AUTOMATIC GENERATION CONTROL OF A MULTI-AREA POWER SYSTEM BASED ON GREY WOLF OPTIMIZATION ALGORITHM

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Abstract: This paper presents an automatic generation control algorithm applicable for a multi-area power system. A more practical models is used to represent the main components of the power system. The frequency bias factor (B) is set optimally by using an artificial intelligence technique. The generation rate constraints (GRC) are taken into consideration with dead band characteristics of the governor. For the first time, a sequential optimization of the fractional order (PID) control parameters, the governor speed regulation (R) and the frequency bias factor (B) is proposed. The objective function to be minimized is the updated integral time absolute error (UITAE). The tuning of the control parameters is dependent on minimizing the objective function by using the Grey wolf optimization (GWO) algorithm. The proposed algorithm is tested on an interconnected three power pools different system (Reheat, Gas and Hydro) with varying degrees of load step change. The simulation results of the presented process are compared to those achieved by using the particle swarm optimization method. The results obtained reveal the robustness of the proposed algorithm in terms of settling time and peak overshoot.

Keywords: *frequency bias factor, automatic generation control, fractional order, multi-area, gray wolf*

1. Introduction

Automatic generation control (AGC) or load frequency control is vital in power system operation. The aim of AGC is to keep the frequency and the power exchange lines

between them at their nominal values, regardless of small load variations. There are two signals of concern for each area, the frequency variance and the deviation of the power exchange of the tie-lines coming from the area. Their measured combination is a single control power signal called Area Control Error (ACE). Frequency bias factor (B) applies to the weight of the frequency deviation. To avoid any mismatch between total active power production and total active power demand with losses, an active AGC system should chase load variability and follow generation units. There has been a lot of researchers [1-16] in the area of AGC in the past. The problem was addressed by applying the principles of centralized and decentralized controllers. The AGC method has been studied from the perspective of efficient linear regulator architecture by a number of researchers [1-10]. In [11-12], an algorithm for developing a sliding mode controller (SMC) for an AGC system was suggested. Adaptive load frequency controllers were proposed to account for parametric instability, it focused on various publications [13–17]. Ref [20] was highlighted a literature review on different control methods used in AGC of power systems. The strategies used in AGC were the subject of reference [21].

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It also emphasized the usage of energy storage systems in AGC. Alovic'et.al [22] established a tool to fix systemic errors in load frequency controllers induced by tie line losses. Other researchers [23-31] used a conventional PID controller to solve the AGC problem. Bacterial foraging [23,25], Firefly Algorithm [24], Genetic Algorithm [25], Artificial Bee Colony algorithm [27], Evolutionary computation [28], Gases Brownian Motion Optimization (GBMO) [29], quasi-oppositional harmony quest algorithm [30], imperialist competitiveness algorithm [31] were some of the swarm's artificial intelligence used to tune the control parameters. Several smart control strategies have been suggested to elimination the drawback conventional LF controllers. Any of them were developed using the two-degree-of-freedom controller and fractional order PID controller [32]. Other techniques included using an alternative derivative filter [35-36] or cascading traditional controllers [33-34]. Kothari et al. [37] analyzed the effect of GR controller and sampling time on the efficiency of automatic generation control. an investigation of the proper selection of the speed control (R) of a thermal system showed by [38]. In [39-43] was introduced for the application of fuzzy logic theory in LF controller. ANN-based load frequency controllers were suggested by some researchers [44]. It was discovered that utilizing a two-level organized control approach based on the several Agent System (SAS) methods by [45] would handle the conflicts between frequency control and ACE control of the autonomous controller. Recently, a sequential optimization of the major load frequency regulation with the parameters of the PID controllers has interested many researchers [46-47]. It was discovered that setting the droop regulation optimally by sequential tuning of the controller parameters and the speed regulation improved in the AGC dynamic efficiency. the bias frequency factor(B) hasn't widely studied. It

