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Analysis of Multi- Area Power System Robust Load Frequency Control

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Abstract:

This article presents, in recent times developed, novel and effectual meta-heuristic optimization technique called Black Widow Optimization Algorithm (BWO) to optimize automatic generation control (AGC) or load frequency control (LFC) for multi-area interconnected power system. Recently developed BWO, algorithm is a powerful method for solving continuous nonlinear optimization problems. In order to validate the proposed method, three area reheated thermal power system are considered and separately optimal BWO-PIDF is designed for each area by using integral of square of absolute error (ISAE) based fitness function. The validity of proposed method is tangibly verified by comparing its simulation results with those of Gravitational search algorithm (GSA), Particle Swarm Optimization (PSO) and other approaches available in the literature (Jalali, Razmi, & Doagou-Mojarrad, 2020). Then, physical constraints such as Governor Dead Band (GDB) and Generation Rate Constraint (GRC)are included in the system model. Finally, to show the robustness of the designed controller, sensitivity analysis is performed under different uncertainty conditions, the performance of the proposed method is superior than conventional and state-of-art methods with comparative analysis

Keywords: Black widow optimization Algorithm, Load frequency Control, PIDF Controller, Multi-area power systems, Sensitivity analysis

1. Introduction

For satisfactory operation of a large-scale multi - area power system to provide continuous supply of power with a tolerable quality to all consumers. Due to the rising and falling of generation and load demand, the system becomes non-

equilibrium and its frequency deviates from the nominal value (elgerd, 1971). Normally, the large-scale power systems are consisting of control areas representing coherent groups of generators which are interconnected through tie-lines. Tie-lines are used for contractual energy exchange and responsible for inter-area support in the case of abnormal conditions (Hassan, 2014). For the stable operation of a power system, AGC or LFC plays the key role in planning and operating power systems to maintain frequency within the predefined values. In order to provide adequate and reliable electric power possessing better quality (Pappachen & A. Peer, 2016). To accomplish this, it is necessary to regulate the operations of main hydro gates or steam valves automatically according to a suitable control strategy, which controls the real power output of electric generators consecutively. The controlling of electric generators output in this manner is called automatic generation control (AGC) (elgerd, 1971). The main goals of AGC problem is to diminish transient deviations of frequency in each area and tie-line interchange power to improve their steady state errors to be zeros (Guha, Kumar Roy, & Banerjee, 2016). Numerous traditional controllers' structure such as integral (I), integral derivative (ID), proportional integral (PI), proportional integral derivative (PID) and integral double derivative (IDD) were widely used to minimize the steady state frequency error of the system in modern power systems (Safi, Tezcan, Eke, & Farhad, 2018). Because of fixed structure and constant gain parameters of conventional PI and PID controllers, they are used to tune for one operating condition commonly (Duman & Yorukeren, 2012). However, owing to the complication of the power systems like variable operating points and nonlinear load characteristics, the PI and PID-controllers tuning with conventional methods may be not suitable for some operating conditions (Gözde, Taplamacioğlu, & Kocaarslan, 2009). Literature reported on problem of load frequency control points out a number of control strategies exists to achieve better performance (Singh, Tiwari, Ibraheem, & Singh, 2013). In the last few decades, several control strategies based on classical controllers, intelligent controllers including neural network, adaptive controller, hybrid neuro-fuzzy controller, fuzzy logic, internal model control, fractional order controller, and robust controller are demonstrated to sustain the system frequency and tie-line interchange power at their nominal value during normal and disturbed conditions (Guha, Kumar Roy, & Banerjee, 2016). For LFC of four-area interconnected power system, a new systematic approach is proposed (Bevrani, Mitani, & Tsuji, 2004) to design synthesis and analysis based sequential decentralized load frequency controllers. For setting the desired level of stability, the design strategy has enough flexibility and performance and the practical constraints by introducing applicable uncertainties is considered. In (Hiyama & Bevrani, 2008) for the issue of load frequency control

(LFC) two robust decentralized proportional integral (PI) controllers with communication delays are designed ; and in both methodologies, the PI based LFC problem is reduced to a static output feedback (SOF) control synthesis for a multiple delay system. In (Sonker, Kumar, & Samuel, 2019), dual loop-internal model control (DL-IMC) scheme are presented for LFC of multi-source multi-area power systems. To confirm the robustness for the suggested scheme, inserting ± 50% parametric uncertainty and applying external load disturbances in different combinations form. (Wang, Chen, Meng, Hu, & Wang, 2020), designed and investigated load-frequency controller with time delays under deception attacks and addressed on the basis of event-triggered scheme. They have been used a scheme of an event-triggered for reduction the amount of transmission data to reduce communication problems and save network resources. (Wang, Liu, Zhao, & Wei Wei, 2020), have addressed the problem of distributed frequency control systems by considering manageable load with a non-smooth cost. They applied distributed controller for optimal LFC of power system. For the effectiveness of the proposed method verification, the simulations carried out on the IEEE 68-bus system.

