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LOAD FREQUENCY CONTROL USING OPTIMIZED CONTROL TECHNIQUES

Ashraf Hemeida, Shimaa Mohamed, Mountasser Mahmoud

Electrical Engineering Department, Faculty of Energy Engineering, Aswan University, Aswan, Egypt

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ABSTRACT:

The current study addresses the impact of the optimized controller to load frequency control (LFC) problem. The proportional-integral-derivative (PID) parameters is determined for both single area and two area control system using genetic algorithms (GA), Particle swarm optimization (PSO), and grey wolf optimization techniques (GWO). The LFC is a stochastic problem due to the load variations and changing the system operating conditions. This results in failing the conventional controller to adapt the LFC in case of implementing the conventional PID. So that, implementing optimized, the PID controller parameters using GA, PSO, and GWO. The technique is used for single area system as well two-area system. The results show the accuracy and robustness of implementing the optimized controller parameters. MATLAB/Simulink is used to solve the system equations. The suggested optimized controller shows fast response with better control quality in compared with conventional controller.

Keywords: Load Frequency Control, PID Controller, Optimization techniques; GA; PSO; GWO.

1. Introduction

Interconnection of different control areas using tie lines forming power systems became an essential because of installing new stations in different areas [1-2]. The generators output power in different control areas changes related to any speed variation. So that, the speed must be maintain constant to ensure constant frequency. The load rejection, and or load insertion usually results in frequency deviations, and tie line power deviation, which are undesired phenomena. So that control system is an urgent matter to ensure damping frequency oscillations and keep the tie line power variation within permissible values [3].

The load frequency control leads to keep the frequency constant and power transferred between areas constant in the tie-line. This can be developed by choosing accurate and robust control system [4]. Smart controllers for two-area systems was designed considering different turbine configurations. These controllers succeeded in elimination the frequency deviation, and tie-line power deviation. Different optimization techniques were implemented to design smart controller [5]. Fractional order controller was developed for LFC of two area system with simple model of the system. CRONE fundamentals were implemented with simple model for improving the two-area system performance in case of load rejection or insertion [6]. Comprehensive review on the designing of PID controller for LFC in electrical energy system was introduced [7]. Different models, configuration of electrical energy systems integrated with area control system were addressed. Tuning process of PID controller parameters using intelligent, and optimization techniques was developed. In addition to the different expected challenges in unsolved problem for future research study. Coefficient diagram algorithm (CDA) integrated with proportional-integral-derivative acceleration (PIDA) controller was introduced to design LFC system cope with high overshoot, and big settling time. The suggested controller is developed for two-area system in the presence of variations of systems parameters and operating conditions [8].

Harris Hawks optimizer is implemented for determining the parameters of LFC in an interconnection power plants considering the renewable energy source [9]. LFC of interconnected electrical energy system is developed using optimized fuzzy self-tuning PID controller through implementing Tribe-DE algorithm, integrated with rule adjustment approach [10].

Grasshopper optimization technique is utilized to develop advanced PID controller in flexible multi-power station with battery stations. The results obtained shows the robustness of this technique in damping the oscillation very fast with better control quality [11]. Modified Jaya optimization is implemented successfully for online LFC in wind integrated energy system.

The technique is implemented successfully with wind station connected to IEEE-39 bus system [12].
Population extremal algorithm is used to design LFC of multi-area electrical energy systems. The technique considers the load dynamic of the system, to indicate the impact of the approach in damping the frequency fast [13]. The grasshopper optimization algorithm (GOA) is implemented to design an accurate, reliable, and fast under frequency load shedding (UFLS) technique [14]. Optimization of communication capacity shared risk link group in source grid load system is designed for load control [15]. The coefficient diagram method (CDM) is implemented to design an optimal load frequency controller of realistic power system equipped with storage devices-based grasshopper algorithm [16]. The approach is implemented for three-area thermal power system equipped with redox flow battery (RFB). This paper introduces implementation of genetic algorithms (GA), (PSO), and (GWO), to calculate the optimal parameters of PID controller for interconnected two area system. Different load excursions were applied and the impact of using these optimized parameters proves their powerful and robustness in damping the oscillations very fast with better control quality. In the addition to the comparative study proves its superiority over implementing the convention PID controller.