has been said that the frequency bias factor (B) has a noticeable effect on the system's dynamic control. as well as, in [50] it was proposed that half of the frequency response properties β is to be set at the best value for the frequency bias component. The goal of this study is to optimize the frequency bias factor(B). This is achieved through a FOPID controller with AGC system. Sequential tuning of frequency droop and frequency bias factor for the controller parameters must be carried out by minimizing grey wolf optimization (GWO) algorithm [18] based on the output index. A composite three-area power pools (Thermal, Gas and Reheat) whose data is given in [48] is used for the application of the proposed technique. A practical model of the load frequency control system elements includes dynamics of boiler, a non-linear dead band governor, and generation rate constraints are used. The article is arranged accordingly; The mathematical model of the load frequency control system elements is presented in Section 2. In Section 3 includes the structure of the PID fractional order controller. In Section 4 provides a study of the Grey wolf optimization (GWO) algorithm. The simulation of the test system is defined in Section 5. This part also provides a discussion of the findings collected. Conclusion is outlined in Section 6.

2. Mathematical Modeling for the Investigated Power System

Three different power pools exist in this paper (Reheat, Gas and Hydro). The three power pools have a total of 8000 MW, 4000 MW, and 2000 MW, sequentially. The Reheat, Gas and Hydro models' turbines are used in these power fields. An effective transfer function is used to model the elements in each power area as seen in Figure.1. The mathematical model of AGC takes the following physical nonlinear constraints [53-54].

Figure 1. Transfer function of three power pool-hybrid with nonlinearities.

2.1. The Boiler's Nonlinear Dynamics

A boiler is a steam generator that produces pressurized steam. The thermal turbine units in this paper are presumed to have a recirculation boiler, whose transfer function is provided in Appendix. A gas or oil-fired boiler is being used to achieve load demand requirements for a faster response than other systems. A drum-type boiler is considered in this study. Pressure is used in the long-term dynamics of fuel and steam movement on the boiler tank. Figure.2 [50] shows a model of a recirculation boiler. They are the major components of Figure 1 power structure.

Figure 2. Dynamic boiler diagram.

2.2. The Generation Rate Constraint (GRC)

In a steam plant, the rate of change of the power is limited. If this rate is not taken into consideration, the LFC may happen disturbances major transient fluctuations. The literature shows that the generation rate restriction has a major effect on the AGC's dynamic efficiency. A dynamic response of GRC characteristics which have a longer settling period and a greater peak overshoot. A GRC of 0.1 p.u. per minute is used and modelled in this work, as seen in Figure 3.

Figure 3. Turbine model with GRC.

2.3. The Governor Dead Band (GDB)

The dead band (backlash) can be known is the range which the load frequency controller may allow the frequency to deviate without taking any control action and as shown in Figure 4.

Figure 4. Dead-band in governor control loop.

3. The Fractional Order PID Controller

Fractional order PID controller ($PI^\lambda D^\mu$) may be showed by equation (1) [50]:

$$u(t) = e(t) \{K_p + K_i D_t^{-\lambda} + K_d D_t^\mu\} \quad (1)$$

Where $u(t)$ is the regulation signal and $e(t)$ are the error signal. The error signal $e(t)$ in this study is the Area Control Error (ACE). Transform eq (1) to Laplace domain equations and given the original zero. The transfer function T.F requirements can be defined by eq. (2) as follow:

Figure 5. Controller Scheme Investigated

$$g_c(s) = K_p + K_i s^{-\lambda} + K_d s^{\mu} \quad (2)$$

To reduce calculation time, noise effects, and the System Influence of different nonlinearities. The action is set to the derivative fractional a simple filtered derivative process ($\mu = 1$). The transition function TF of the studied controller is published in the following way:

$$g_c(s) = \frac{u(s)}{e(s)} = K_p + K_i s^{-\lambda} + K_d \frac{SN}{s+N} \quad (3)$$

where $g_c(s)$ is the controller output, $u(s)$ is the control signal, $e(s)$ is the error signal, K_p is the proportional control error constant gain, K_i is the integrated constant gain, K_d is the derivative constant gain, (λ) is the order of integration and (μ) is the order of differential. The conversion role of the analysed controller and of the investigated controller Plane representation of various integer and fractional forms. Figures 5 represent the controller scheme of FOPID.

