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A Novel Black Widow Optimized Controller Approach for Automatic Generation Control in Modern Hybrid Power Systems

Kanika Wadhwa[1*] and S. K. Gupta[2]

[1,2]Department of Electrical Engineering, Deenbandhu Chhoturam University of Science & Technology, Murthal, Sonipat, India

***Correspondence:** Kanika Wadhwa; 18001902002kanika@dcrustm.org;

ABSTRACT- This research paper demonstrates an application of the Black Widow Optimization (BWO) approach to address the issue of load-frequency control (LFC) in networked power systems. BWO is an innovative metaheuristic method that quickly suggests technique is initially evaluated on a non-reheat thermal-thermal (NRTT) power system spanning two areas of interconnection, and then it is applied to two different actual power systems: (a) a two-area thermal-thermal considering Generation Rate Constraint (GRC); and (b) a two-area having thermal, hydro, wind, solar, and gas systems. The BWO method uses two fitness functions based on integral time multiplied absolute error (ITAE) and integral square error (ISE) to optimize controller gains. The suggested BWO algorithm's performance has been compared to that of existing meta-heuristic optimization methods, such as grey wolf optimization (GWO), comprehensive learning particle swarm optimization (CLPSO), and an ensemble of parameters in differential evolution (EPSDE). The simulation results show that BWO's tuning skills are better than other population-based planning methods like CLPSO, EPSDE, and GWO. The ITAE value is enhanced by 33.28% (GWO), 40.28% (EPSDE), and 43.27% (CLPSO) when the BWO algorithm is used in conjunction with the PID Controller for thermal system.

Keywords: Automatic Generation Control, Black Widow Optimization, Integral Time Absolute Error, Integral Square Error, Interconnected Power System.

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1. INTRODUCTION

Distributing electricity is so vital, power companies must ensure that their consumers always have access to a sufficient supply of safe, high-quality electricity. AGC is a crucial component of power systems' operation that aims to maintain the balance between generation and demand by adjusting the output of generating units. AGC systems utilize control algorithms and optimization techniques to continuously monitor the system frequency and automatically adjust the power output of generators based on the deviation from the scheduled frequency. By doing so, AGC helps maintain the load-frequency balance, minimize frequency deviations, and ensure efficient power sharing among generating units.

Optimization control plays a key role in AGC by determining the optimal generation schedule that minimizes the system's operating cost while satisfying various operational constraints. Optimization control techniques often employ mathematical models, algorithms, and real-time data to make accurate and timely decisions.

For successful control and operation of current IPS, AGC requires the use of a proper control strategy, which is thoroughly and critically reviewed in [1], [2] . Due to their stability and ease of construction and implementation, traditional PI and PID programmed controls are still frequently used in industry[3], [4] . However, they often fail to provide optimal performance under variable situations. The robust control techniques, such as optimal control, internal model control (IMC) [4], H-infinity (H-∞) control[3], [5] , etc., that have been proposed as solutions to this issue. It has the potential to provide better performance; These methods are difficult to implement because they require either a strong state reconstructor or proof of the system's states.

Several different types of new control methods, such as the grey wolf optimization based integral (I) [6], the ICA tuned PID[7] , the combination of pattern search -adaptive gravity search method tuned PID [8], tuning of PIDN (PID with filter) by the wind-driven optimization (WDO) algorithm [9], particle Swarm Optimization[10] and the firefly-algorithm (FA) tuned PID/PI/I [10] is studied. However, they reveal several flaws in realistic PS implementations. Energy Storage System is studied in[12]. Due to their increased adaptability and robustness, fractional order (FO) controllers have been seeing more use in recent publication[11]-[14] [17]. Each management zone in a realistic PS uses a variety of power plants (hydro, thermal, gas, etc.) to meet local demand[18]-[23].

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For this reason, a comprehensive study of multi-source AGC systems is essential. Thus, the present study's authors have also considered a realistic two-region IPS with different types of power plants (thermal, hydro, solar, wind and gas) in each area.

1.1 Main Objective and Contributions

Following is a list of what this work aims to accomplish and how it contributes something new to the field:

(i) We propose a novel BWO-tuned PID-configured controller to address the AGC problem in a NRTT power system.

(ii) Comparisons to other control strategies, including GWO optimized PID, EPSD-tuned PID, and CLPSO-tuned PID, are made to identify the benefits of the proposed control approach.

(iii) To extend the scope of the study to the already available realistic two-area thermal-thermal using GRC.