This paper introduces a novel and effectual meta-heuristic optimization technique called Black Widow Optimization Algorithm (BWO) for optimal tuning of PIDF controllers. The numerous advantages in different aspects of the BWO are reported in (Hayyolalam & Kazem, 2020), such as quick convergence and reaching optimized fitness value compared to other algorithms. The proposed algorithm provides a better achievement in exploration and exploitation stages and avoids local optima problem. The motivation behind this study is to prove and demonstrate the robustness of BWO-PID controller, and to improve the dynamic response of both frequency deviation and tie line power for different load conditions with the existence of nonlinearities of system.

The work of this paper is achieved in six sections. In Section-2, the model of a multi-area interconnected power system is presented. The structure of PIDF controllers are shown with details in Section 3. The BWO algorithm is used for tuning of PIDF parameters in section 4. Simulations for all operating conditions are shown to demonstrate the effectiveness of the proposed unified method in section 5. The proposed BWO based PIDF controller's performance are compared with PSO, GSA, TDE based fuzzy PID, PID, 2DOF IDD and PD–PID Cascade based PID controllers. Finally, in Section 6 conclusions are presented for describing possible extensions and future work on this issue.

2. Power System Model

For propose of design and analysis, multi-area with reheat turbine unit, power system model and transfer function as show in Fig.1 is considered. A PIDF controller is considered in each area. Each area of the system consists of generator, turbine and speed governing system. In Fig.1, ΔP_{Di} is load disturbances, ΔP_{Tie} is power error of tie-line, ACE_i is area control errors, β_i is the frequency bias parameters, U_i is the outputs of the PIDF-controller, R_{Ti} is the regulation parameters of speed governor in Hz/p.u MW, T_{gi} and T_{Ti} are the speed governor time constants and the reheat turbine time constant in second respectively. K_{PSi} is the power system gains, T_{psi} is time constant of power system in second for control area, Δf_i is the system frequency deviations in Hz and T_{ij} is the coefficients of synchronizing. Nominal parameters of power system under investigation are available in (Jalali, Razmi, & Doagou-Mojarrad, 2020). The generalized theory on LFC modeling is contained with more detail in the literature (Hassan, 2014) & (elgerd, 1971). In normal operation, the power flow of tie-line between control areas can be given as fallow:

$$P_{tie,ij} = \frac{|V_i||V_j|}{X_{ij}} sin(\delta_i - \delta_j) \qquad (1)$$

Where *Xij* is tie-line reactance between control areas, *Vi* and *Vj* are the voltages at machine terminals, *δi* and *δj* are the power angles of equivalent machines in control area *i* and *j* respectively. The turbine linearized model is represented by the following transfer function:

$$G_T(S) = \frac{\Delta P_T(s)}{\Delta P_V(s)} = \frac{1}{1 + sT_r} \qquad (2)$$

The governor's transfer function is as follows:

$$G_G(S) = \frac{\Delta P_V(s)}{\Delta P_T(s)} = \frac{1}{1 + sT_g} \qquad (3)$$

The speed governing system has two inputs like Δf and ΔP_{ref} with one output $\Delta P_G(s)$ is given by:

$$\Delta P_G(s) = \Delta P_{ref}(s) - \frac{1}{R}\Delta F(s) \qquad (4)$$

The generator and load is represented by the transfer function:

$$G_P(s) = \frac{K_{ps}}{1 + sT_{ps}} \qquad (5)$$

Where $K\text{ps}=1/D$ and $T\text{ps}=2H/\text{F}D$.

The generator load system has two inputs ΔPT(s) and ΔPD(s) with one output *Δf(s)* given by:

$$\Delta F(s) = G_p(s)[\Delta P_T(s) - \Delta P_D(s) \qquad (6)$$

For small deviation of tie-line power flow between controls areas can be written as:

$$\Delta P_{tie,ij} = \frac{2\pi}{s} T_{ij}\big(\Delta f_i(s) - \Delta f_j(s)\big) \qquad (7)$$

3. Structure of Controller

The PID controller consists of the proportional integral plus derivative modes, respectively. A proportional term is used for reducing the rise time, however it cannot zeros the steady-state error. The gain of integral in PID controller can zero the steady-state error, however it may create the worse transient response. The controller derivative parts are used to increase the system stability, improving the transient response and decreasing the overshoot (Safi, Tezcan, Eke, & Farhad, 2018) . In practical applications, due to the derivative kick pure derivative terms is never used, produced in the control signal for a step input, and to the undesirable noise amplification. For solution to these problems the derivative terms generally can be equipped by a low pass first-order filter. In Figure 2 the structure of PID with first-order low pass filter is given where proportional (K_P) integral (K_I) plus derivative (K_D) gains respectively, and N is the first-order low pass filter coefficient is selected from 1 up to100. The Eq. 8 represents the PIDF-controller transfer function (Laplace Domain).

$$TF_{PID} = \left[K_p + K_i(\frac{1}{s}) + K_d(\frac{Ns}{s+N})\right] \qquad (8)$$