4. Objective Function

The main purpose objective of the automatic generation control system is to adjust the parameters of the controllers to maintain the frequency and the interchange power in the scheduled values. For this study, so as to meet the desired requirements such as lower overshoot, fast settling time and lower error, it is very important to define an objective function. In many previous studies, the integral time multiplied absolute error (ITAE) is generally used as an objective function and is given by:

$$ITAE = \int_0^{ts} \{ |t(\Delta f_1)| + |t(\Delta f_2)| + |t(\Delta f_3)| \} dt \quad (4)$$

The ITAE objective function will minimize the settling time, but it can't reduce the overshoot properly. To do this, this paper proposes an updated UITAE objective function that includes an overshoot minimizing of the system and the faster settling time and as shown in eq.5.

$$UITAE = \int_0^{ts} t \{ \sum_{i=1}^3 \{ |\Delta f_i| + |\Delta P_{tie-i}| + \text{Max}|\Delta f_i| + \text{Max}|\Delta P_{tie-i}| \} \} dt \quad (5)$$

The optimization problem can be expressed in the model:

$$\text{Minimize } (K_p, K_d, K_i, \lambda, \mu, N, \beta \text{ and } b)$$

Subject to:

$$\begin{aligned} K_p^{min} &\leq K_p \leq K_p^{max} \\ K_i^{min} &\leq K_i \leq K_i^{max} \\ K_d^{min} &\leq K_d \leq K_d^{max} \\ \lambda^{min} &\leq \lambda \leq \lambda^{max} \\ \mu^{min} &\leq \mu \leq \mu^{max} \\ R^{min} &\leq R \leq R^{max} \\ Y^{min} &\leq B \leq Y^{max} \end{aligned} \quad (6)$$

Where K_p , K_i , K_d are the controller parameters, the integral fraction (λ) is a factor, β is an area frequency response and equal to $(D + 1/R)$, D : sensitivity system, $(= \Delta P_{Di} / \Delta f_i)$, B is a frequency bias constant of area and it limits are between $(Y^{min} = 0.1\beta^{min}, Y^{max} = 1.5\beta^{max})$, [24-53], we could calculate the optimal value in each area, (μ) is the order of differential, it is presumed to be equivalent to 1.

5. Gray Wolf Optimization

Grey wolf optimization is attempted for LFC in this paper. This algorithm was submitted to the behaviour of Grey Wolves.[19]. Grey wolves are known to be strongest of all and find what we need. Figure 9.

Alpha is the powerful and strongest member of the pack and it may be a male or a female. Decisions about migration, choosing home, hunting made by the *alpha* wolf. The *Alpha*

wolf who is best in controlling the pack but not essentially it can be strongest member of the pack, which means that organization is better than strength. Beta wolf is the second level in the hierarchy. When wolf makes choices, the function of beta wolf is to assist *lpha*. When the *alpha* wolf is sick or died, beta Wolf will lead the pack in addition to being an advisor to *alpha* Wolf. *Delta* wolves are in the third level in the hierarchy. the duties of *delta* are making report to *alpha* and beta wolves. hunters and caretakers belong to *delta* third. *Omega* is the lowest ranked in the hierarchy. The importance of these wolves is that due to keep out problems and fighting in the pack.

Figure 6. Grey wolves' hierarchy.

5.1. Mathematical Model of GWO

In this part, the social order of wolves, chasing, circling and attaching a victim are mathematically modelled, [19].

5.1.1 Social Hierarchy

The first optimal is called *alpha*, the second best is *beta*, the third best is *delta* wolves, while the rest of the pack's solutions are called *Omega* wolves throughout this optimization technique.

5.1.2 Encircling

During circle the victim by the Gray wolves is considered mathematical model.

$$\bar{R} = |\bar{L} \cdot \bar{Y}_p(t) - \bar{Y}(t)| \quad (7)$$

$$\bar{Y}(t + 1) = \bar{Y}_p(t) - \bar{M} \cdot \bar{R} \quad (8)$$

Where $\bar{Y}_p(t)$ remark to current location of prey and t remark current iteration. The following equations used to calculate the values of $\bar{M}$ and $\bar{L}$.