(iv) The method's efficacy was verified by comparing it to other intelligent control techniques for the system, such as optimum output feedback, GWO based PID, hFA-PS based PID, and FA based PID controllers.

(v) The research will include a larger region with five power plants (thermal, hydro, gas, wind, and solar).

2. MATHEMATICAL MODELLING

For initial design and analysis purpose, *figure 1* depicts the first test system, a two-area thermal power system without a reheat turbine. The literature [23], [26] often uses the concerned power system model to investigate the dynamic behavior of the linked system in both typical and atypical scenarios. Each section has a 2000 MW rating and a 1000 MW nominal loading. The power system components, non-reheat type steam turbine, and speed governor are all installed in both control areas. All localized generators are in sync with one another. System parameters with nominal values were obtained from [22], [24].

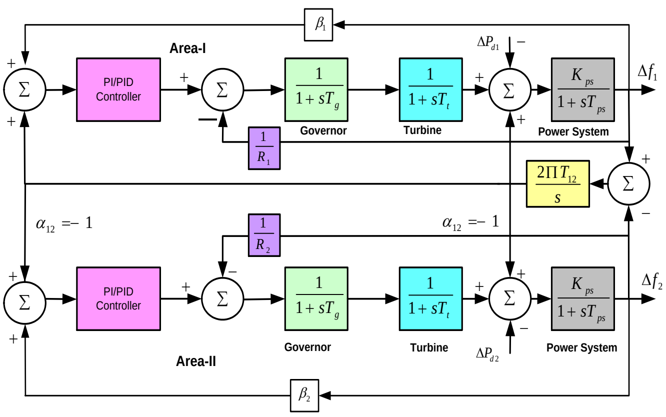

Figure1: Test System 1 (NRTT power system)

System modeling includes the correct steam turbine GRC value. Whenever a steam turbine is included in an actual power system scenario, GRC is always considered because otherwise the system would suffer huge transient disturbances that might lead to instability in the power system network. In a thermal power plant, a GRC of 5% is considered [24].

Figure 2 depicts the second testing system. This model considers five generating sources reheat thermal, hydro, gas, wind, and solar (RTHGWS). Data utilized in this test system is taken from[25]

3. CONTROLLER STRUCTURE WITH PROBLEM FORMULATION

The secondary controller is designed to swiftly restore nominal operation after a fast load perturbation by returning the frequency of both area and tie-line power variations to *zero*, and the BWO method is used to build an optimal PI/PID controller. When an unanticipated load disturbance disrupts the regulated regions, the controller takes appropriate action to reduce the ACE in each area until it reaches *zero*.

According to the IEEE's description of AGC terms, the Area Control Error in a linked power system is a number that shows whether there is too much or too little power in a control area.

$$ACE_j = \beta_j \Delta f_j + \Delta P_{tie} \qquad (1)$$

Where ACE_j represent the area control error for their respective areas given in *equation 1*. The controlled inputs u_j for *area 1* and *area 2* to the plant may be acquired in the following manner given in *equation (2)*.

$$u_j = K_{pj} ACE_j + K_{ij} \int ACE_j + K_{dj} \frac{d(ACE_j)}{dt} \qquad (2)$$

A good dynamic response is achieved in all operating conditions by optimally selecting the gains of the PID-controller, which requires a performance index targeted to the problem's structure. LFC's primary goal is to quickly bring the area control error (ACE) down to a minimum or *zero*, which is also the target value for the ACE.

In this perspective, LFC may be seen as a restricted optimization problem, and the controller parameters define the bounds of its restrictions.

4. METHODOLOGY

The Black Widow Optimization Algorithm (BWOA)[26] is a metaheuristic optimization algorithm inspired by the hunting behavior of black widow spiders. It was proposed as a swarm intelligence algorithm for solving complex optimization problems. The BWOA is a population-based algorithm that simulates the interactions between male and female black widow spiders during the mating process. In the algorithm, each

