Hybrid Algorithm of PSO and GWO Based PITIDF Controller for Load Frequency Control of Two-Area Power System

Abdessamade Bouaddi*‡, Reda Rabeh**, Mohammed Ferfra*

*Department of Electrical Engineering, Mohammadia School of Engineers, Mohammed V University, Rabat, Morocco

** International University of Rabat, ECINE, Sale, Morocco

(bouaddi@emi.ac.ma, reda.rabeh93@gmail.com, ferfra@emi.ac.ma)

‡Corresponding Author; Abdessamade Bouaddi, (301), Rja Fellah-Yac Al Mansour 10050, Rabat,

Tel: +212611298164, bouaddi@emi.ac.ma

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Abstract- In today's world, most power systems are interconnected to enhance the reliability of electrical system operation. Hence, load frequency control (LFC) has proven to be a difficult task for power system engineers. When several power generation sources are used, the complexity of the task is increased. In this work, it is suggested to use a PI controller with a TID (tilt-integral derivative) included DF (derivative filter) (PITIDF) for LFC task of a two-area interconnected power system. Furthermore, the suggested PITIDF controller parameters are optimized by a new hybrid optimization technique known as Particle Swarm Optimization and Grey Wolf Optimizer (PSO-GWO). The suggested optimization technique, in particular, controls the tie-line power and frequency deviation in the considered two-area power systems. The suggested hybrid algorithm-based PITIDF controller is compared to various control methods in order to evaluate its effectiveness. The studied system will be exanimated under variable perturbation in load (case 1: 1% step load for area 1 and 3% step load for area 2; case 2: variable Load) and changing of system parameters (case 3: step load with parameter uncertainties) to demonstrate the proposed method's robustness. The results obtained from all simulations, using MATLAB-Simulink tool, and shows that the proposed method achieves excellent results such as minimal objective values obtained for the two-area system.

Keywords Load frequency controller, two-area power systems, PITIDF controller, hybrid algorithm optimization.

1. Introduction

An essential indication to evaluate the performance of dynamic power systems is frequency stability control. In order to maintain the nominal range, an interconnected power system regulates frequency and controls the flow of electricity. A power system with several areas has the advantage of reinforcing continuity of service by giving the different areas the possibility of being interdependent with each other by allowing an exchange of energy between them when necessary, this exchange being able to be done through interconnection lines.

The LFC (Load frequency control) or AGC (Automatic Generation Control) allows for fast adjustment of the system's oscillations to the normal and optimal range. The generation-load mismatch and system degradations cause the power system's frequency to fluctuate. The tie-line power among the various areas of the system may also fluctuate as a result of this. Controlling the tie-line power and the generator is necessary to keep the dynamics of the system stable, the term used to describe this control is Area Control Error (ACE). The two main goals of AGC are [1]: (1) the frequency variations of the system must be within the allowable range. (2) The tie-line power variations must be within the allowable range.

Thus, in addition to the problems caused by the mismatch between the demand load and the generation, the penetration of renewable energy sources (RESs) presents new issues for the modern power system. Besides, the security and stability of the electricity grid are impacted by these difficulties. As a result, monitoring tie-lines' power flow between the power system locations and sustaining grid frequency under normal or abnormal operating circumstances are both solved by load frequency control (LFC).

For the LFC problem, in recent years, a variety of control solutions have been put out by different researchers. In [2], where several control strategies for the Automatic Generation Control problem have been investigated. Engineers continue to favor the traditional PID controller and its variations because of their basic design, dependability, and attractive price/performance ratio. For a two area interconnected system, authors in [3] uses SSA (Salp Swarm Algorithm) and MVO (Multi-verse optimizer) to optimize PID controller. Using a Whale Optimization Algorithm, the PID controller for LFC of multi-area power systems is optimized in [4]. In [5] an M-ADRL (multi-agent deep reinforcement learning) method is used to regulate the controller’s coefficients in multi-area power systems.

Sliding Mode Control [6, 7], Model Predictive Control [8–9], ANFIS [10, 11], Internal Model Control [12], Quantitative Feedback Theory [13], Fractional Order PID [14, 15], Variable Frequency Drive (VFD) [16] and other sophisticated control approaches are used to LFC problems [17,18]. These techniques appear to be superior to PID control strategies at first appearance, but it is noted that these controllers are sophisticated and not frequently employed in industry.