$$\bar{M} = 2\bar{q} \cdot \bar{f}_1 - \bar{q} \quad (9)$$

$$\bar{L} = 2 \cdot \bar{f}_2 \quad (10)$$

the random vectors are f_1, f_2 in $[0, 1]$. As number of iterations progresses, the value of (q) decreases linearly from 2 to 0 and is defined as:

$$\bar{q} = 2 - 2 \left(\frac{\text{iteration}}{\text{iteration}_{\max}} \right) \quad (11)$$

Where iteration and iteration maximum represent current iteration and maximum number of iterations, sequentially. The limited of $\bar{M}$ is $[-2\bar{q}, +2\bar{q}]$

5.1.3 Hunting

The capacity of the Grey wolves is to recognize the prey position and encircle the prey. With the given equation in the Encircling phase, the grey wolves relocate their location to anywhere in the work space. As mentioned above, for remain of the pack and for hunting procedures, social hierarchy consider a key role. The mathematical model of hunting procedures of the GW has been shown in [19,26]. The formulas for new the location are as follows.

$$\bar{Y}(t + 1) = \frac{\bar{Y}_1 + \bar{Y}_2 + \bar{Y}_3}{3} \quad (12)$$

The values of $\bar{Y}_1, \bar{Y}_2$ and $\bar{Y}_3$ are calculated as

$$\bar{Y}_1 = \bar{Y}_\alpha - \bar{M}_1 \cdot \bar{R}_\alpha \quad (13)$$

$$\text{where } \bar{R}_\alpha = |\bar{L}_1 \cdot \bar{Y}_\alpha - \bar{Y}|$$

$$\bar{Y}_2 = \bar{Y}_\beta - \bar{M}_2 \cdot \bar{R}_\beta \quad (14)$$

$$\text{where } \bar{R}_\beta = |\bar{L}_2 \cdot \bar{Y}_\beta - \bar{Y}|$$

$$\bar{Y}_3 = \bar{Y}_\delta - \bar{M}_3 \cdot \bar{R}_\delta \quad (15)$$

$$\text{where } \bar{R}_\delta = |\bar{L}_3 \cdot \bar{Y}_\delta - \bar{Y}|$$

5.1.4 Attacking Prey (exploitation)

As shown above, one time the prey stops moving, the GW hunt and encircle the prey. The hunting operation gets ended by attacking the prey. The mathematical model of approximation the prey is modeled by decreasing the value of $\bar{q}$, that in turn decrease the fluctuation range of $\bar{M}$ in the arbitrary value interval of $[-2 \ 2]$. The discovery of prey is ensuring when the value of M greater than one or M less than minus one and using it and ensure when $-1 < M < 1$. The algorithms finding out and using behavior submit on the value of M has been submitted by running the program 5 times in the reference [26]. Although the agents update their location for attacking the prey, submit on the position of *alpha*, best and *beta* wolves and the values of parameters $\bar{M}$, $\bar{R}$ and $\bar{q}$, the algorithm exposed to slump at local optimal. Thus, there is a need for more parameters for discovery.

5.1.5 Search for Prey (Exploration)

As well as to the parameters defining above, there is another parameter valid discovery of the algorithm is $\bar{L}$. The values of $\bar{L}$ different randomly in $[0 \ 2]$ in differing with $\bar{q}$, which decreases linearly from 2 to 0. The contribution of prey in limiting the next location of wolves is decided by the value of $\bar{L}$. When the value of parameter $\bar{L} > 1$, the wolves were attracted more towards the prey. The value of $\bar{L}$ is randomly created through the algorithm, the emphasis is more towards discovery from beginning to final iteration to avoid local optimal.

5.2. Grey Wolf Optimization Controller Algorithm for AGC Problem

As mentioned above, in this study Gray Wolf Optimization controller has been implemented for optimum tuning of fractional PID controller ($PI^\lambda D^\mu$) gains for AGC of stand-alone microgrid and multi-microgrid systems. The algorithm carries out steps are enumerated as following:

1. Population size (p^{size}), $iteration^{max}$, number of controls variable(n), (i.e.; $k_p, k_d,$

k_i, λ and μ for each controller), boundaries of fractional PID controller ($PI^\lambda D^\mu$) gains ($K_p^{min,max}, K_I^{min,max}, K_D^{min,max}, \lambda^{min,max}$ and $\mu^{min,max}$)