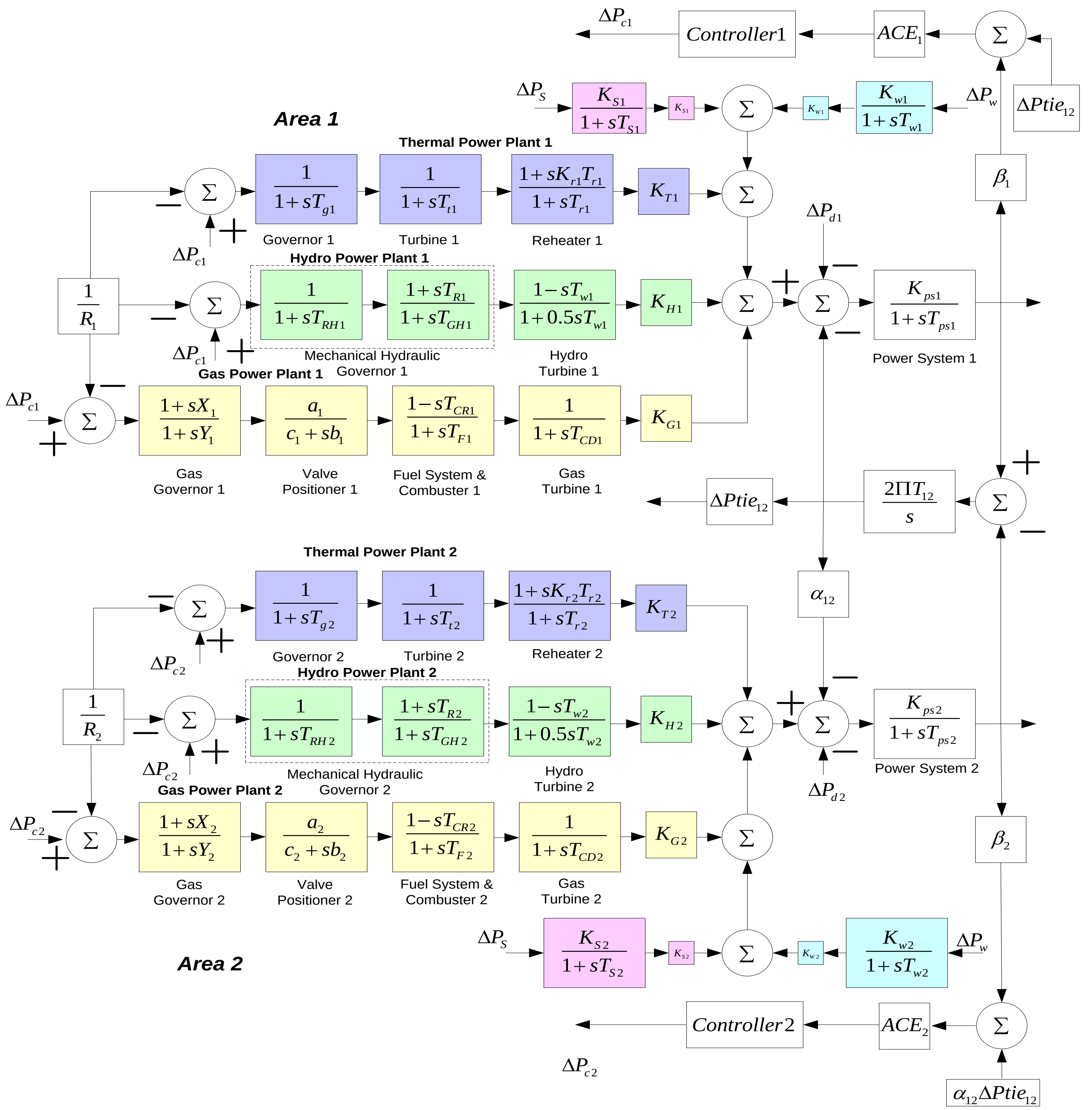

Figure 2: Test System 2 (RTHGWS power system)

potential solution to the optimization problem is represented as a spider in the population. The spiders interact and move in the search space to find the optimal solution. There are four steps to the BWO algorithm: population seeding, procreation (reproduction), cannibalism, and mutation.

5. SIMULATION OUTCOME

This study analyzes two separate power system networks to gauge the superiority and effectiveness of the anticipated algorithm. The test system transfer functions are modeled in MATLAB/SIMULINK, and the BWO optimization method is coded in an m file. Using the BWO method, the optimal gains of the controller settings are determined by minimizing the objective function, which is based on the ITAE criteria for NRTT system and the ISE criterion for the RTHGWS system. Using 10% S-L-P in area-1 for NRTT system, 5% S-L-P in area-1 considering GRC for NRTT system, and 1% S-L-P in area1 for RTHGWS system, the dynamic performances of test

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systems are studied. The current research uses a population size of 20, with a maximum of 80 iterations, to successfully execute the BWO algorithm.