In time domain, the output of PID controller is given by;

$$u_i(t) = K_p * ACE_i(t) + K_i \int_0^t ACE_i(t)dt + K_d \frac{d}{dt}(ACE_i) \qquad (9)$$

Where $ACE_i(t)$ is error signal and $u_i(t)$ is control signal. In the PIDF controllers, control inputs and outputs are ACE_i and u_i respectively. On relating the inputs and outputs of the system are given as:

$$ACE_i = \Delta P_{tie,i} + \beta_i \Delta f_i \qquad (10)$$

$$u_i = ACE_i\left(K_{pi} + \frac{K_{ii}}{s} + K_{di}s\right) \qquad (11)$$

In this work, the constraint of setting the gains of PIDF controller is a major problem. Therefore, the PID gains should be in limits;

$$Kp_{min,i} \le Kp_i \le Kp_{max,i} \qquad Ki_{min,i} \le Ki_i \le Ki_{max,i}$$

$$Kd_{min,i} \le Kd_i \le Kd_{max,i} \qquad N_{min,i} \le N \le N_{max,i}$$

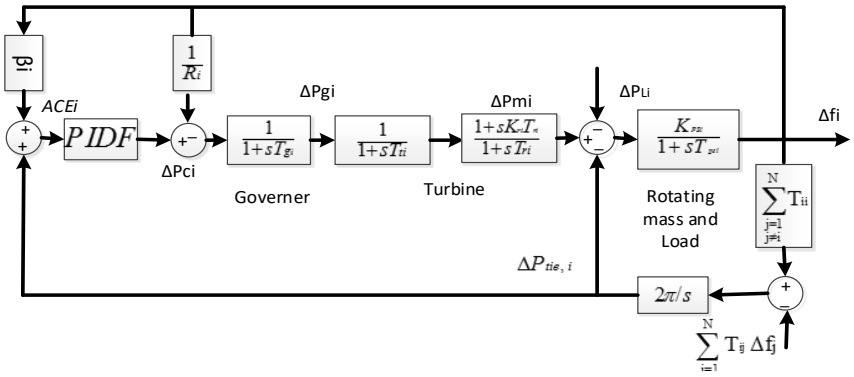


Figure 1: Generalize model of multi area power system

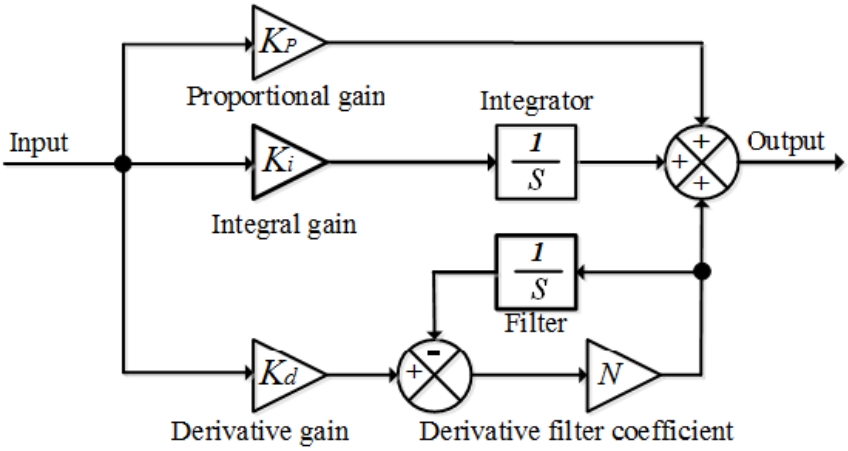


Figure 2: structure of PIDF controller

4. Black Widow Optimization (BWO) Algorithm

In recent times, a novel and effectual meta-heuristic optimization technique named Black Widow Optimization (BWO) Algorithm is developed by (Hayyolalam & Kazem, 2020). The black widow optimization algorithm imitates the lifestyle of the black widow spider's evolution. Commonly, female black widow spiders

construct the net during the night and leave some pheromone in some places of the constructed net for attracting male black spiders to mate. This pheromone cause to attract the male black widow spiders to join in constructed net. The male black widow is eaten by the female one during mating or after. Then she carries stored sperms in her sperm thecae and releases them into egg sacs. At least 11 days being laid, after that period of time, young spiders come out from the egg sacs. These spiders will participate in sibling cannibalism. They live together on the maternal web for a number of days to a week, during that time sibling anthropophagy is appeared. They are then carried away from each other in the wind. Some young spiders are even eaten by mother during that brief period. Other young spiders from the net are considered the fittest young spiders. Based on this concept different Pseudo - Code of BWO Algorithm are as followings:

1 The initial population of black widow spiders
2 Based on the procreating rate, calculate the number of reproductions "nr"
3 Select the best nr solutions in pop and save them in pop1 // Procreating and Cannibalism
4 For i = 1 to nr do
5. Randomly select two solutions as parents from pop1
6. Generate D children using Equation 1