It is suggested in [19] to use the Improved Grey Wolf Optimization (IGWO) approach to optimize the fuzzy PID (FPID) parameters. In [20], a new hybrid fuzzy PI (FPI) controller is suggested for frequency regulation of four-area interconnected power systems with Renewable sources. In [21], a new fuzzy logic type II controller tuned by WOA whale optimization algorithm is proposed for a secondary frequency regulation in power system combines renewable and conventional power resources. Heuristic intelligent algorithms such as GWO-CS [22], MFO-WC [23], GA-TLBO [24], GA [25, 26], FA [27], LOA [28] and JAYA [29] have been used to look for optimal controller gains in LFC of Power System in handling optimization issues. In [30], In order to preserve dynamic frequency stability in power grid, authors present a study on a wind turbine equipped with a variable-speed mechanism and a flywheel.

To the best of our knowledge, hybridizing GWO and PSO has not been used to examine the performance of frequency regulation under load change of two area interconnected Power Systems. It is clear from a review of the literature that the objective function, controller design, and optimization algorithm all affect how effectively LFC executes. To enhance the guidance and optimization capabilities of the proposed approach, an objective function is proposed, which incorporates time-weighted integral of absolute error (ITAE), settling times , overshoot and undershoot, with chosen weight coefficients taking into account a variety of load changes and system uncertainties for the studied two-area connected power system's frequency stability.

The main contributions of this research are noted in the list that follows.

a. Propose a structure of PITIDF as the suggested controller for the studied two-area interconnected power system for LFC.

b. Further, a new Hybrid Algorithm of Particle Swarm Optimization and Grey Wolf Optimizer (PSO-GWO) is employed to optimize the gains of the proposed PITIDF regulator of the considered system.

c. The performance of the PITIDF controller proposed in this study, utilizing PSO-GWO, is validated through a comparative analysis against various other control techniques and other basic algorithms (e.g., PSO, GWO, GA)

d. To confirm the robustness and the effectiveness of the PITIDF controller, we assess its performance under different load scenarios, including step load perturbations, variable load disturbances, and system uncertainties, within the context of the studied two-area interconnected power system.

This paper starts by describing, in Section 2, the model of the considered power system of LFC for two-area is discussed. The suggested controller scheme is described in section 3. The optimization hybrid (PSO-GWO) is described in section 4. Section 5 gives the problem formulation. For the simulation results and discussion, see section 6. Finally, conclusion is presented in the last section.

2. Modeling of Two-Area Power System

2.1. Single-Area Power System

Figure 1 shows that the linear model of the power system comprises four elements: The load, governor, turbine and generator. There are three main types of traditional turbines, depending on the utilization scenario: reheat, non-reheat, and hydro [31].

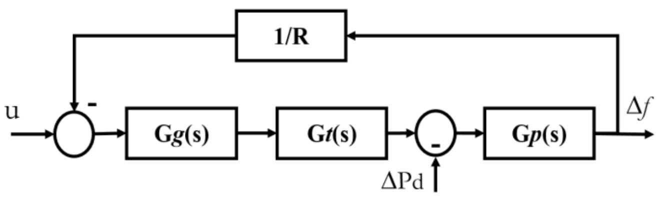

Fig. 1. Single-area power system.

Non-reheat turbine:

$$G_t(s) = \frac{1}{1 + T_t s} \tag{1}$$

With T_t represent the turbine’s time constant.

Reheat turbine:

$$G_t(s) = \frac{K_r T_r s + 1}{(T_r s + 1)(T_t s + 1)} \tag{2}$$

With *Kr:* the reheat gain and Tr : the time constant.

Hydro-turbine:

$$G_t(s) = \frac{(-T_w s + 1)(T_R s + 1)}{(0.5T_w s + 1)(T_2 s + 1)} \quad (3)$$

Where T_R, Tw and T_2 are the time constants.

The gas turbine power plant which consists of the gas turbine, fuel system, speed governor, and value positioner is also taken into account in this study. Its dynamic transfer function is:

$$G_t(s) = \frac{1}{(c_g s + b_g)} \frac{(X_c s + 1)}{(Y_c s + 1)} \frac{(-T_{CR} s + 1)}{(T_F s + 1)} \frac{1}{(T_{CD} s + 1)} \quad (4)$$

Where

c_g , b_g : constants of the valve positioner,

Y_c : the lagging time constant.

T_{CR} the combustion response time delay in the gas turbine, and T_F stands for fuel time constant. T_{CD} indicates time constant of the compressor.

X_c : the leading time constant.

Generator:

$$G_p(s) = \frac{K_p}{T_p s + 1} \quad (5)$$

Where *Tp*: the time constant; Kp : the gain constant.

2.2. Modelling the Multi-Area Power System

Figure 2 represents the design of the model for *i-th* area in an *i*-area power system for LFC, which consists of different areas connected by tie-lines [31].