Case 1: ***NRTT system for 10% SLP in area 1***

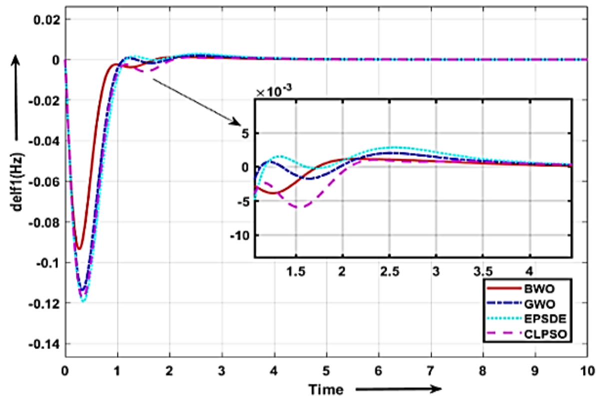
To demonstrate that the BWO algorithm is better in its execution, it has been applied to a two-area conventional model of a thermal unit. To examine the dynamic behaviour, a 10% step load perturbation is applied to test *system-1* of *area-1*. The given BWO technique is only one of several optimisation algorithms available in recent literature that may be used to fine-tune the performance of traditional PI/PID controllers. *Table 1* shows the optimum gain value for the controller. *Table 2* compares the performance of the proposed BWO method to that of other previously published conventional and meta-heuristic methods for the same power system and fitness function. It shows that the BWO method yields the lowest ITAE value. *Figure. 3* shows the responses of *area1* frequency, *area2* frequency and tie line power.

Table 1. Best controller parameter settings for NRTT system

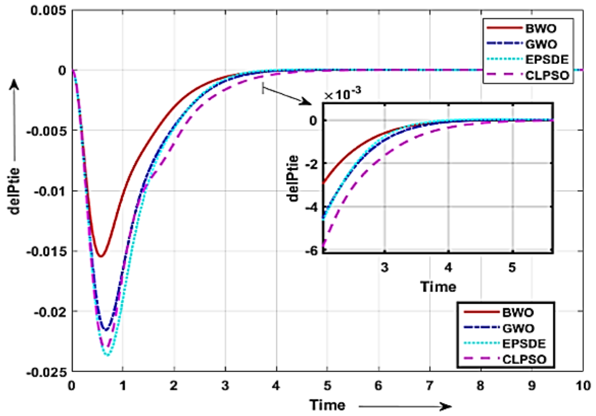
	Kp1	Ki1	Kd1	Kp2	Ki2	Kd2	ITAE
BWO :PID	-1.830	-2.707	-0.619	-1.741	0.011	-1.745	0.089
GWO :PID	-1.056	-1.910	-0.422	-1.748	-0.040	-1.198	0.134
EPSDE:PID	-0.859	-1.773	-0.388	-1.041	-0.165	-1.011	0.149
CLPSO:PID	-1.014	-1.705	-0.384	-1.720	-0.428	-0.583	0.156
BWO _PI	0.064	-0.695	-	-0.570	-0.018	-	0.093
GWO :PI	-0.063	-0.556	-	-0.073	-0.019	-	0.138
EPSDE:PI	-0.014	-0.850	-	-0.047	-0.033	-	0.153
CLPSO:PI	-0.024	-0.966	-	-0.015	-0.114	-	0.194

Table 2. ITAE values' and settling time performance comparison for NRTT system

	Settling Time (s)			ITAE
	delF1	delF2	delPtie	
Proposed BWO tuned PID	0.8455	2.7633	2.8564	0.089337
Proposed BWO tuned PI	0.9629	2.825	2.96	0.093
PSO tuned PI [18]	7.37	7.82	5	1.2142
hBFO-PSO tuned PI[18]	7.39	7.65	5.73	1.1865
GWO tuned PID[6]	1.06	3.17	3.34	0.1340
EPSDE tuned PID[6]	2.88	3.37	3.56	0.1497
CLPSO tuned PID[6]	1.89	3.60	3.80	0.1569
GWO: PI[6]	1.70	3.25	3.40	0.1388
EPSDE: PI[6]	6.22	7.80	6.67	0.1539
CLPSO: PI[6]	7.19	8.80	7.64	0.1949



(a) Frequency deviation



(b) Tie-line power fluctuation

Figure 3: NRTT system responses

The ITAE value is enhanced by 33.28% (GWO), 40.28% (EPSDE), and 43.27% (CLPSO) when the BWO algorithm is used in conjunction with the PID Controller for thermal thermal system. The ITAE value is enhanced by 23.24% (PSO), 92.14 % (hBFO-PSO), 32.85% (GWO), 39.44% (EPSDE), and 52.18% (CLPSO) when the BWO algorithm is used in conjunction with the PI Controller for thermal thermal system.