7. Destroy father
8. Based on the cannibalism rate, destroy some of the children (new achieved solutions)
9. Save the remain solutions into pop2
10. End For // Mutation
11. Based on the mutation rate, calculate the number of mutation children "nm"
12. For i = 1 to nm do
13. Select a solution from pop1 |
14. Randomly mutate one chromosome of the solution and generate a new solution
15. Save the new one into pop3
16. End For // Updating
17. Update pop = pop2 + pop3
18. Return the best solution
19. Return the best solution from pop

5. Simulation and Results

Initially, a three area interconnected power system without any physical constraints is taken into account. The under study model of the system is given in Fig. 1. The software program is developed in the environment of MATLAB/SIMULINK with applied 1% step load increase in area-1. The PIDF controller parameters are tuned by BWO and the obtained results are compared with some newly published techniques like GSA and PSO algorithm. In this study, integral of absolute magnitude of square of error (IASE) is used to obtain the PIDF-controller optimum gains, and the cost function of that is given as follows:

$$j = \int_0^{t_{sim}} (|\beta_i \Delta f_i + \Delta P_{tie,ij}|)^2 \cdot t \cdot dt \qquad (12)$$

To reveal the robustness of the designed controller, sensitivity analysis is carried out by varying operational loading conditions and system parameters in the range of ±50% instep of 25%. In order to demonstrate the superiority of the proposed method, physical constraints such as GRC and GDB are taken into account. Further, in this study the designed BWO-PIDF controller parameters held fixed and various step load disturbance are applied at different time in area-1, area-2, and area-3 to examine the performance of the proposed LFC system. The parameters of optimum PIDF controller are given in table 1.

Case 1: A step increase in demand of 1 p.u applied to area-1 at t = 0 and the responses of system dynamic and tie-line power change in control area-1, area -2 and area-3 are presented in Figs. 3, 4, 5 and 6, respectively. From figures (3, 4, 5 and 6), it's clear that the BWO-PIDF controller provides better dynamic performance than GSA and PSO based PIDF controller for frequency response of the test system under investigation. The proposed controller is able to damp all oscillations, minimize settling time and reduce overshoot as shown in Table 1.

Case 2: Sensitivity analysis is performed to prove the robustness of the designed controller by varying operational loading conditions and system parameters such as T_g, T_t, T_r, K_r; T_{ps}, Kps, R_i and B_i are changed in the range of ±50% instep of ±25%. The PIDF controller gains are held fixed then the system dynamics have been investigated. The optimal controller gains are available in table 1 and in Table 2 illustrates the performance of the system for a 1% step increase in demand in control area-1 under nominal and other different conditions. It is clearly reveals from Table 2, the deviation of frequency peak overshoot and settling time values are varying within allowable ranges and are adjacent equal to the obtained values with nominal parameter of the system. It is observed that the BWO-PIDF enables the controller to perform stable and robust control satisfactorily, if the

system is subjected to wide range variation in loading conditions and system parameters, it is not necessary to reset the gains of controller.

Table 1: Simulation results obtained by different algorithms

Controller / Control Area		Area-1	Area-2	Area-3
BWO-PIDF	K_P	10	8.9643	7.7573
	K_i	8	5.4175	8
	K_D	4	2.2557	2.3092
	N	100	86.7241	36.9617
	ΔF [Hz]	-0.00504	-0.00145	0.00153
	Settling time [S]	2	3.30	3.31
	ΔP_{tie}	ΔP_{tie1-2}	ΔP_{tie2-3}	ΔP_{tie3-1}
		0.000005	0.000487	0.00049
	Settling time [S]	0.90	3.37	3.37
GSA-PIDF	K_P	4.000	0.1000	4.000
	K_i	4.000	2.1695	4.000
	K_D	1.0703	2.000	2.000
	N	91.571	100	90.760
	ΔF [Hz]	-0.0056	-0.0017	0.00177
	Settling time [S]	2.21	3.81	2.81
	ΔPtie	ΔPtie1-2	ΔPtie2-3	ΔPtie3-1
		0.00142	0.00004	0.00140
	Settling time [S]	4.6	2.83	3.3
PSO-PIDF	K_P	8.3876	2.5373	2.6866
	K_i	6.7178	3.6189	4.8803
	K_D	3.2875	1.6847	1.5662
	N	76.236	69.746	72.651
	ΔF [Hz]	-0.00921	-0.0042	-0.0041
	Settling time [S]	3.18	3.92	3.33
	ΔPtie	ΔPtie1-2	ΔPtie2-3	ΔPtie3-1
		0.00060	0.000008	0.00060
	Settling time [S]	3.61	0.01	3.61

Case 3: To demonstrate the capability of the suggested method to deal with nonlinearity such as Generation Rate Constraint (GRC) governor dead band (GDB) and are considered in test system. In each control areas, there is a single reheat turbine with GDB of 0.06 % and GRC of 3% per minute respectively (Hassan, 2014).