2. Create the population (Pop) randomly inside their boundaries.
3. Play the Simulink program and assess the fitness (UITAE) values for all the populations by the Equation 5.
4. Sorting the population depending to fitness. Assign *alpha*, *beta*, *delta* & *Omega* wolves based on fitness values.
5. Refresh the location of *alpha*, *beta*, *delta* grey wolves based on fitness value as following:

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For  $i = 1$  to  $p^{size}$ 
  if ( fitness ( pop (i)) < fitness (alpha)
    alpha = pop(i)
  End
  if ( fitness (pop(i))
    > fitness (alpha) and fitness (pop(i))
    < fitness (beta)
    beta = pop(i)
  End
  if (fitness ( pop (i)) > fitness (alpha) and
    fitness (pop(i)) > fitness (beta) and
    fitness (pop(i)) < fitness (delta)
    delta = pop (i)
  End
End

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6. Refresh the position of *Omega* grey wolves by use the Equations (13–15).
7. Refresh the control variables using Equation 13 and verify whether they are violating their boundaries. If violated, keep within their boundaries.
8. Move to step (3) and returns the above steps until convergence criteria are complacent.

Table 1. Parameters of GWO

Parameters	Value
Number of generations	400
Population sizes	40
Crossover probability	0.85
Mutation probability	0.65

6. Result and Discussion

Using the MATLAB/SIMULINK toolbox, extensive simulation is carried out to apply the presented algorithm on a three-power pool for (Reheat, Gas and Hydro) systems shown in Figure.1. The dynamic performance obtained by using a fractional PID controller are obtained by using a traditional PID controller so as to test the robustness of the fractional PID controller. The efficiency of the Grey wolf optimization (GWO) mechanism is determined by comparing the results to those obtained using the PSO algorithm as an optimization method. The disturbance in the active power demand is simulated by a step change of 1% in the load demand. There are a many different operational scenarios which are investigated. The controller's benefits, droop regulation R, and frequency bias factor B are all optimally obtained in each scenario. The minimized performance to be in the presented algorithm is the updated integral time absolute errors (UITAE), that are given as follow:

$$UITAE = \int_0^{ts} t \{ \sum_{i=1}^3 \{ |\Delta f_i| + |\Delta P_{tie-i}| + \text{Max}|\Delta f_i| + \text{Max}|\Delta P_{tie-i}| \} dt$$

Table 2. Optimal controller settings determined by the GWO.

Controller parameter	Controller types	Area-1	Area-2	Area-3
k_p	<i>PID</i>	6.2568	5.2654	1.1586
	$PI^\lambda D^\mu$	3.2687	0.2002	11.257
k_i	<i>PID</i>	12.244	4.1245	0.1202
	$PI^\lambda D^\mu$	15.262	11.786	14.101
k_d	<i>PID</i>	3.4577	7.1254	1.0012
	$PI^\lambda D^\mu$	4.4511	7.1452	6.2575
λ	<i>PID</i>	0.8020	0.6524	0.6235
	$PI^\lambda D^\mu$	0.7525	0.2575	0.9444
μ	<i>PID</i>	0.4215	0.8000	0.7250
	$PI^\lambda D^\mu$	0.9945	0.6250	0.7582
R	<i>PID</i>	2.1450	2.0235	8.009
	$PI^\lambda D^\mu$	2.0121	2.0500	3.0521
β	<i>PID</i>	0.8565	1.2500	1.9850
	$PI^\lambda D^\mu$	0.8547	1.4258	1.4512

Table 3. Optimal controller settings determined by the PSO.