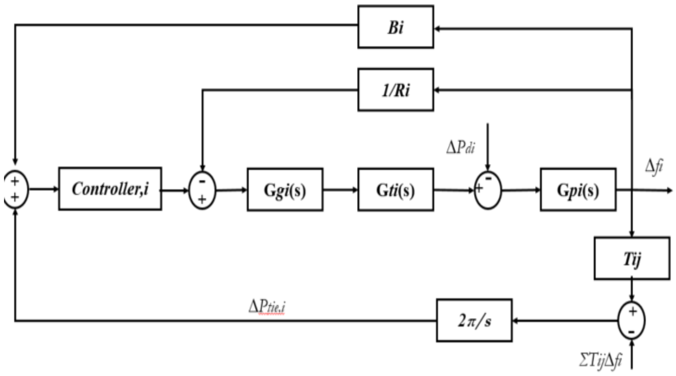

Fig. 2. Model of Multi-area power system.

In Figure 2, ΔP_{tie} symbolizes the tieline power variation deviation to the frequency changess through $2\pi/3$, T_{ij} signifies the time constant for synchronization between area *j* and area *i* . Δf_i , ΔP_{di} are frequency deviation and load disturbance of the area *i* respectively , B_i is the frequency response parametre , R_i indicates the area *i* speed droop constant, and many coefficients, which can be expressed a :

$$\Delta P_{tie,i} = \frac{2\pi}{s} \sum_{j=1, j\neq i}^{n} T_{ij}(\Delta F_i(s) - \Delta F_j(s)) \quad (6)$$

The modelling diagram for the studied system type is illustrate in Figure 3. For the model's parameters, see Table 1. Each region is made up of hydro, thermal and gas units, as can be shown in Equations (4) and (5). Each unit in this area uses a PITIDF controller to complete the LFC in order to avoid frequency and tie-line power variations resulting from fluctuations in load.

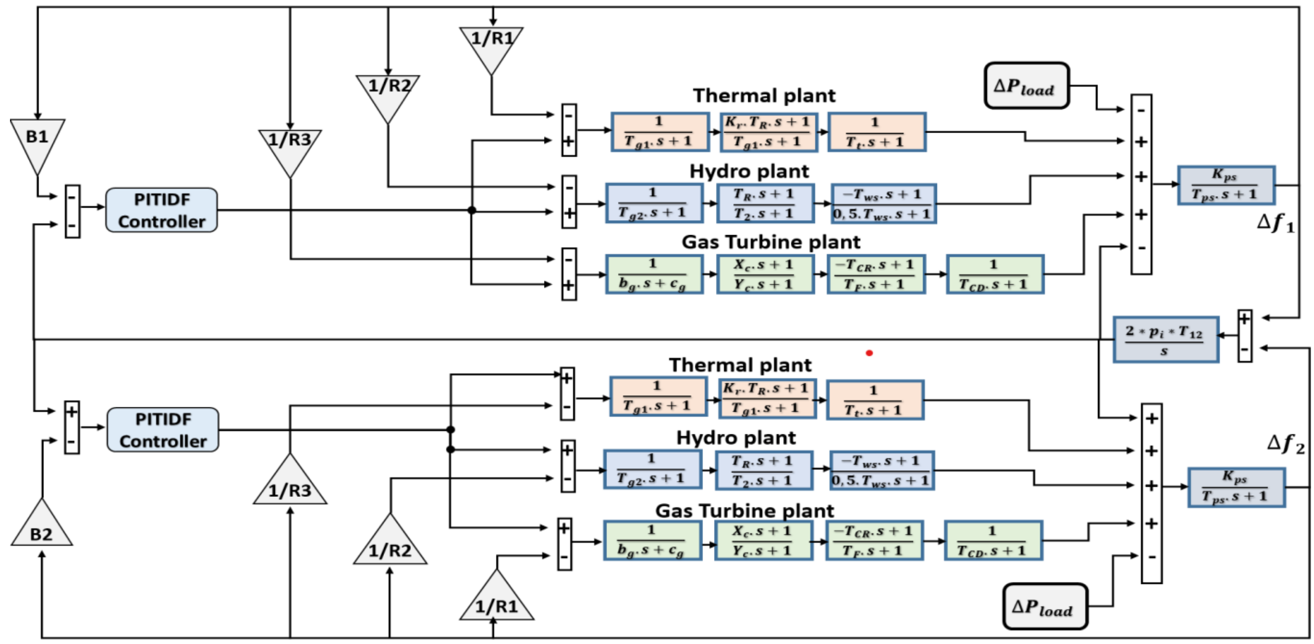

Fig. 3. Modelling diagram for the power system.