2. Studied System Model

The studied power system for LFC study is approximated through linearized the system equation around operating points [17]. Single area control is system is depicted in Fig. 1 [18].
The model of the system components can be discussed as the following:

2.1 Governor

$$G_g(s) = \frac{1}{T_g s+1} \tag{1}$$

2.2 Turbine

Different configuration of turbine is exit, and can be discussed as the following:
2.2.1 Non reheated turbine

$$G_{t1}(s) = \frac{1}{T_t s+1} \tag{2}$$

2.2.2 Reheated turbine

$$G_{t2}(s) = \frac{cT_r s+1}{(T_r s+1)(T_t s+1)} \tag{3}$$

2.2.3 Hydro turbine

$$G_{t3}(s) = \frac{1 - T_w(s)}{1 + 0.5T_w(s)} \quad (4)$$

2.3 Load and machine

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

The system overall transfer function without droop effect is given as:

$$G_{wd}(s) = G_g(s)G_p(s)G_{ti}(s) \quad (6)$$

Where, i=1, 2, 3
The system overall transfer function with droop effect can be calculated as:

$$G_d(s) = \frac{G_g(s)G_p(s)G_{ti}(s)}{1 + \frac{G_g(s)G_p(s)G_{ti}(s)}{R}} \quad (7)$$

Where, i=1, 2, 3.

3. Modeling Studied System

3.1 Single Area

Fig. 1 shows the diagram of LFC of turbogenerator [6, 19].

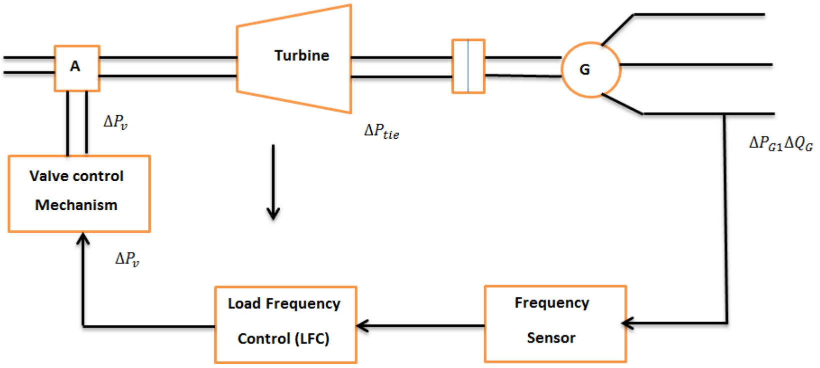

Fig.1 Schematic diagram of p-f controller [6]

3.2 Two Area

The studied two area power system forming two-area control system connected via tie-line. Different models of two area system can be discussed as the following:

3.2.1 Thermal–thermal model [20]

Fig. 2. Depicts the two-area (thermal-thermal) electrical energy system [20]. The model of this system can be represented by the following equations [21]:

$$\Delta\dot{f}_1 = -\frac{1}{T_{p1}\Delta f_1} + \frac{K_{p1}}{T_{p1}}\left(\frac{1}{\Delta P_{g1}} - \frac{1}{\Delta P_{tie}} - \frac{1}{\Delta P_{d1}}\right), \tag{8}$$

$$\Delta\dot{P}_{g1} = -\frac{1}{T_{r1}}\left(\frac{1}{\Delta P_{g1}} - \Delta P_{r1}\left(1 - \frac{T_{r1}K_{r1}}{T_{r1}}\right)\right) + \frac{K_{r1}}{\Delta X_{E1}}, \tag{9}$$

$$\Delta\dot{P}_{r1} = -\frac{1}{T_{t1}}\left(\frac{1}{\Delta X_{E1}} - \frac{1}{\Delta P_{r1}}\right), \tag{10}$$

$$\Delta\dot{E}_{x1} = -K_{E1}(B_1\Delta f_1 + \Delta P_{tie}), \tag{11}$$

$$\Delta\dot{f}_2 = -\frac{1}{T_{p2}\Delta f_2} + \frac{K_{p2}}{T_{p2}}\left(\frac{1}{\Delta P_{g2}} - \frac{1}{a_{12}\Delta P_{tie}} - \frac{1}{\Delta P_{d2}}\right), \tag{12}$$

$$\Delta\dot{P}_{g2} = -\frac{1}{T_{r2}\Delta P_{g2}} + \Delta P_{r2}\left(\frac{1}{T_{r2}} - \frac{K_{r1}}{T_{r2}}\right) + \frac{K_{r2}}{T_{r2}\Delta X_{E2}}, \tag{13}$$

$$\Delta\dot{P}_{r2} = -\frac{1}{T_{t2}}\left(\frac{1}{\Delta X_{E2}} - \frac{1}{\Delta P_{r2}}\right), \tag{14}$$

