Automatic Generation Control of Multi-area Power System with UPFC using Grey Wolf Optimized PID Controller

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Abstract: This paper proposes GWO based Proportional Integral Derivative (PID) controller for Automatic Generation Control in Multi-area power system with UPFC. The performance of the Particle Swarm Optimization (PSO) based PID controller and Genetic Algorithm (GA) based PID controller has been analyzed in order to demonstrate the superior efficiency of the proposed GWO in tuning PID controllers. By comparison with the conventional technique, the effectiveness of the anticipated scheme is confirmed. A three area non reheat thermal system is considered to be equipped with PID controllers. GWO is employed to search for optimal controllers parameters to minimize certain performance index. The UPFC is placed in the tie line for further improvement in system performance.

Key Words : **GWO ,PID, PSO, GA**

The objective of automatic generation control is to keep frequency at a nominal value as well as interchange power at the scheduled values between interconnected areas. Load frequency control (LFC) is of significance in electrical power system design and operation. In an interconnected power system, objective is to maintain the frequency of each area and to keep tie-line power flows within some pre-specified tolerances by adjusting the MW outputs of the LFC generators so as to put up the fluctuating load demands. Load Frequency Control is a essential part in power system operation and control. The constant monitoring is needed for the adequate supply and uninterrupted power. In order to guarantee good quality and reliability to the consumers and to obtain the above understood criteria, it is obligatory to interconnect all the power system which includes thermal and hydro, gas system. In power system function of LFC is to deliver the necessary power to the load with least transient oscillation. The existing circumstances of the power system are the interconnection of different power plants. Stand alone power system is basically a dynamic device, and has the tendency to become unstable after a sudden disturbance. Thus, there is a need for an effective innovation and control to maintain its stability. In addition, an effective control scheme is required for interconnected operations. Here the problem in the interconnected power system is damped out the frequency and tie line power oscillations. In LFC if no adequate damping is provided, the oscillations may persevere for a long time, causing collapse of the system. Many control strategies have been employed in the design of load-frequency controllers in order to accomplish better dynamic performance [1],[2]. PID controllers are used as supplementary controller in multi area system to maintain the constant frequency and minimize the scheduled power flow deviations to zero.

Introduction of Flexible AC Transmission System (FACTS) devices are being increasingly considered to assist the damping of oscillations and to improve the voltage stability, steady state stability and transient stability of a power system. FACTS devices become reasonable due to the new advancement in power electronic technology.

FACTS devices can be classify as shunt, series, series-series and shunt-series controllers namely, Static VAR Compensator (SVC), Thyristor Controlled Series Capacitor (TCSC), Static Compensator (STATCOM), Static Synchronous Series Compensator (SSSC) and Unified Power Flow Controller (UPFC) [3]. Most of FACTS devices are proportional integral derivative (PID) type, though its performance under varying system conditions is not satisfactory compared with fuzzy based control schemes, intelligent fuzzy control of FACTS have been designed to achieve smooth power control [4],

[5]. PID controllers provide variable gains and were automatically tuned with a nonlinear damping constituent [6].

SVC with PID controllers used to tune for power system stability improvement [7]. An artificial intelligence based control of two machine transmission system with SVC to improve power system stability [8]. Improvement of Dynamic Stability of a multi-machine system using STATCOM has proposed [9]. By using SSSC controller, an improvement of power system stability has been proposed [10].

Damping of power system oscillations, compared for various FACTS devices has been presented [11],[12]. In [13], modeling and analysis of FACTS devices for enhancement of voltage under different fault conditions. For UPFC, the simulation of D-Q control system has been detailed in [14],[15].The various modes of operation of UPFC has been explained in [16].The influence of UPFC on the voltage of the connected bus and the effect on the amount active and reactive power flowing through the transmission system has studied in [17]. A complete evaluation and performed investigative study through simulation of the damping function of the multiple damping controllers has given in [18].

GA tuned PID controller provides good response in terms of steady state error, settling time and peak overshoot compared to the responses of PI controller and fuzzy controller[19]. PSO algorithm provides a better performance due to its inherent ability to bring out the global and local searches concurrently [20]. In [21] GWO provides acceptable damping performance under different contingencies, load changes and step disturbances in two interconnected areas.

2. Three Area Power Systems

2.1 Modeling of Three Area System

Investigations have been carried out on three equal area power system connected by a tie line where f_i is the system frequency (Hz), R_i is regulation constant (Hz/unit), T_{Gi} is speed governor time constant (s) , T_{Ti} is turbine time constant (s) and T_{Pi} is power system time constant (s), ACE_I is the area control error, ΔP_{Di} is the load demand change, ΔP_{Ci} is the change in speed changer position, ΔP_{Gi} is the change in governor valve position, ΔK_{Pi} is power system gain, and ΔP_{tie} is the change in tie line power and the outputs are frequency deviation Δf and area control area, ACE. The ACE signal is the area control error, which controls the steady state errors of frequency deviation and tie-power deviation. Mathematically ACE can be the outputs are frequency deviation Δf and area control error, ACE.