Table 1: Settings of the studied power system

Parameter	Value	Parameter	Value
B_1 , B_2 (pu)	0.4312	**T_w(s) and T_R(s)**	1 and 5
R_1 , R_2 , R_3 (Hz/pu)	2.4	**b_g and c_g**	0.05 and 1
T_{ps} (s)	11.49	**T_2 (s)**	28.75
T_{12} (s)	0.086	**K_r**	0.3
T_t (s) and T_r (s)	0.3 and 10	**X_C(s) and Y_C(s)**	0.6 and 1
T_{g1}, T_{g2} (s)	0.08	**T_{CR} (s) and T_{CD} (s)**	0.001 and 0.2
K_{ps}	68.96	**T_F (s)**	0.23

3. The Controller Structure

3.1. PIDF and TIDF Controller

The most simple and efficient solution to any control issues is the PID controller (proportional integral derivative) and its derivatives control, because they increase the control system response's transient and steady-state requirements, and due to their simplicity and functionality. Similar to PID, TID controller also uses integral and derivative actions, but tilted component with transfer function KP x 1/s1/n replaces PID's proportional action. The parameters are: KP (proportional), KI (integral), KD (derivative), and FC (filter), and n (tilt coefficient) is a nonzero real TIDF parameter [32].

3.2. PITIDF Controller

The benefits of the cascade controller for LFC of power systems are illustrated in [30]. So, this paper propose cascade PITIDF with the goal of improving performance. In the suggested PITIDF, the error is introduced as input in the PI controller, and the output response of PI corresponds to the TIDF controller. From TIDF, the final regulated output is obtained. The main benefit of PI is that it lowers steady state error. The tilt-integral derivative TIDF controller produces an enhanced transient response, more stable response, and a greater disturbance rejection when parameter changes are made. Therefore, the suggested PITIDF utilizes PI and TIDF benefits in the right sequence. Figure 4 shows the projected PITIDF structure, where KPP is the proportional parameter and KIP represent the integral parameter of the PI, respectively.

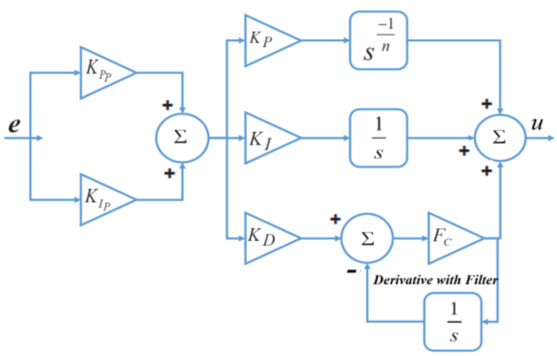

Fig. 4. Structure of the PITIDF controller.

4. The Objective Function

Optimal control is realized when the controller's parameters are adapted to minimize the objective function to its lowest possible value. The fitness function indicating the controller's performance must be accurately determined in order to obtain relatively superior controller parameters. The most frequently used criterion, time-weighted integral of absolute error (ITAE), has a significant impact on practical implementation. In contrast to the objective functions like ITSE, IAE and ISE, time-weighted integral of absolute error (ITAE) is favored as an objective function because it decreases overshoot, oscillation and settling time [23]. In this work, ITAE was considered as an objective function. As a result, the objective function employed by LFC may be written as:

$$min(J) = ITAE = \int_0^{t_{sim}} (|\Delta f_1| + |\Delta f_2| + |\Delta P_{tie}|).t.dt \quad (7)$$

Subject to:

$$K_{cpimin} \leq K_{cpi} \leq K_{cpimax} \quad (8)$$

With Δf_1 and Δf_2 reflect variations in frequency corresponding respectively to areas 1 and 2, and ΔP_{tie} is the variation in tie-line power. The suggested optimization method for determining the considered PITIDF controller's parameters minimized the objective function. K_{cpi} are the controller gains to be optimized and K_{cpmin}, K_{cpmax} are the controller gains' lower and upper limits respectively.

5. Hybrid PSO-GWO Approach

5.1. Particle Swarm Optimization

PSO Particle swarm optimization is a population meta-heuristic technique using memory. It is an optimization approach based on swarm intelligence that uses individuals, initialized randomly, to move them in a part of the search space to find the optimum solution to the problem. These individuals are called particles and each constitutes a potential solution to the problem. It drew inspiration from the social interactions observed in birds. PSO, a meta-heuristic optimization methodology, offers a population based search approach for global optimization, with the main benefit of being simple to use and requiring few parameters to be adjusted [33].