$$\Delta\dot{E}_{x2} = -K_{E2}(B_2\Delta f_2 + a_{12}\Delta P_{tie}), \tag{15}$$

$$\Delta P_{tie} = 2\pi T_{12}(\Delta f_1 - \Delta f_2) \tag{16}$$

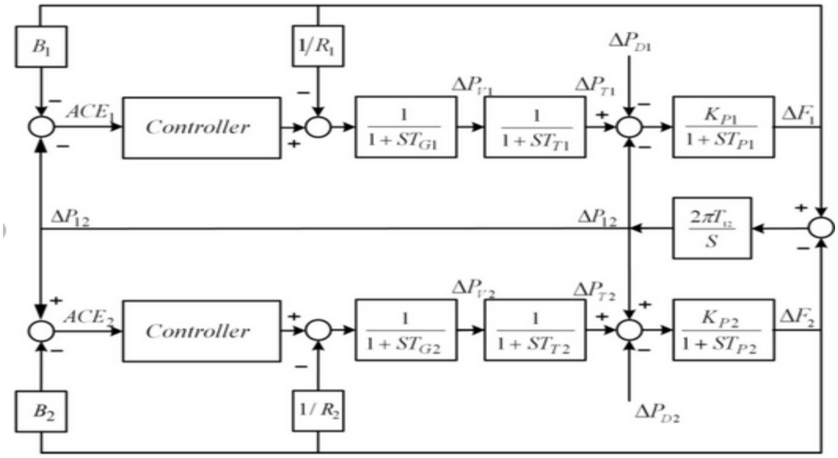

Fig. 2 Block diagram of two area power system (thermal–thermal) [21].

4. Compensator Design

The PID topology in this paper is given via block diagram in Fig. 3 [22].

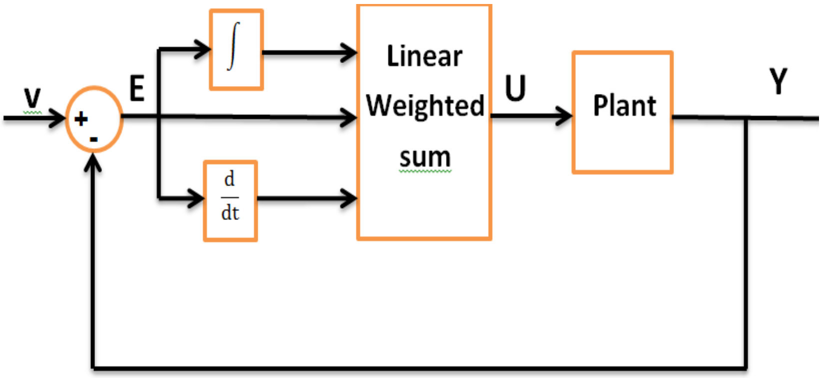

Fig.3: PID Topology [22]

$$u = k_0 \int_0^t e d\tau + ke + k_2 de \tag{17}$$

5. Optimization Techniques

Different optimization approaches were introduced to design the PID controllers for the LFC objectives [23]. According to the main optimization rule "No free launch", no optimization algorithm can be globalizing, and the Three different optimization algorithms ware used in this paper which are (GA), (PSO), and GWO.

5.1 Genetic Algorithms (GA)

The graphical illustration-based GA is given in Fig. 4 [24]. The solution steps-based GA algorithm can be found in [24].

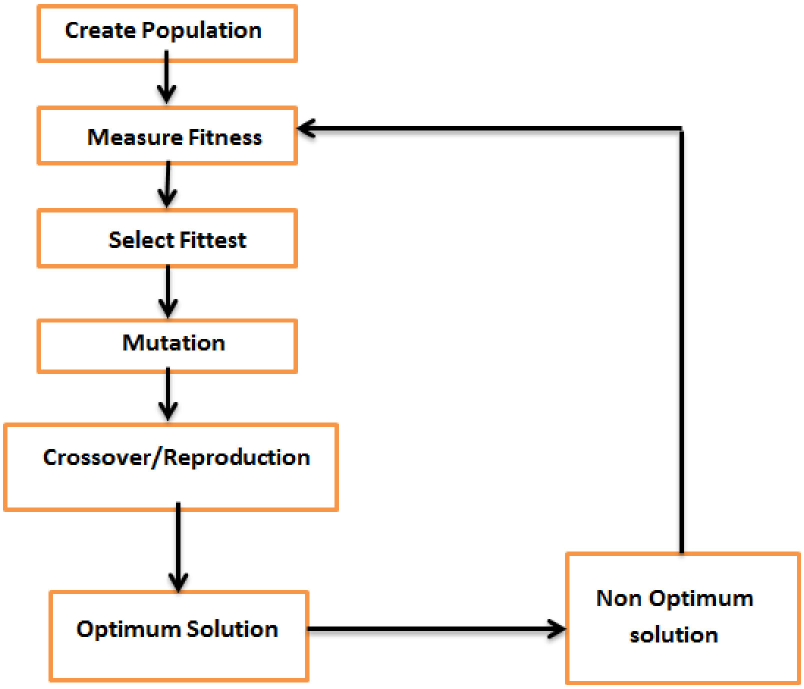

Fig. 4: Graphical Illustration the Genetic Algorithm Outline [24]