Controller parameter	Controller types	Area-1	Area-2	Area-3
k_p	<i>PID</i>	5.5251	7.2541	2.2542
	$PI^\lambda D^\mu$	5.7750	2.0001	15.001
k_i	<i>PID</i>	18.001	5.2548	1.2100
	$PI^\lambda D^\mu$	16.562	10.254	13.001
k_d	<i>PID</i>	3.7861	5.2565	0.0001
	$PI^\lambda D^\mu$	3.1323	5.5685	6.7621
λ	<i>PID</i>	0.7411	0.5477	0.7106
	$PI^\lambda D^\mu$	0.5852	0.5256	0.9666
μ	<i>PID</i>	0.9879	0.7809	0.7855
	$PI^\lambda D^\mu$	0.9945	0.7756	0.8511
R	<i>PID</i>	2.0012	2.2501	8.8526
	$PI^\lambda D^\mu$	5.2586	2.5200	3.2500
β	<i>PID</i>	0.77195	1.5004	1.0250
	$PI^\lambda D^\mu$	0.65018	1.4782	1.2583

6.1. The First Scenario

In this scenario, a few step load increases of 1% ΔP_{D1} is happened in power pool 1 (Reheat, Gas and Hydro). The frequency deviation for dynamic response and exchange in the tie-lines power are shown in figures 7-12. The frequency bias factor (B) along with the droop regulation factor (R) are optimal synchronously with the controller parameters as in the table-2. The optimal result of the frequency bias factors for the scenario are found to be $B_1^* = 0.40248$ p.u MW/Hz, $B_2^* = 0.65841$ p.u MW/Hz, and $B_3^* = 0.71611$ p.u MW/Hz. It is obvious from these figures that the suggested $PI^\lambda D^\mu$ controller using GWO provides best dynamic characteristics in terms of damping all oscillations, minimizing decreasing overshoot and settling time.

Table 4. Fitness value

	Controller parameter	UITAE	S.T(s)	Overshoot	Undershoot
Area-1	FOPID-	0.7652	6.254	0	9.786
	FOPID-PSO	0.9002	11.58	6.256	13.130
	PID-GWO	2.3899	10.06	4.758	13.300
	PID-PSO	3.7014	11.55	5.854	13.845
Area-2	FOPID-	-	8.950	0	0.00194
	FOPID-PSO	-	13.12	0.0006	0.00524
	PID-GWO	-	15.15	0.0014	0.00282
	PID-PSO	-	13.11	0.0016	0.00400
Area-3	FOPID-	-	8.852	0	0.00221
	FOPID-PSO	-	12.45	0.0011	0.00440
	PID-GWO	-	14.35	0.0003	0.00385
	PID-PSO	-	18.86	0.0014	0.00174

Figure (7)

Figure (8)

Figure (9)

Figure 7, 8 and 9. Deviation of Δf_1 , Δf_2 and Δf_3 for $\Delta P_{D1} = 0.01 \text{ p.u.}$

Figure (10)

Figure (11)

Figure (12)

Figure 10, 11 and 12. Deviation of ΔP_{tie-1} , ΔP_{tie-2} and ΔP_{tie-3} for $\Delta P_{D1} = 0.01 p.u$

Figure (15)

Figure 13, 14 and 15. Deviation of Δf_1 , Δf_2 and Δf_3 for $\Delta P_{D1} = 0.02 p.u$

6.2. The Second Scenario

The effect of the size of load disturbance on the AGC is investigated in this scenario. A chain of a step load of 2% ΔP_{D1} , 4% ΔP_{D1} , 6% ΔP_{D1} , 8% ΔP_{D1} and 10% ΔP_{D1} consequentially is applied to power pool-1 (Reheat, Gas and Hydro). The dynamic performance of the deviation in frequency and the tie-lines power exchange deviation responses in the three power pools are shown in figures (13, 14 and 15) consequentially. It is clear from these figures that the suggested $PI^\lambda D^\mu$ controller using Grey wolf optimization (GWO) still superior compared with the other controllers. In addition to, the tuning of the controller provided by (GWO) algorithm is best obtained by using PSO algorithm as in table-3. As well as it is important to observe that the other controller PID adjust by PSO algorithm is fail to eliminate the exchange in tie-lines power and frequency error for a relatively large step load demand disturbance 8% ΔP_{D1} and 10% ΔP_{D1} .