5.2. Grey Wolf Optimization

A newly created meta-heuristic algorithm called the GWO (Grey Wolf Optimizer) imitates the swarming hunting behavior of wolves. The male and female pack leaders in GWO are referred to as alpha (α) and are the first and best individuals. The second and third top wolf are referred to (β) and (δ). The grey wolf's lowest rank is omega (ω), which is subordinate to all other governed wolves. [34].

5.3. PSO–GWO Algorithm

The algorithm PSO-GWO is a recent swarm-based meta-heuristic endowed with several advantages, including simple implementation and low memory utilization. The key idea is to combine the exploration and exploitation capabilities of PSO and GWO to produce variants with strength and memory consumption. They operate simultaneously in various ways. The PSO-GWO algorithm is used to both exploit and explore the positions of the initial three agents in the search space. The following equations shows the mathematical expressions:

$$\boldsymbol{X_1} = X_\alpha - \boldsymbol{A_1} \cdot |\boldsymbol{C_1} \cdot X_\alpha - X| \tag{9}$$

$$\boldsymbol{X_2} = X_\beta - \boldsymbol{A_2} \cdot |\boldsymbol{C_2} \cdot X_\beta - X| \tag{10}$$

$$\boldsymbol{X_3} = X_\delta - \boldsymbol{A_3} \cdot |\boldsymbol{C_3} \cdot X_\delta - X| \tag{11}$$

$$\boldsymbol{X}(t+1) = \frac{X_1(t) + X_2(t) + X_3(t)}{3} \tag{12}$$

Where A1, A2, A3, C1, C2, and C3 stand for the top three wolves' coefficient vectors, while X1, X2, and X3 stand for the positions of the top three wolves relative to the corresponding prey. X designates the location of the current solution.

Equations (13) and (14) show how the PSO technique can be used to update the wolves' positions and speeds, which are denoted by x_i^k and v_i^k:

$$v_i^{k+1} = \left(v_i^k + r_1 c_1 \left(x_1 - x_i^k\right) + r_2 r_2 \left(x_2 - x_i^k\right) + r_3 r_3 \left(x_3 - x_i^k\right)\right) \tag{13}$$

$$x_i^{k+1} = x_i^k + v_i^{k+1} \tag{14}$$

Where the revised positions and speeds of the top three wolves are indicated by x_i^{k+1} and v_i^{k+1}, respectively. $r_1 \in [0, 1]$, $r_2 \in [0, 1]$ and $r_3 \in [0, 1]$ are random number, besides, the optimization parameters, denoted by c_1, c_2, and c_3 and are set to 0.5.

The objective is to optimize the proposed PITIDF controller in the system. It is important to note that the PITIDF 's parameters were set utilizing a hybrid PSO-GWO. In order to get the best values depending on the system requirements, the PSO-GWO Matlab code includes the lowest and highest values of PITIDF gains.

For this study, a number of Steps were utilized to obtain the best values for the PITIDF controller's parameters, illustrated in Figure 5.

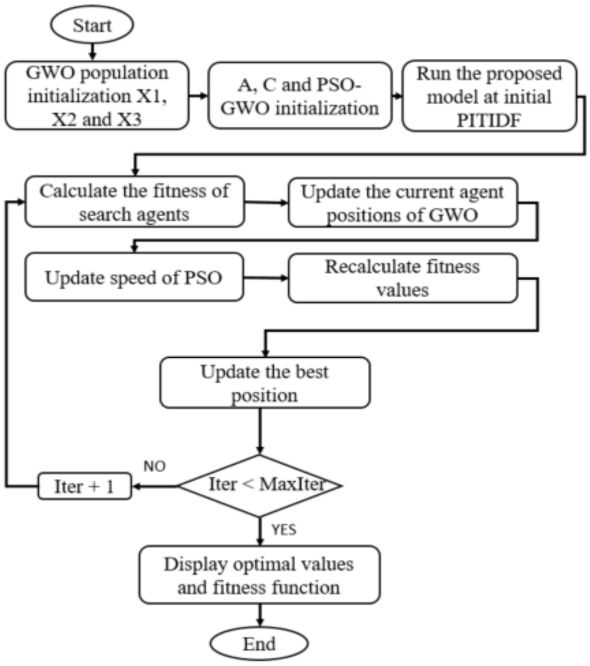

Fig. 5. Flowchart for hybrid PSO-GWO algorithm.