5.2 Particle Swarm Optimization (PSO)

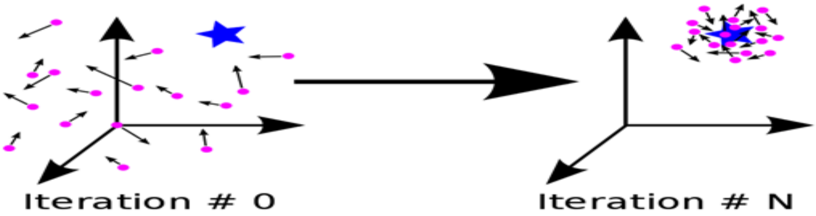

Fig.5: Particle swarm optimization [25]

Particle swarm optimization (PSO) is depicted in Fig. 5. It is introduced in 1995 [25]. Fig. 6 showed the flow diagram that illustrating the particle swarm optimization algorithm [26].

5.3 Grey Wolf Optimization Technique

GWO technique is discussed in [27]. The solution steps are also given and discussed in [27].

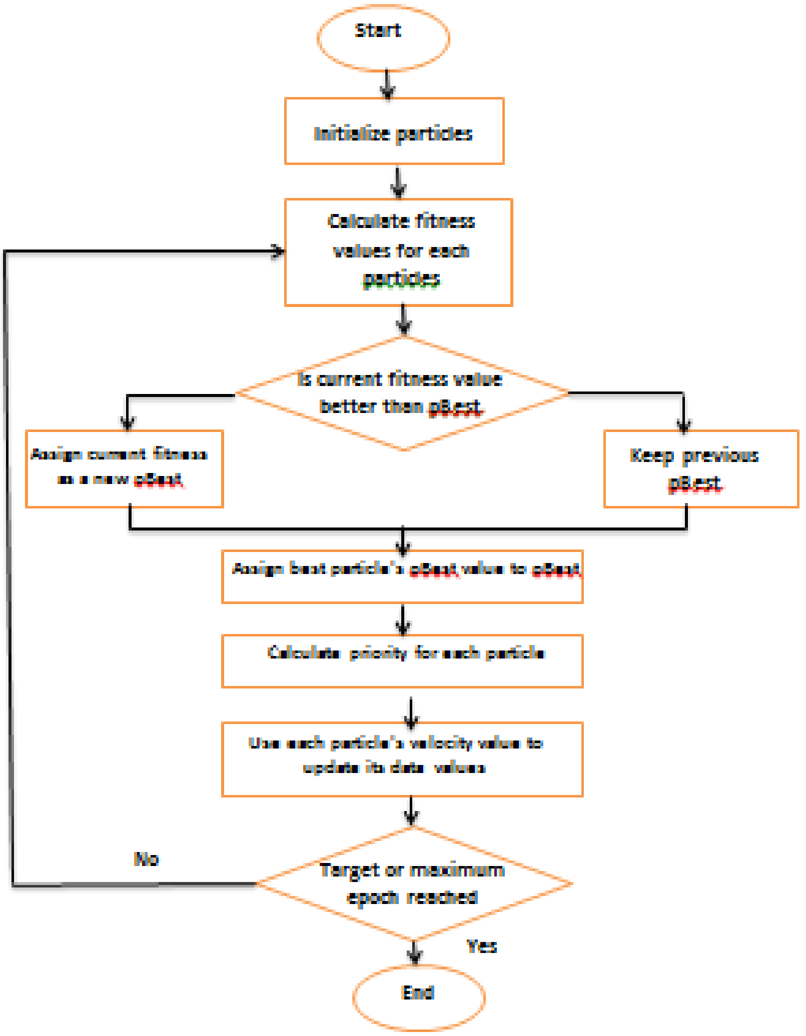

Fig.6: Flow diagram illustrating the particle swarm [25]

6. Results

6.1 For single area

Four different behavior indices were considered to solve the LFC problem, which are IAE, ISE, ITAE, and ITSE. The GA, and PSO, are implemented to determine the PID controller parameters for single area system. The controller parameters for both GA and PSO is tabulated in Table 1.