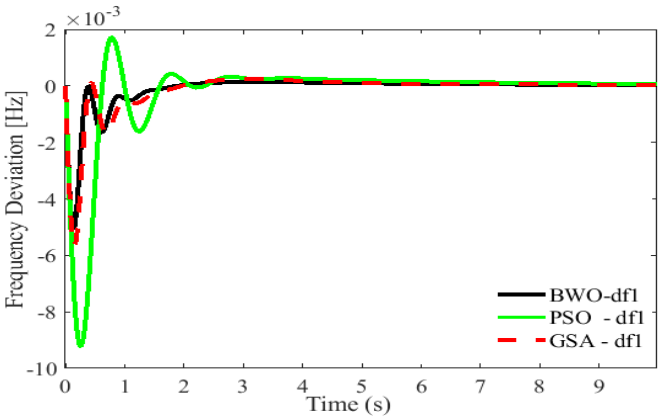


Figure 3: Deviation of Δf_1 for 1 % of ΔP_{D1} in area-1

Table 2: Analysis with fixed Robust controller gains

Parameters	Change [%]	Frequency & tie-line power deviation			
		ΔF_1	ΔF_2	ΔF_3	$\Delta Ptie1,2$
Tg	-50	-0.0041	-0.0011	-0.0012	-0.00041
	-25	-0.0041	-0.0011	-0.0012	-0.00041
	+25	-0.0046	-0.0013	-0.0014	-0.00043
	+50	-0.0058	-0.0019	-0.0020	-0.00059
Tt	-50	-0.0016	-0.0009	-0.0009	-0.00037
	-25	-0.0016	-0.0009	-0.0009	-0.00037
	+25	-0.0018	-0.0009	-0.0009	-0.00037
	+50	-0.0023	-0.0009	-0.0009	-0.00037
Tr	-50	-0.0050	-0.0015	-0.0016	-0.00048
	-25	-0.0050	-0.0015	-0.0016	-0.00048
	+25	-0.0050	-0.0015	-0.0016	-0.00048
	+50	-0.0050	-0.0015	-0.0016	-0.00048
Kr	-50	-0.0071	-0.0031	-0.0032	-0.00097
	-25	-0.0071	-0.0031	-0.0032	-0.00097
	+25	-0.0058	-0.0021	-0.0022	-0.00162

	+50	-0.0041	-0.0010	-0.0011	-0.00031
β	-50	-0.0067	-0.0037	-0.0039	-0.00076
	-25	-0.0067	-0.0037	-0.0039	-0.00076
	+25	-0.0057	-0.0023	-0.0024	-0.00060
	+50	-0.0041	-0.0008	-0.0009	-0.00038
Kps	-50	-0.0034	-0.0012	-0.0013	-0.00048
	-25	-0.0034	-0.0012	-0.0013	-0.00048
	+25	-0.0041	-0.0012	-0.0013	-0.00045
	+50	-0.0057	-0.0012	-0.0013	-0.00043
Tps	-50	-0.0066	-0.0012	-0.0013	-0.00043
	-25	-0.0066	-0.0012	-0.0013	-0.00043
	+25	-0.0053	-0.0011	-0.0012	-0.00042
	+50	-0.0038	-0.0012	-0.0013	-0.00046
R	-50	-0.0050	-0.0014	-0.0015	-0.00048
	-25	-0.0050	-0.0014	-0.0015	-0.00048
	+25	-0.0050	-0.0015	-0.0016	-0.00048
	+50	-0.0050	-0.0016	-0.0016	-0.00049
T_{12}	-50	-0.0052	-0.0010	-0.0010	-0.00036
	-25	-0.0052	-0.0010	-0.0010	-0.00036
	+25	-0.0051	-0.0013	-0.0014	-0.00039
	+50	-0.0049	-0.0011	-0.0012	-0.00063

The controller optimum gain parameters such as K_p, K_i, K_d and N are tuned by BWO algorithm which are shown in table 3. To evaluate the effectiveness of proposed approach, 1% step increase in demand load is applied at $t = 0s$ in area -1 and the dynamic response of the system is shown in Fig 7, 8, & 9. To establish the supremacy of proposed approach the dynamic responses are compared with TDE based fuzzy PID (Jalali, Razmi, & Doagou-Mojarrad, 2020), PID (Yatin Sharma, 2015), 2DOF IDD (Puja, Lalit, & Nidul, 2014) and PD–PID Cascade (Dash, Chandra, & Nidul, 2015). It is clearly identifying from fig.7, 6 & 8 and Table-3, that the dynamic response of the PIDF controller has less oscillation and short settling time to reach the steady value than others. Thus, in the presence of nonlinearities

that the BWO based PIDF controller is capable of providing sufficient damping to the system oscillations which is also verified the robustness of the controller.