6. Simulation Results and Discussion

The studied system was developed as a Simulink block diagrams by employing the Matlab/Simulink environment R2022a on Intel Core i7 with 16GB RAM. Furthermore, MATLAB was used to implement the suggested approach. Additionally, MATLAB was used to incorporate other optimization techniques as PSO and GWO in order to compare the performance of all of these algorithms. The hybrid PSO-GWO optimization algorithm is executed with a population size of 40 and 100 iterations. In Table 1, you can find the parameters considered in the analyzed system. After conducting several experiments and adjustments, the controller gain boundaries are presented in Equation 8. Additionally, Table 2 displays the controller gains for different strategies obtained through simulation studies.

Table 2: Controller gains

	PSO	**GWO**	**PSO-GWO**
$\mathbf{K_{pp}}$	67.3487	65.0453	75.0799
$\mathbf{K_{ip}}$	100	99.9887	98.5162
$\mathbf{K_p}$	5.4565	4.3352	7.1621
$\mathbf{K_i}$	12.8576	7.3469	9.9193
$\mathbf{K_d}$	2.8941	1.1471	0.7023
$\mathbf{F_C}$	296.5824	165.7746	240.3773

6.1. Case 1 - System Response for Step Load Change.

Simulations are run to compare the PSO-GWO and the other algorithms with relation to a step perturbation as presented in Figure 6 , Step load disturbance (SLD) ΔP_{L1} =

0,03pu is utilized within area 1 and ΔP_{L2} = 0,01pu is utilized within area 2. Table 2 lists the parameters that these algorithms produced. When compared to previous algorithms, Figures 7, 8 and 9 exhibit the dynamic response of the proposed PSO-GWO tuned PITIDF controller to the frequency deviations Δf_1, Δf_2 and the tie-line power change ΔP_{tie}. The suggested algorithm optimized PITIDF controller have superior resilience and dynamic performance, it has a minimum settling time and a low overshoot as shown in Figures 7, 8 and 9. Table 3 shows also that the ITAE value of the proposed PSO-GWO is the lowest than other algorithms.

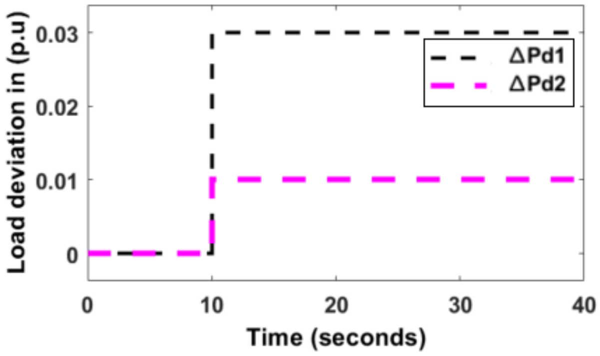

Fig. 6. Step Load disturbance.

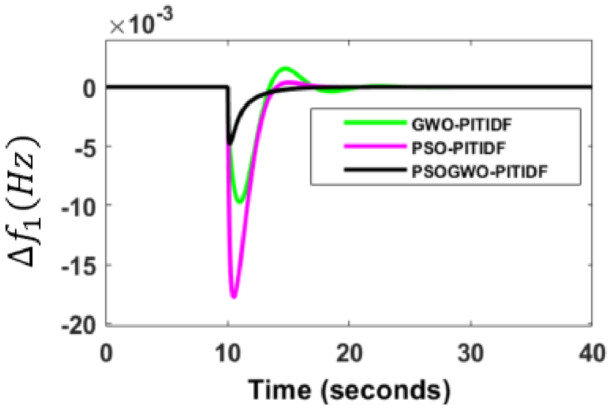

Fig.7. Dynamic response: Frequency deviation of the area (1) for step load disturbance.

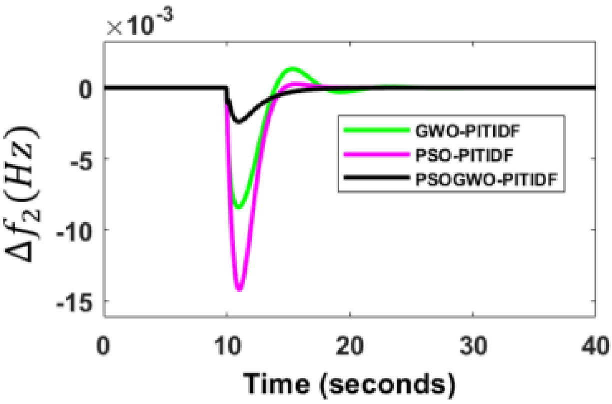

Fig.8. Dynamic response: Frequency deviation of the area (2) for step Load disturbance.