The used data is given in [29-30]. A comparative study for the performance analysis of implementing optimum PID based GA, and PID based PSO is performed. The performance is based on overshoot, undershoot, settling time for 10% step upload. The dynamic response for implementing GA based PID controller, and PSO based PID controller for 10% step upload is depicted in

Fig. 7. Four cases are suggested for the study, which are performance index IAE, performance index ISE, ITSE and ITAE. The step response of the system for 10% load change using GA-PID controller and PSO-PID is as shown in Figure 7.

Table 1: GA, and PSO controller parameters

GA	Crossover function	Stall generation			No of iter.
	0.650	125			50
PSO	Swarm size	Self-adjustment	Social adjustment	CF	No of iter.
	10	1.49	1.49	0.73	50

Case 1: IAE

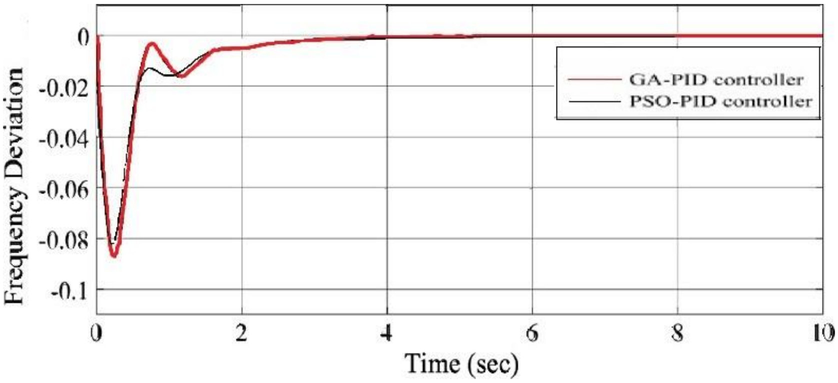

Fig.7 GA-PID and PSO-PID based step response for 10% load change.

A comparison study between implementing GA, and PSO is tabulated in table2.

Table 2: Comparison of GA-PID and PSO-PID for 10% load change (case 1)

	k_p	k_I	k_D	IAE	overshoot	undershoot	Settling time
GA-PID	1.9912	1.9990	0.3484	0.50025	0	-0.087366	5 sec
PSO-PID	2.000	2.000	0.2865	0.04999	0	-0.081529	5 sec

Case 2: ISE

The ISE is subjected to minimization process. The dynamic response, of applying GA based PID controller, and PSO based PID controller is depicted in Fig. 8. They seem very close with very close response.

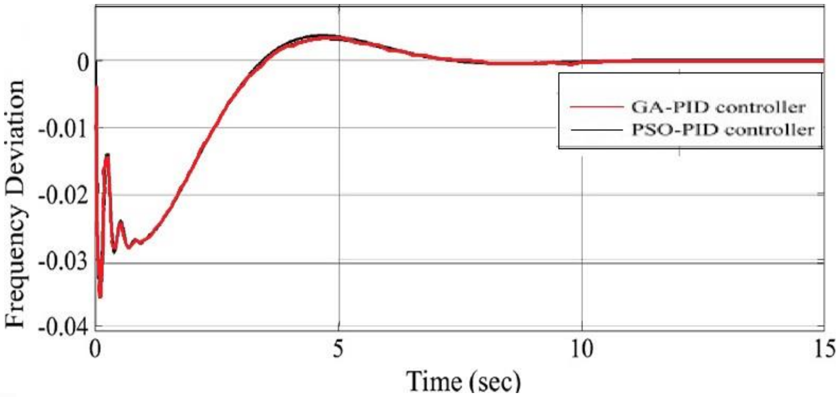

Fig.8: GA-PID and PSO-PID based step response for 10% load change (case 2)

The studied system behavior index, for step up load disturbance with 10% is tabulated in Table 3.

Table 3. The studied system behavior index, for step up load disturbance with 10%

	Overshoot	Undershoot	Settling time
GA-PID	0.00132	-0.036	11.8 sec
PSO-PID	0.00127	-0.035	11.8 sec

The PID controller parameters according to ISE, and behavior index is tabulated in Table 4.

Table 4: Comparison of GA-PID and PSO-PID for 10% load change (case 2)

	k_p	k_I	k_D	IAE	overshoot	undershoot	Settling time
GA-PID	1.9970	1.9315	1.9374	0.001318	0.003342	-0.035966	12 sec
PSO-PID	2.000	2.000	1.9990	0.001272	0.003602	-0.035932	12 sec

Both GA and PSO based PID provide very close results, i.e. they are powerful and robust in this case. In addition to the performance evaluation indicate the same results as the time simulations.