The ACE signal is the area control error, which controls the steady state errors of frequency deviation and tie-power deviation. Mathematically ACE can be defined as

$$ACE = B\Delta f + \Delta P_{tie} \qquad (1)$$

where B is the frequency bias parameter.

For the three area considered in this study, PID controller with the following structure

$$K(s) = K_p + \frac{K_I}{S} + K_D S \qquad (2)$$

Where K_P is the proportional gain, K_I is the integral gain, and K_D is the differential gain, respectively.

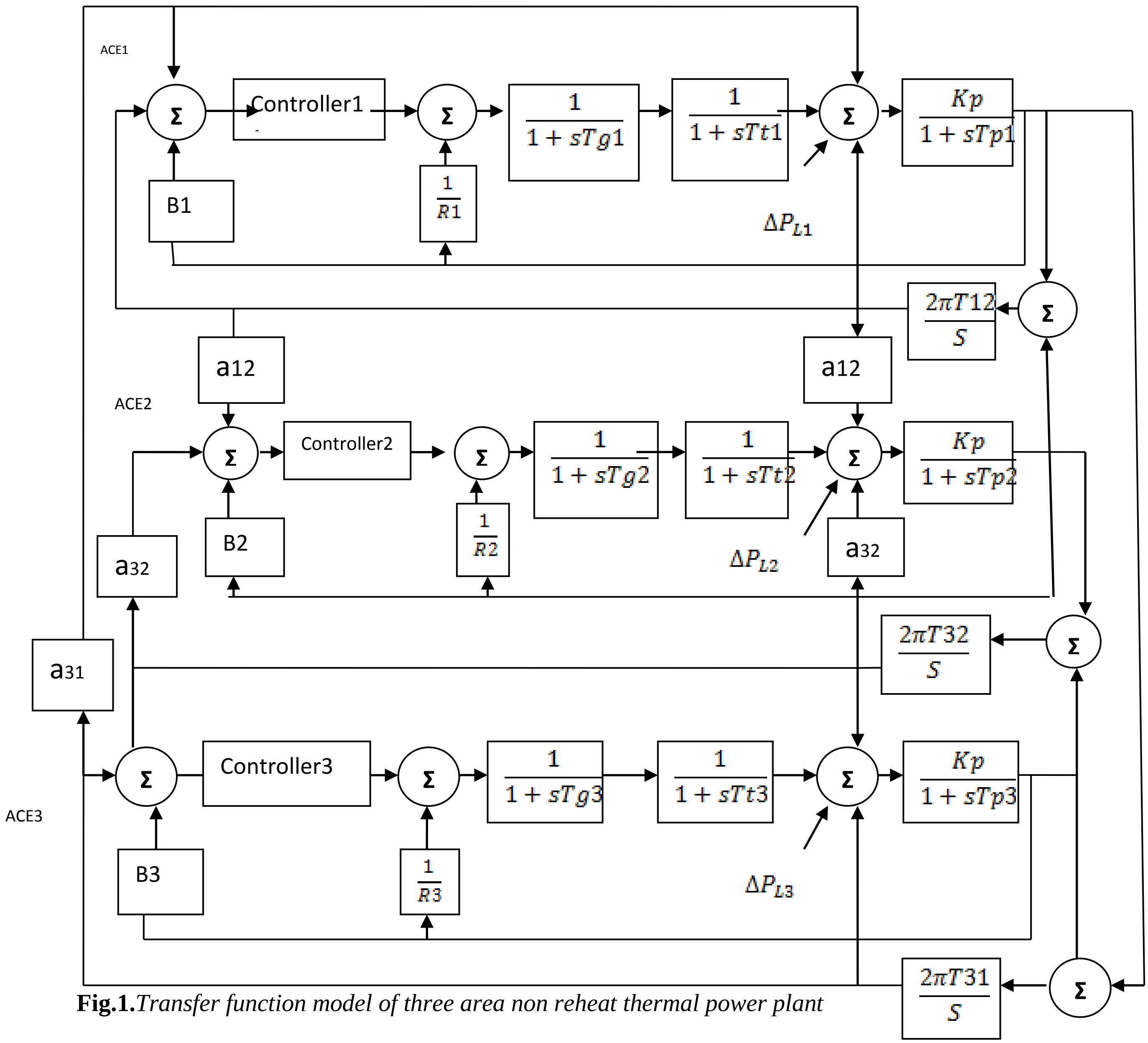

Fig.1.*Transfer function model of three area non reheat thermal power plant*

Table 1 The optimum values for controller parameters for GA, PSO and GWO

	GA based PID	PSO based PID	GWO based PID
Controller parameters	$K_P = 0.2688$ $K_I = 0.2585$ $K_D = 0.2595$	$K_P = 1.9836$ $K_I = 2.5013$ $K_D = 10.013$	$K_P = 3.2965$ $K_I = 2.9862$ $K_D = 2.3334$