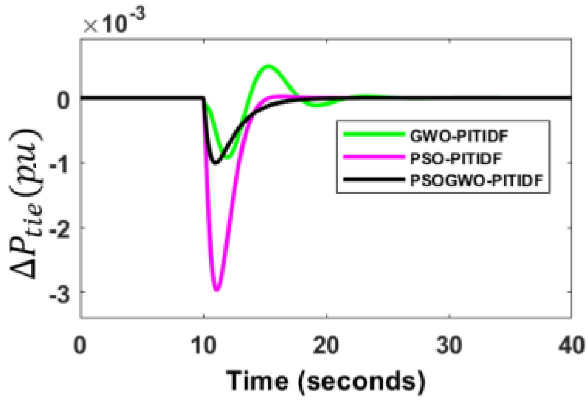

Fig. 9. Dynamic response: *ΔP_{tie}* Tie-line power change for step load change.

Table 3: ITAE values

	ITAE case (1)	ITAE case (2)	ITAE case (3)
PSO	0.07995	0.6647	0.2456
GWO	0.06307	0.4329	0.0989
PSO-GWO	**0.04893**	**0.2270**	**0.0874**

6.2. Case 2 - System Response for Variable Load Change.

This section discusses the frequency fluctuations of both area and the tie line power as a result of variable load changes. As seen in Figure 10, the two-area system experienced a variable load changes. Table 2 displays the applied PITIDF coefficients that were determined using the suggested algorithm in contrast to other algorithms. Figures 11, 12 and 13 show that this method is far better to other algorithms and that the system can easily dampen any changes in load and will never become unstable. Table 3 demonstrates that the ITAE value of the suggested PSO-GWO is the lowest than other algorithms.

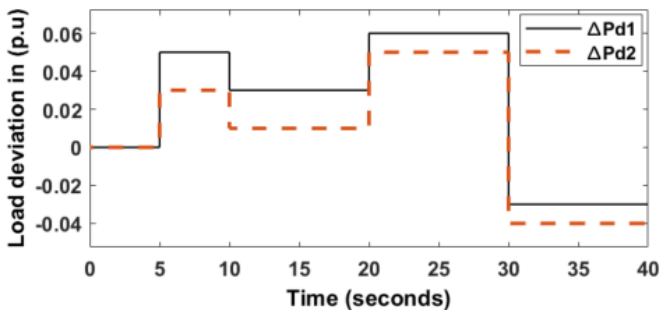

Fig. 10. Variable load change

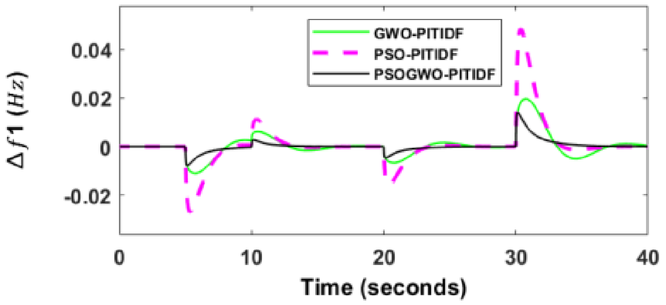

Fig. 11. Dynamic response: Δf_1 Frequency deviation in area (1) for variable load change.

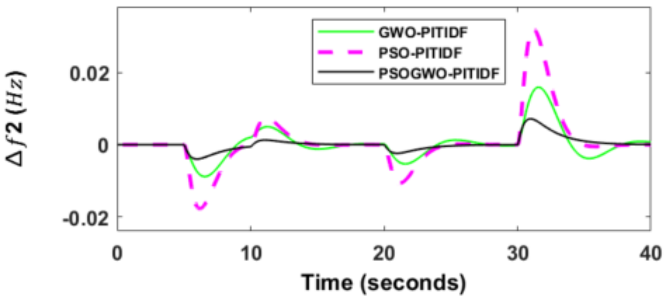

Fig. 12. Dynamic response: Δf_2 Frequency deviation in area (2) for variable load change.

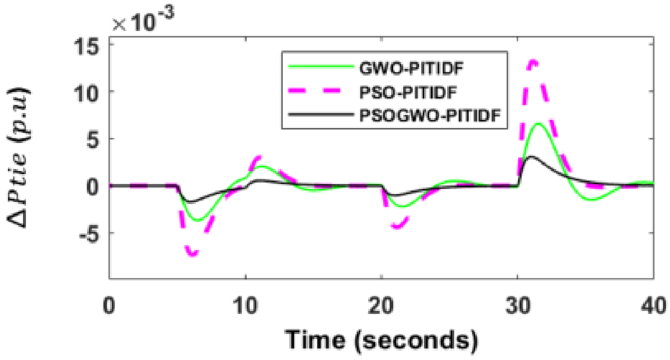

Fig. 13. ΔP_{tie} Tie-line power change for variable load change.