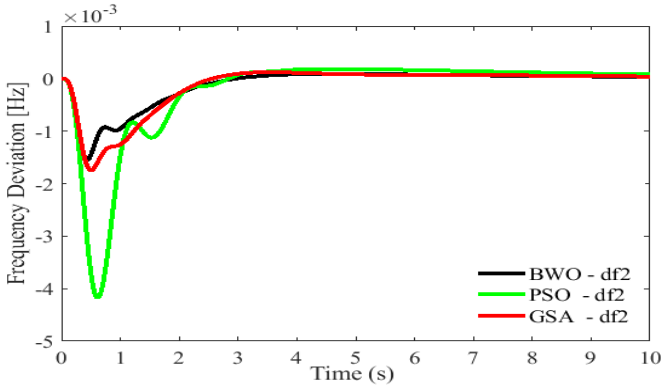


Figure 4: Deviation of Δf_2 for 1 % of ΔP_{D1} in area-1

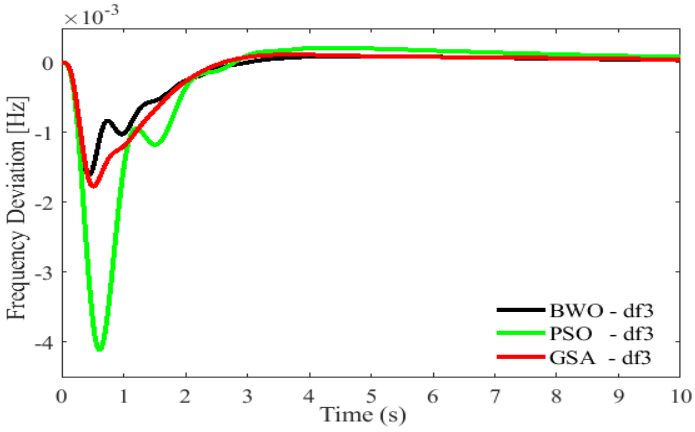


Figure 5: Deviation of Δf_3 for 1 % of ΔP_{D1} in area-1

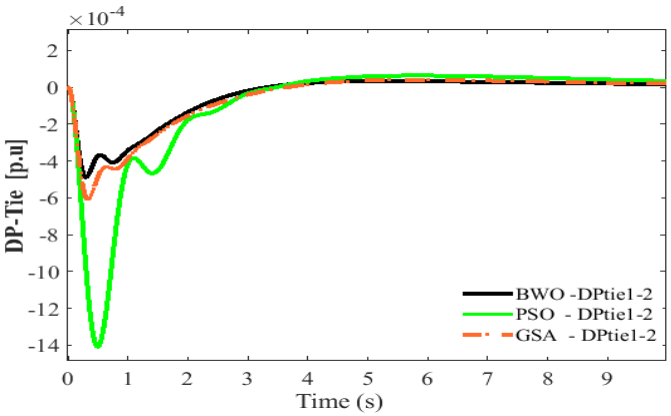


Figure 6: Deviation of ΔP-tie for 1 % of ΔP_{D1} in area-1

Table 3: Comparative analysis for test system.

Controller		Settling time [s]		
		Δf_1	Δf_2	Δf_3
Proposed method	Overshot	0.001243	0.001187	0.001188
	Undershot	0.0126	0.0161	0.0161
	Settling time [S]	8.8281	8.95899	11.999
TDE based fuzzy PID (Jalali, Razmi, & Doagou-Mojarrad, 2020)	Overshot	0.0011	0.0049	0.0015
	Undershot	0.0026	0.0159	0.0191
	Settling time [S]	23.1614	19.8176	24.2801
PID (Yatin Sharma, 2015)	Settling time [S]	34.81	35.56	32.35
2DOF IDD (Puja, Lalit, & Nidul, 2014)	Settling time [S]	34.10	28.00	27.12
PD–PID Cascade (Dash, Chandra, & Nidul, 2015)	Settling time [S]	32.02	28.34	NR

Furthermore, to investigate the usefulness of the proposed controller, there are applied different kinds of random load disturbances to area-1, area-2 and area-3 according to fig.10. The step load is random both in duration and magnitude. The frequency variation (Δf_1, Δf_2 & Δf_3) is shown in Fig. 11.

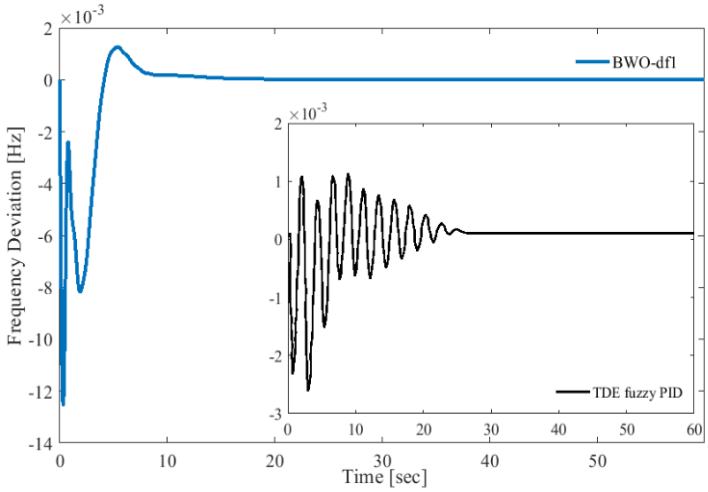


Figure 7: Deviation of Δf_1 in presence of nonlinearity

From Fig. 11 it is obvious that the proposed incorporated system with BWO based PIDF controller gives better transient response. It is clear, that with proposed approach the oscillations and settling times are minimum and system works effectively.