Case 3: ITAE

The behavior index ITAE is an objective function. The system dynamic response for 10% step up in load is depicted in Fig. 9.

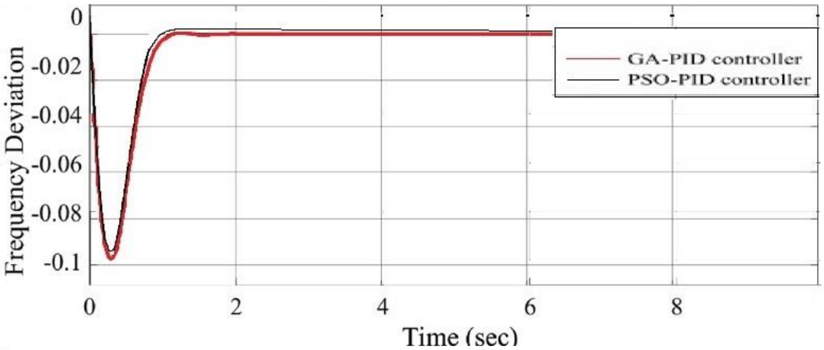

Fig.9: GA-PID and PSO-PID based step response for 10% load change (case 3)

The studied system behavior index, for step up load disturbance with 10% is tabulated in Table 5.

Table 5 The studied system behavior index, for step up load disturbance with 10%

	Overshoot	Undershoot	Settling time
GA-PID	0.01913	−0.097744	1.31 s
PSO-PID	0.01913	−0.09769	1.29 s

The PID controller parameters according to ITAE, and behavior index is tabulated in table 6.

Table 6 Comparison of GA-PID and PSO-PID for 10% load change (case 3)

	k_p	k_I	k_D	IAE	overshoot	undershoot	Settling time
GA-PID	1.2544	2.000	0.2679	0.01913	0.00027431	-0.097744	1.3 sec
PSO-PID	1.2573	2.000	0.2680	0.01913	0.0001744	-0.09769	1.28 sec

6.2 For Two Area

The system dynamic response is as shown in Fig. 10, 11, when exposed to step up load disturbance with 10%. The GA-PID, and PSO-PID are very close when applying each one individually. The impact of both PID based GA, and PID based PSO is evident.

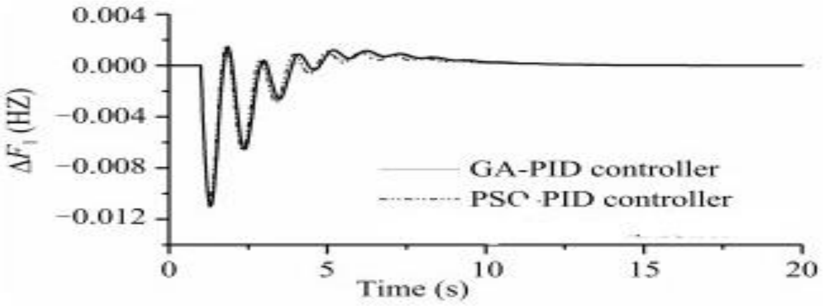

Fig.10: The frequency deviation of area 1 for 50 iterations.

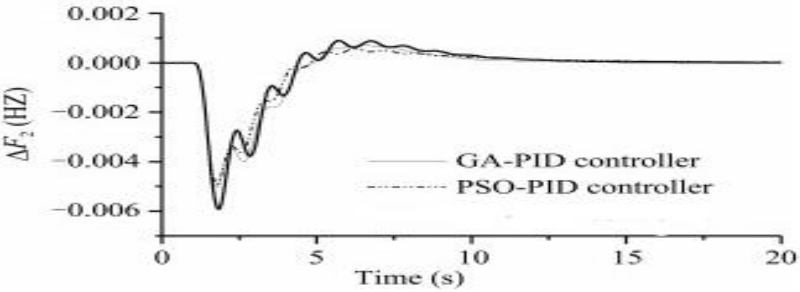

Fig.11: The frequency deviation of area 2 for 50 iterations.

The PID controller parameters-based GA and PSO are developed with 70 iterations. The dynamic response is depicted in Fig. 12, 13. It is evident in both GA and PSO, the results are very near, and the performance evaluation indicate that both GA and PSO based PID controller parameters provide very close results.