BWO optimised PID controller reduces settling time by 12.20% delf1, 2.25% delf2, and 3.5% delPtie compared to BWO based PI-controller.

Case 2: ***NRTT system with 5% SLP with GRC***

Extending the research to a nonlinear system considering GRC of the steam turbine to prove the superiority of the suggested BWO algorithm. As a practical matter, GRC limits the turbine's reaction time. In this research, we examine the dynamic performance of the NRTT system while applying a 5% load perturbation (SLP) to region 1[6]. *Table 5* displays the results of a comparison between the proposed BWO algorithm and other popular meta-heuristic optimisation methods. The optimal PID-controller with GRC parameters is shown in *table 4*.

Table 5 shows that the BWO method achieves the lowest ITAE value when the controller structure, goal function (ITAE), and GRC value are ± 0.05.

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Table 3. BWO-based PID-controller parameters at their ideal values for NRTT system with GRC

	GRC= ± 0.05			
	BWO	**GWO[6]**	**FA[22]**	**hFA-PS[22]**
Kp1	-1.0426	0.9843	0.3259	0.3834
Ki1	-1.0093	1.9766	0.5743	0.6127
Kd1	-0.5999	0.3463	0.4024	0.4021
Kp2	-1.0426	1.9892	0.3259	0.3834
Ki2	-1.0093	0.2150	0.5743	0.6127
Kd2	-1.5999	1.0085	0.4024	0.4021
ITAE	0.0127	0.1308	0.3240	0.2782

Table 4. Performance comparison of various optimization methods for NRTT system with GRC

	GRC= ± 0.05			
	delF1	**delF2**	**delPtie**	**ITAE**
BWO	2.32	2.60	1.96	0.0127
GWO[6]	2.64	2.86	3.14	0.1308
hFA-PS[22]	2.80	4.50	4.0	0.2783
FA[22]	3.10	4.90	4.3	0.3240

In comparison to the other optimisation methods shown in *table 5*, BWO improves the objective function by a factor of 90.29 percent (GWO), 95.43 percent (hFA-PS), and 96.08 percent (FA).

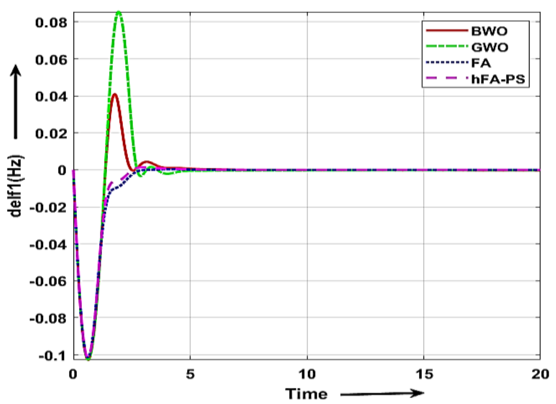
Case 3: *RTHGWS system for 1% SLP in area 1*
Considering green energy power plants as part of a RTHGWS system to show that the suggested BWO method is better. It's solar and wind input is taken from [19]. In this model settling time of *area 1* frequency is 9.08 sec, *area 2* frequency is 12.33 sec and ptie line power is 11.35sec. The ideal controller gain value is shown in *table 5* while the settling times for the tie line power, *area 1* frequency, and *area 2* frequency are shown in *table 6*, taking integral square error into account.

Table 5. Controller value for RTHGWS system

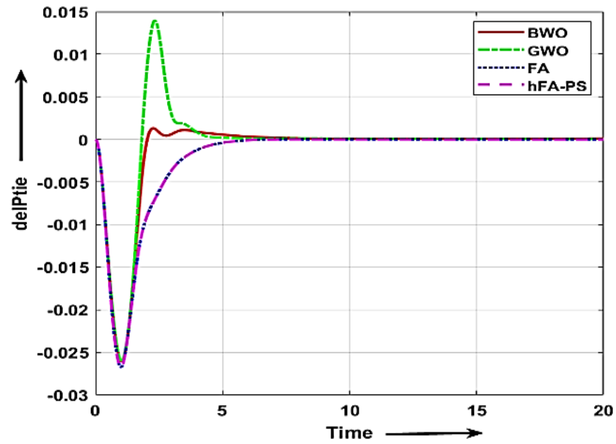
	Kp1	**Ki1**	**Kd1**	**Kp2**	**Ki2**	**Kd2**	**ISE**
BWO	-1.4333	-1.9690	-0.7681	-2.3069	-2.0681	-1.2404	0.0011