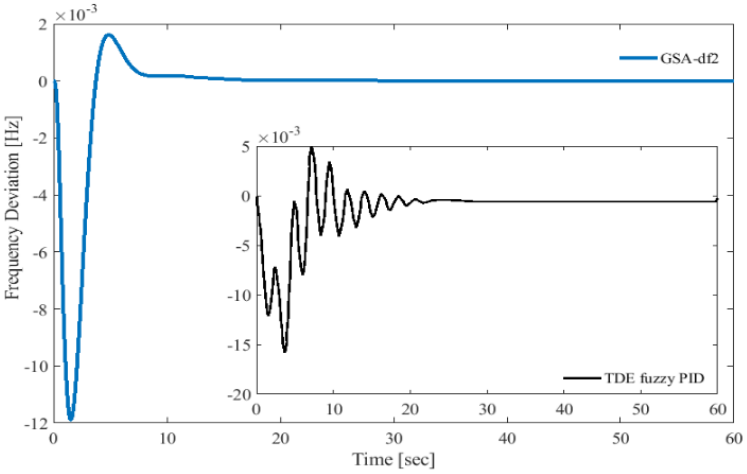


Figure 8: Deviation of Δf_1 in presence of nonlinearity

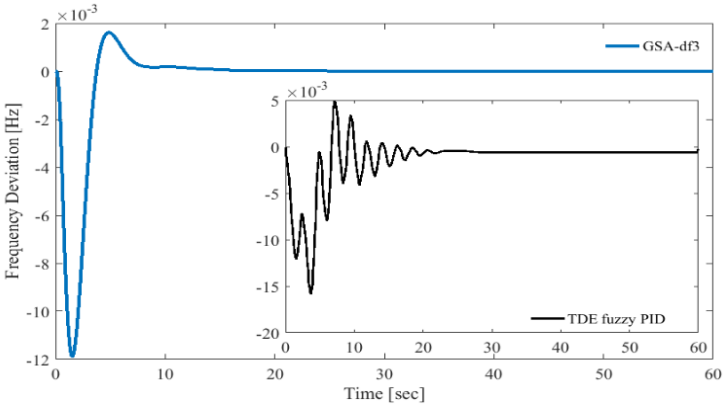


Figure 9: Deviation of Δf_1 in presence of nonlinearity

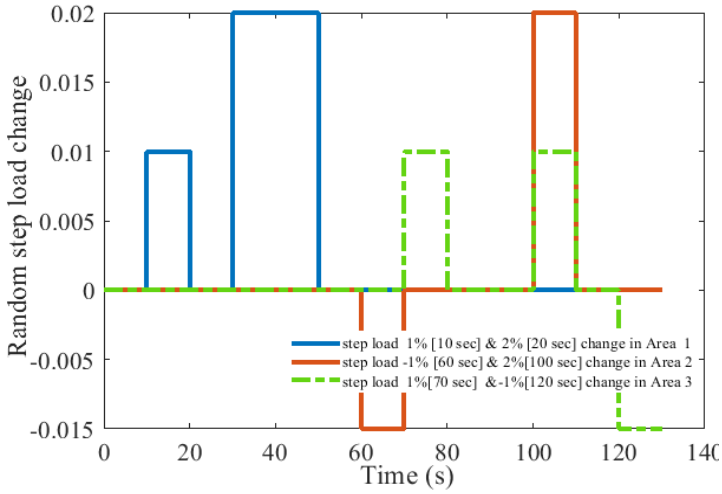


Figure 10: random load disturbances in all control area

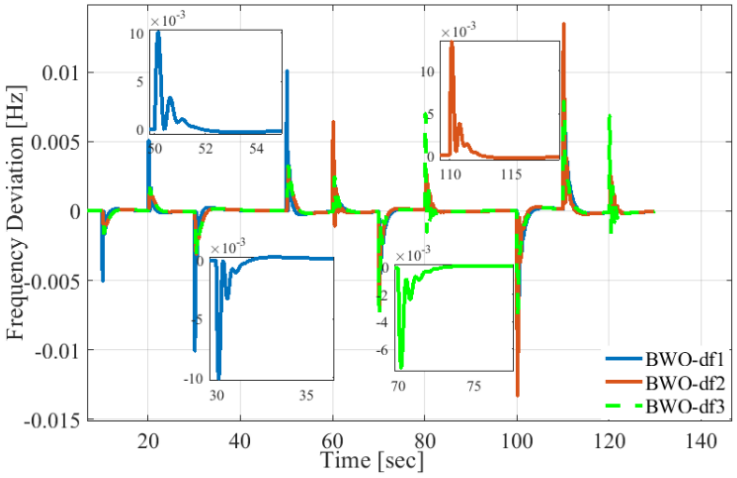


Figure 11: frequency deviation in all control area

5. Conclusion

In this paper, the Black Widow Optimization (BWO) based PIDF controller has been proposed for Automatic Generation Control of three-area interconnected power systems. At first, power system without any physical constraints is taken into account and the controller gains are optimized by BWO optimization algorithm. The results of simulation emphasize the effectiveness of the BWO-PIDF dynamic performance in terms of the least damping ratio, peak overshoots, undershoots and settling times in frequency and tie-line power deviations compared to some newly published approaches such as GSA and PSO based PIDF for the similar power system. Then, the designed controller gains are held fixed and sensitivity analysis is performed to prove the robustness of the controller by changing the load conditions and system parameters in the range of +25% to −25% from their nominal values. The evident indicates that the proposed BWO-PIDF enables the controller to perform stable and robust control satisfactorily. The parameters of the BWO-PIDF controllers need not to reset even if the system is subjected to wide variation in loading conditions and system parameters. Furthermore, to demonstrate the capability of the suggested method physical constraints such as GRC and GDB are considered in test system. Sensitivity analysis also demonstrates that the BWO based PIDF-controller is exactly robust and gives satisfactory performance under uncertainty. Finally, random load disturbances both in magnitude and duration are applied to area-1, area-2 and area-3, and the obtained simulation results indicate the effectively effects improvement of the proposed LFC method and reveal the superior performance of it over existing methods.

6. References

1. Bevrani, H., Mitani, Y., & Tsuji, K. (2004). Sequential design of decentralized load Frequency Controllers using Synthesis and Analysis. *Energy Conversion and Management*, 865 - 881.

2. Dash, P., Chandra, S., & Nidul, S. (2015). Automatic generation control of multi area thermal system using Bat algorithm optimized PD–PID cascade controller. *International Journal of Electrical Power & Energy Systems, 68*, 364-372.

3. Duman, S., & Yorukeren, N. (2012). Automatic Generation Control of the Two Area Non-reheat Thermal Power System using Gravitational Search Algorithm. *Przeglad Elektrotechniczny*, 254-59.

4. elgerd, o. i. (1971). *electric energy system theory. an introduction.* Mc Graw-Hill,Inc.