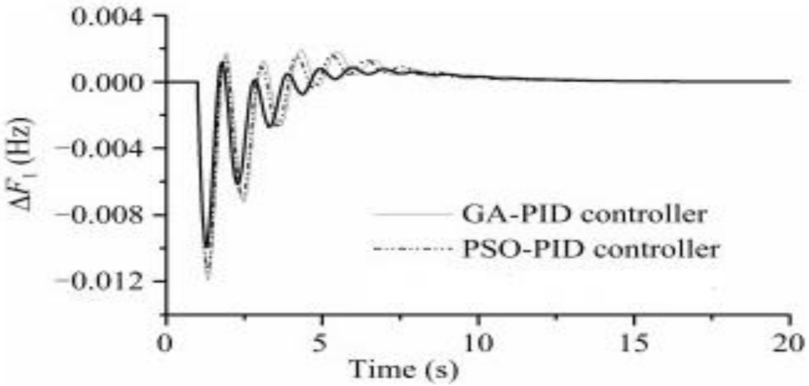

Fig.12: Frequency deviation of area 1 for 70 iterations

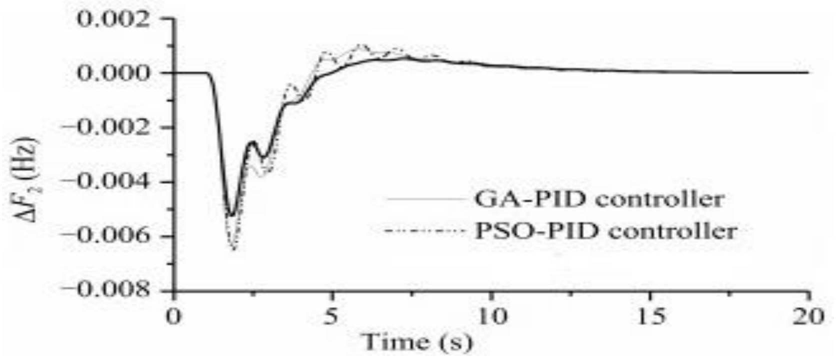

Fig.13. Frequency deviation of area 2 for 70 iterations

The comparative study-based system dynamic response, and performance index is tabulated in table 7, for 50 iterations.

Table **7** Comparison values of settling time, peak overshoot for 50 iterations

	Settling time		Peak overshoot		Peaks undershoot	
	GA	PSO	GA	PSO	GA	PSO
$\Delta \boldsymbol{F_1}$	18.99	17.01	0.00146	0.0015	0.0109	0.0104
$\Delta \boldsymbol{F_2}$	21.10	16.3	0.00068	0.00029	0.0059	0.0050
$\Delta \boldsymbol{F_3}$	22.2	20.11	0.00009	0.00001	0.0053	0.0052
$\Delta \boldsymbol{F_4}$	21.9	18.90	0.00049	0.00047	0.0059	0.0051
$\Delta \boldsymbol{P_{tie1}}$	23.55	24.83	0.0005	0.0003	0.0079	0.0072
$\Delta \boldsymbol{P_{tie2}}$	19.2	16.77	0.0018	0.00043	0.0051	0.0047
$\Delta \boldsymbol{P_{tie3}}$	24.95	24.60	0.0006	0.0022	0.000077	0.00004
$\Delta \boldsymbol{P_{tie4}}$	17.44	16.66	0.0002	0.00045	0.00013	0.00008
$\boldsymbol{ACE_1}$	17.84	16.34	0.00071	0.00042	0.0049	0.0047
$\boldsymbol{ACE_2}$	25.94	22.71	0.00063	0.00057	0.00093	0.00098
$\boldsymbol{ACE_3}$	18.11	16.55	0.0006	0.00043	0.0047	0.0050
$\boldsymbol{ACE_4}$	25.34	23.22	0.00088	0.00078	0.0020	0.0014
$\Delta \boldsymbol{F_1}$	18.99	17.01	0.00146	0.0015	0.0109	0.0104

6.3.2 GWO Algorithm

Figures 14, 15 and 16 depicts the frequency response of area 1, area 2 and tie-line power deviations. The quantitative analysis of Figures 14, 15 and 16 is tabulated in Table 8.