6.3. Case 3 - System Response for Step Load Change with Parameter Uncertainties.

The frequency and the power response under parameter uncertainties must be evaluated in order to investigate the robustness of any technique to know how well the power system stands up to significant changes in the system parameters as showing in table 4. The objective of this case is to value the robustness of the suggested approach under strict changes of MG settings of the system with load perturbation. Figures 14 to 16 display the system's dynamic behavior using a PITIDF controller that has been optimized by PSO-GWO for step load variations in two areas. It is evident that the suggested technique offers a reliable and stable control and the above results demonstrate that the studied system is highly resistant to variations of all parameters.

Table 4. Variation of system parameters

Parameter	Actual value	Variation range	New value
Kp	68.96	-50%	34.48
Tp	11.49	-45%	6.3195
Tg1	0.08	+50%	0.105
R	2.4	+35%	3.24
Tt	0.3	-45%	0.165

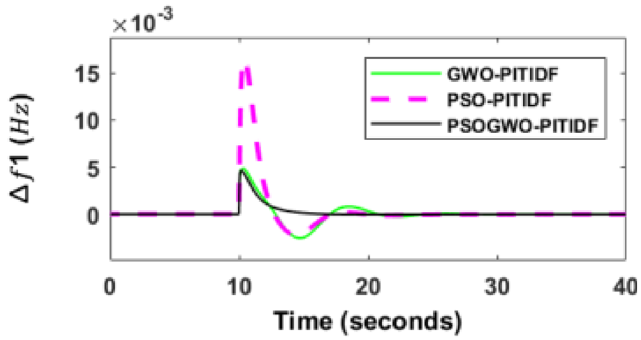

Fig. 14. Dynamic response: Δf_1 Frequency deviation for the area (1) under parameter uncertainties.

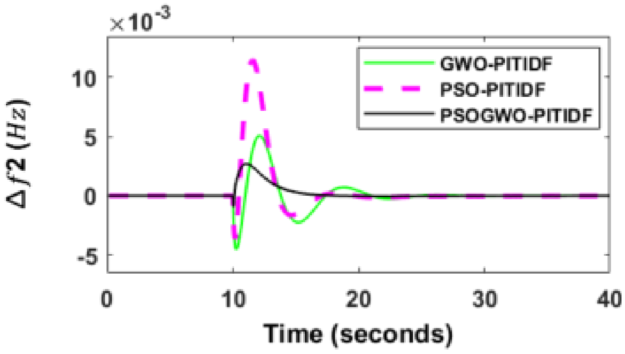

Fig. 15. Dynamic response Δf_2 Frequency deviation for the area (2) under parameter uncertainties.

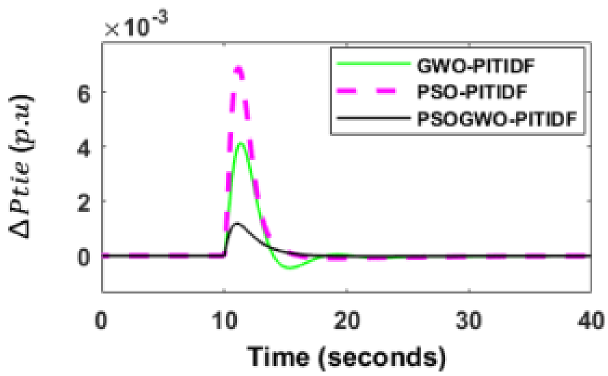

Fig.16. Dynamic response: ΔP_{tie} Tie-line power change under parameter uncertainties.

7. Conclusion

This work formulates a load frequency control (LFC) task using a power system with two areas including three types of generating units, namely gas, hydro, and reheat thermal. The PITIDF controller's parameters are tuned using a new hybrid method called PSO-GWO through minimizing ITAE performance indices. MATLAB/Simulink was used to analyze system performance while taking perturbation load change into account in both areas. The results make it abundantly clear that the suggested controller tuned by the suggested algorithm performs admirably in resolving the optimization problem by supplying suitable coefficients more quickly than the time required for the other algorithms such as PSO and GWO. Thus, it is evident that the proposed approach effectively sustains the equilibrium between supply and demand, minimizing frequency errors and swiftly restoring frequency deviations. As perspectives, power systems can be examined from several angles by using these optimization issues that deal with voltage regulation. Additionally, analysis can be performed on cost components and sectoral utilization in various industrial contexts.

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