Table 6. Settling time of RTHGWS system

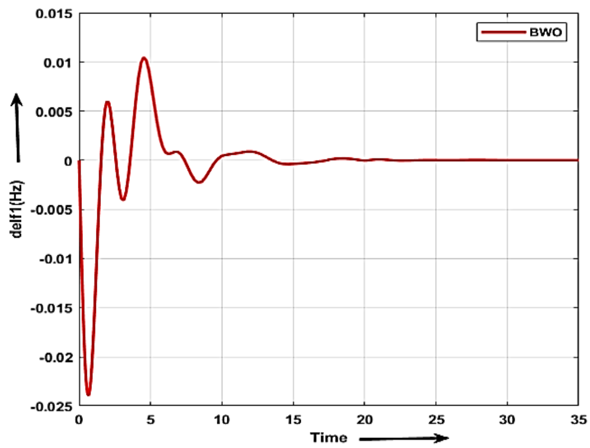
	Settling Time (sec)			ISE
	delF1	**delF2**	**delPtie**	
Proposed BWO tuned PID	9.08	12.33	11.35	0.0011



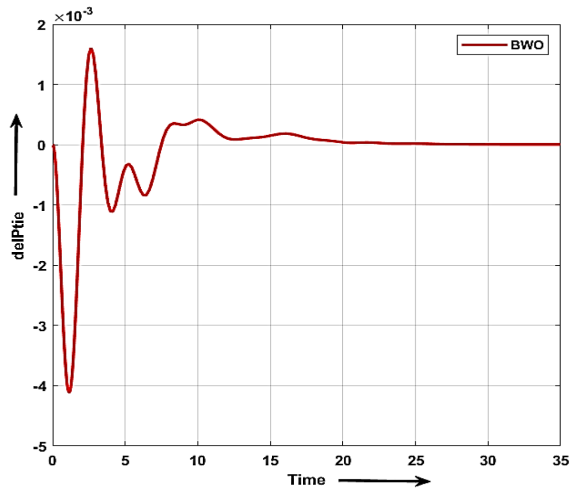
(a) Frequency deviation



(b) Tie-line power fluctuation
Figure 4: NRTT system responses with GRC = 0.05



(a) Frequency deviation



(b) Tie-line power fluctuation
Figure 5: RTHGWS system responses

5. CONCLUSION

To solve the LFC issue in the power system, this article introduces a novel evolutionary algorithm, called BWO, and details how it was developed and put into practice for the first time. BWO is an innovative meta-heuristic method that can be used for solving continuous nonlinear optimization problems. When compared to other algorithms, BWO excels in several ways. It converges quickly and produces optimal value. An ITAE-based objective function is used to optimize controller settings for a two-area thermal(T-T) power system with and without the steam turbine's GRC using the GWO, EPSDE, BWO, and CLPSO algorithms. The simulation results for a similar test system show a significant improvement with a BWO optimised PID controller compared to meta-heuristic optimisation techniques. The simulation results show the system's performance is significantly enhanced using the suggested BWO-adjusted PID controller to deal with the nonlinearities. Percentage improvement result is shown in above tables. The ITAE value is enhanced by 33.28% (GWO), 40.28% (EPSDE), and 43.27% (CLPSO) when the BWO algorithm is used in conjunction with the PID Controller for thermal-thermal system. When compared to the BWOA tuned PI controller, the proposed BWOA tuned PID reduces the time it takes for dynamic reactions (delF1, delF2 and delPtie) to settle by 12.20%, 2.25 %, and 3.5%, respectively.

Future scope of the LFC system may include applying a more sophisticated control algorithm to the suggested zone to better the system's dynamics when perturbations are present. However, unpredictable load variations of varying sizes occur continuously throughout the day, stressing the electrical grid. This means that when we modify the dynamics of existing power systems, we consider this load pattern. Together with LFC, we will implement a variety of power system stabilizers to further improve existing stability. Considering a contingency analysis is a great way to broaden the scope of this study.

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