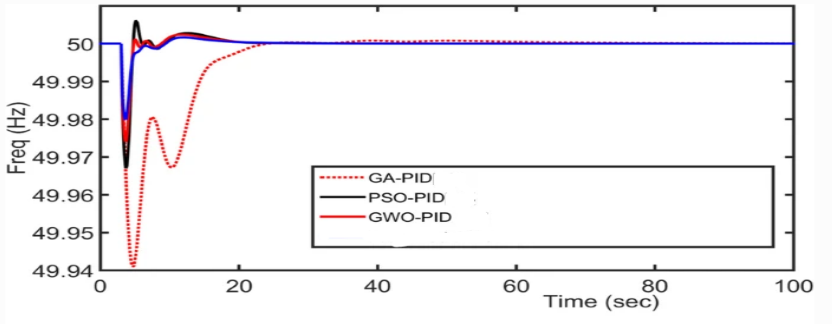

Fig. 14 Frequency of Area One

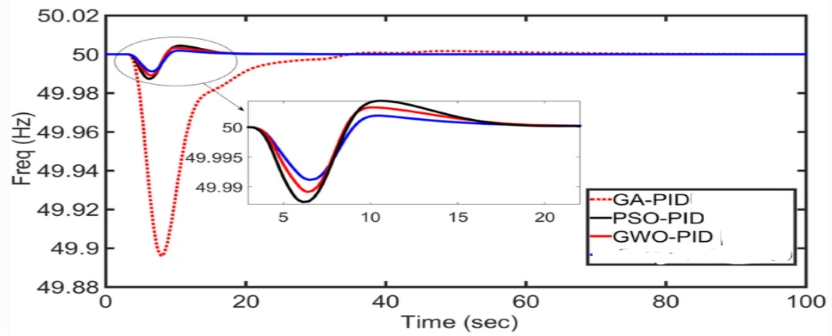

Fig. 15 Frequency of Area Two.

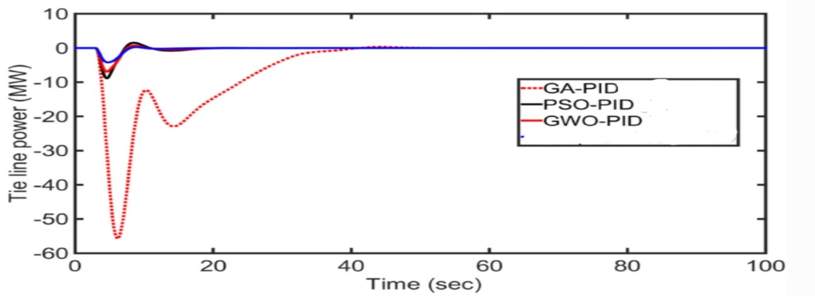

Fig. 16 Tie-line power deviation

Table 8: The quantitative analysis of Figures 14, 15 and 16

Method	Performance Indices					
	Area1		Area2		Tie-line power deviation	
	Peak undershoot	Settling Time	Peak undershoot	Settling Time	Peak undershoot	Settling Time
GA_PID	0.059	44	0.105	51	54	44
PSO_PID	0.031	24	0.014	21	9	20
GWO_PID	0.024	21	0.011	19	8	18

The implementation of GWO technique shows better performance in compared with other GA and PSO. It is evident that it damps the oscillations very fast, with lower undershoot, and overshoot in addition to better control quality. This shows that the GWO is powerful and robust optimization technique.

6. Conclusions

Three different optimization algorithms are applied for obtaining the optimum parameters of PID controller, for solving LFC problem. The implemented algorithms are GA, PSO, and GWO for single-area system as well two-area system. The considered performance indices are IAE, ISE, ITAE and ITSE. These indices are taken as an objective function for designing the PID controller parameters., have been considered as the objective functions for solving LFC problem. The GA based PID, and PSO based PID controller provides near results, with good performance in compared with conventional PID controller. The GWO algorithm provides better performance, with fast response. GWO provide better control quality with fast response and recommended for small signal stability.

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التحكم في التردد الناتج عن تغير الحمل، باستخدام تقنيات تحسين مختلفة

الملخص بالعربي: -

يقدم البحث تطبيق ثلاثة من خوارزميات التحسين المختلفة لتحديد القيم المثلى لبارامترات الحاكم التناسبي ـ التكاملي ـ التفاضلي، للتحكم في التردد نتيجة تغير الحمل في منطقة تحكم واحدة ومنطقتين. وخوارزميات التحسين التي تم تطبيقها هي: الجينات الخوارزمية (GA)، وسرب الجسيمات (PSO)، والذئب الرمادي (GWO). تم تطبيق كل خوارزمية على حدة لإيجاد بارامترات الحاكم المقترح تطبيقه لإخماد ذبذبات التردد الناتجة عن إدخال أو إخراج الأحمال، إضافة إلى الحفاظ على ثبات القدرة في خطوط النقل بين المناطق المختلفة. تم عمل مقارنة بين استخدام البارامترات المشتقة من الحاكم التقليدي، والبارامترات المشتقة من خوارزميات التحسين، وقد أثبتت النتائج المستخلصة فعالية ودقة البارامترات المشتقة من خوارزميات التحسين المختلفة على التقليدية في إخماد الذبذبات سريعا، مع تحسين جودة التحكم.