/EESCO.2015.7253682.

[30] K. K. Kuthadi, N. D. Sridhar, and C. H. R. Kumar, "Optimal placement of FACTs devices for enhancing of transmission system performance using whale optimization algorithm," *Int J Interact Des Manuf*, 2022, doi: 10.1007/s12008-022-00917-x.

[31] R. Kumar, K. K. Kuthadi, "Optimal placement of IPFC device for enhancing transmission system performance using WIPSO," *3rd Electric Power and Renewable Energy*, 2022, doi: 10.1007/s12008-022-00917-x.

[32] C. R. Kumar, K. K. Kuthadi, N. D. Sridhar, "Application of optimization algorithms to enhance the transmission system performance using thyristor controlled series capacitor," *Journal of The Institution of Engineers (India): Series B*, vol. 103, pp. 361–373 2021, doi: 10.1007/s40031-021- 00650-1.

BIOGRAPHIES OF AUTHORS

Majahar Hussain Mahammad received a B.Tech degree in Electrical and Electronics Engineering from Nimra College of Engineering and Technology, Vijayawada, in 2004 and M.Tech degree from JNTUK, Kakinada,A.P. in 2009. Currently, he is pursuing a Ph.D. in Electrical Engineering from the University College of Engineering and Technology, Acharya Nagarjuna University, Guntur, AP-India. He is also working as a lecturer in the College of Engineering, King Khalid University, Abha, Kingdom of Saudi Arabia. His research areas of Interest are Power system operation and control, Application of Intelligent control techniques to Power systems. He can be contacted at email: Mazhar204@gmail.com.

Dr. Chekka Ravi Kumar was born in India in 1981; He received a B.Tech. degree in Electrical and Electronics Engineering from A.S.R. College of Engineering and Technology, Tanuku, in 2003 and MTech degree from JNTU Anantapur, A.P.-India in 2005& Ph.D. from Acharya Nagarjuna University, Guntur, A.P. in 2017. Presently he is working as Asst. Professor & Head of the Department in the University College of Engineering, Acharya Nagarjuna University, Andhra Pradesh, India. His research areas of Interest are Power system operation and control, Application of Intelligent control techniques. He can be contacted at email: chekka.ravikumar@gmail.com.