5. Gözde, H., Taplamacioğlu, M., & Kocaarslan, İ. (2009). A swarm optimization based load frequency control application in a two area thermal power system. *International Conference on Electrical and Electronics Engineering*, (pp. 124-128). Bursa.

6. Guha, D., Kumar Roy, P., & Banerjee, S. (2016). Load frequency control of large scale power system using quasi-oppositional grey wolf optimization algorithm. *Engineering Science and Technology,an International Journal, 19*, 1693–1713.

7. Hassan, B. (2014). *Robust Power System Frequency Control.* Springer International Publishing.

8. Hayyolalam, V., & Kazem, A. A. (2020). Black Widow Optimization Algorithm: A novel meta-heuristic approach for solving engineering optimization problems. *Engineering Applications of Artificial Intelligence, 87*, 103249.

9. Hiyama, T., & Bevrani, H. (2008). Robust decentralised PI based LFC design for time delay power systems. *Energy Conversion and Management*, 193-204.

10. Jalali, N., Razmi, H., & Doagou-Mojarrad, H. (2020). Optimized fuzzy self-tuning PID controller design based on Tribe-DE optimization algorithm and rule weight adjustment method for load frequency control

of interconnected multi-area power systems. *Applied Soft Computing Journal*, 93-106.

11. Pappachen, A., & A. Peer, F. (2016). Load frequency control in deregulated power system integrated with SMES–TCPS combination using ANFIS controller. *International Journal of Electrical Power & Energy Systems*, 519-534.

12. Puja, D., Lalit, C. S., & Nidul, S. (2014). Comparison of performances of several Cuckoo search algorithm based 2DOF controllers in AGC of multi-area thermal system. *International Journal of Electrical Power & Energy Systems, 55*, 429-436.

13. Safi, S., Tezcan, S., Eke, I., & Farhad, Z. (2018). Gravitational Search Algorithm (GSA) Based PID Controller Design for Two Area Multi-Source Power System Load Frequency Control (LFC). *Gazi University Journal of Science, 31*(1), 139-153.

14. Singh, O., Tiwari, P., Ibraheem, & Singh, A. (2013). A Survey of Recent Automatic Generation Control Strategies in Power Systems. *International Journal of Emerging Trends in Electrical and Electronics (IJETEE)*, 1-14.

15. Sonker, B., Kumar, D., & Samuel, P. (2019). Dual loop IMC structure for load frequency control issue of multi-area multisources power systems. *Electrical Power and Energy Systems*, 476-494.

16. Wang, D., Chen, F., Meng, B., Hu, X., & Wang, J. (2020). Event-based secure H ∞ load frequency control for delayed power systems subject to deception attacks. *Applied Mathematics and Computation*, 394.

17. Wang, Z., Liu, F., Zhao, C., & Wei Wei, Z. M. (2020). Distributed optimal load frequency control considering nonsmooth cost functions. *Systems & Control Letters*, 136-143.

18. Yatin Sharma, L. C. (2015). Automatic generation control of a multi-area ST – Thermal power system using Grey Wolf Optimizer algorithm based classical controllers. *International Journal of Electrical Power & Energy Systems, 73*, 853-862.

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