6.3. The Third Scenario

The third scenario is aimed to view the dynamic performance of the suggested ($PI^\lambda D^\mu$) controller using (GWO) with varicose range of load disturbance, the algorithm applied alone on the three power pools system (Reheat, Gas and Hydro) with the step load disturbance change linear from 1% ΔP_{D1} to 10% ΔP_{D1} in the first

Figure (13)

Figure (14)

power pool. The deviation in the frequency to the three pools and the tie-lines power exchange deviation are shown in figures 16,17 and 18. As shown from these figures, the suggested algorithm is capable of eliminating the steady state tie-lines power exchange and the steady-state frequency errors. It desires to note that for a relatively large step load demand disturbance of 10% ΔP_{D1} the settling time may be longer with a high peak over shoot.

Figure 16. Deviation of Δf_1 for (1 – 10)% of ΔP_{D1}

Figure 17. Deviation of Δf_2 for (1 – 10)% of ΔP_{D1}

Figure 18. Deviation of Δf_3 for (1 – 10)% of ΔP_{D1} .

7. Conclusion

A robust fractional controller PID is suggested for maintaining a constant frequency and tie-lines power exchange. The suggested control algorithm applied to a multi power pools (Reheat, Gas and Hydro) systems. The nonlinear constraints like GRC, boiler dynamics and GDB of the different plants implemented in the simulation. An evolutionary algorithm called Grey wolf optimization (GWO) algorithm has been used to set up the optimal controls parameters, the frequency bias factor (B) and droop regulation (R), consequentially. The updated integral time absolute errors (UITAE) were selected as a performance index. A comparison of the dynamic performance obtained by the suggested algorithm made with these obtained by applying conventional PID controller. It was found that the suggested controller algorithms are effective in the enhancement of the dynamic performance in terms of the settling time, peak over shoot for a wide variety of disturbances. Evaluation of the robustness of the suggested algorithm carried out by applying it on a simultaneous step load disturbance on three power pool. It can be concluded that the setting of the frequency bias factor B based on a simultaneous tuning with controllers' parameters and droop regulation is important to get the best dynamic performance up to a relatively large step load disturbance.

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Abbreviations

PID	Proportional Integral Derivative
ΔP_{m1}	mechanical power deviation for the area i (pu)
LFC	Load Frequency Control
ΔP_{ci}	power deviation of area i

AGC	Automatic Generation Control
ΔP_{Li}	load variation of area i
FO-PID	Fractional Order Proportional Integral Derivative
T_{Pi}	power system time constant (s)
ACE	Area Control Error
K_{Pi}	power system gains constant
GRC	Generation Rate Constraint
T_{Ri}	reheater time constant (s)
GDB	Governor Dead Band
T_{Ti}	steam turbine time constant (s)
ISE	Integral of Squared Error
k_{Ri}	coefficient of reheater steam turbine
Δf_i	frequency deviation of area i (Hz)
T_{Gi}	steam turbine speed governor time constant (s)
B_i	frequency bias constant of area i (p.u MW/Hz)
R_i	speed regulation value (Hz/pu)
D_i	$\Delta P_{Di}/\Delta f_i$ (p.u MW/Hz)
β_i	Area frequency response characteristics of i ($=D_i+1/R_i$)

Conflict of Interest

The authors confirm that the publication of this research causes no conflict of interest.

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APPENDIX 1.

$f = 60 \text{ Hz}$, $T_{Gi} = 0.08 \text{ s}$, $2H_i = 0.1666 \text{ s}$, $T_{ri} = 10 \text{ s}$,
 $T_{Ti} = 0.3 \text{ s}$, $D_i = 0.00833 \text{ p.u MW/Hz}$, $K_r = 0.5$, $T_{pi} = 20 \text{ s}$
 $K_{pi} = 120 \text{ Hz/pu MW}$, primary loading = 50%, $T_{ij} = 0.086$.

1.A. Boiler dynamics

$T_d = 0$, $K_1 = 0.85$, $K_2 = 0.095$, $K_3 = 0.92$, $T_f = 10$,
 $T_{RB} = 69$, $C_B = 200$, $K_{IB} = 0.03$, $T_{IB} = 26$.

1.B. Non-linearities

The nonlinear GRC & GDB limitations took into consideration in this analyze are Indicated below:

GRC = ∓ 0.03 per minutes = $0.0005 \text{ p.u MW/min}$ and
 GDB = $\mp 0.0336 \text{ Hz}$.