3. Grey Wolf Optimizer

Grey wolf optimizer was suggested by Mirjalili et.al. in 2014. In GWO the leadership hierarchy and the hunting behavior of grey wolf is imitated. GWO overcomes the possibility of local optimal solutions and has greater exploration and share information about the search space. Grey wolves are basically categorized into four groups namely alpha, beta, delta and omega for the simulation of leadership hierarchy. The three important steps of hunting, searching for prey, encircling the prey, and attacking towards prey are employed to carry out the optimization. Alphas are the leaders of the pack. Alpha are decision makers related to hunting, sleeping place and time to wake up etc and that decision will be followed by the pack. Because of this, alpha wolf is also known as dominant wolf. Alpha is not almost completely the strongest member in the pack but good in organization and control of the pack. Beta comes in the second level on the hierarchy of grey wolves. Betas help alpha wolves in decision making and the activities of the pack. Betas are the best candidate to get the position of alpha in case of alpha wolves passes away or becomes very old. The beta supports alpha's command throughout the pack.

The main stages of grey wolf hunting are.
i) Tracking, chasing and approaching the prey
ii) Pursuing, encircling and harassing the prey
iii) Attack towards the prey

In the mathematical modeling of social hierarchy of wolf, alpha (α) is considered as the fittest solution, beta (β) and delta (δ) are the second and the third best fittest solutions respectively in designing of GWO. The rest of the candidates solutions are considered as omega (ω). The hunting is guided by α, β and δ. The ω wolves follow α, β and δ wolves.

4. Unified Power Flow Controller

The UPFC consists of series and shunt converter which are connected to each other with a common DC link. Series converter or Static Synchronous Series Compensator (SSSC) is used to add controlled voltage magnitude and phase angle in series with the line while shunt converter or Static Compensator (STATCOM) is used to provide reactive power to the ac system beside that it will provide the DC power required for both inverters. Each of the branches consists of a transformer and power electronic converter. These two voltage source converters shared a common DC capacitor. The energy storing capacity of this DC capacitor is generally small. Therefore active power drawn by the shunt converter should be equal to the active power generated by the series converter. The reactive power in both series and shunt converter can be selected discretely giving enhanced flexibility to the power flow control. The coupling transformer is used to connect the device to the system.

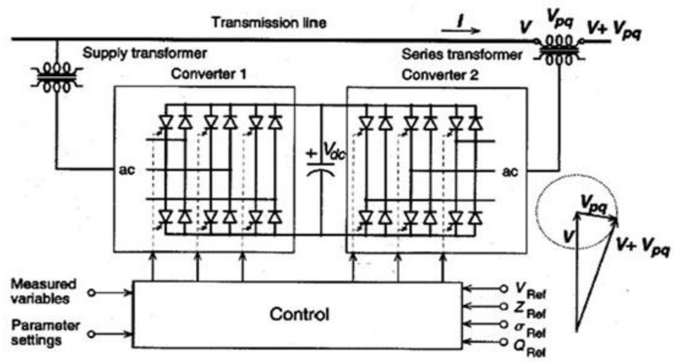

Fig.2. *Schematic diagram of three phase UPFC connected to transmission line*

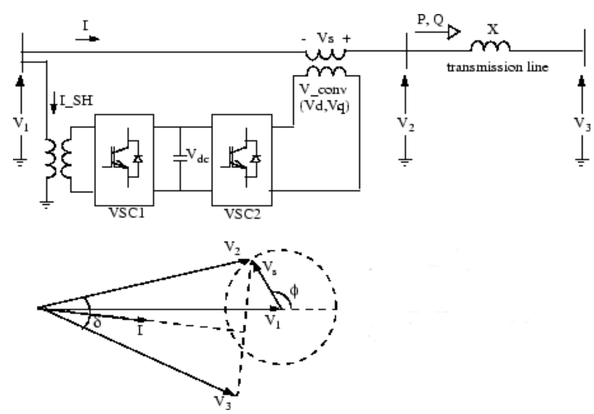

Fig.3*.Single line diagram of UFPC and phasor diagram of voltage and current*

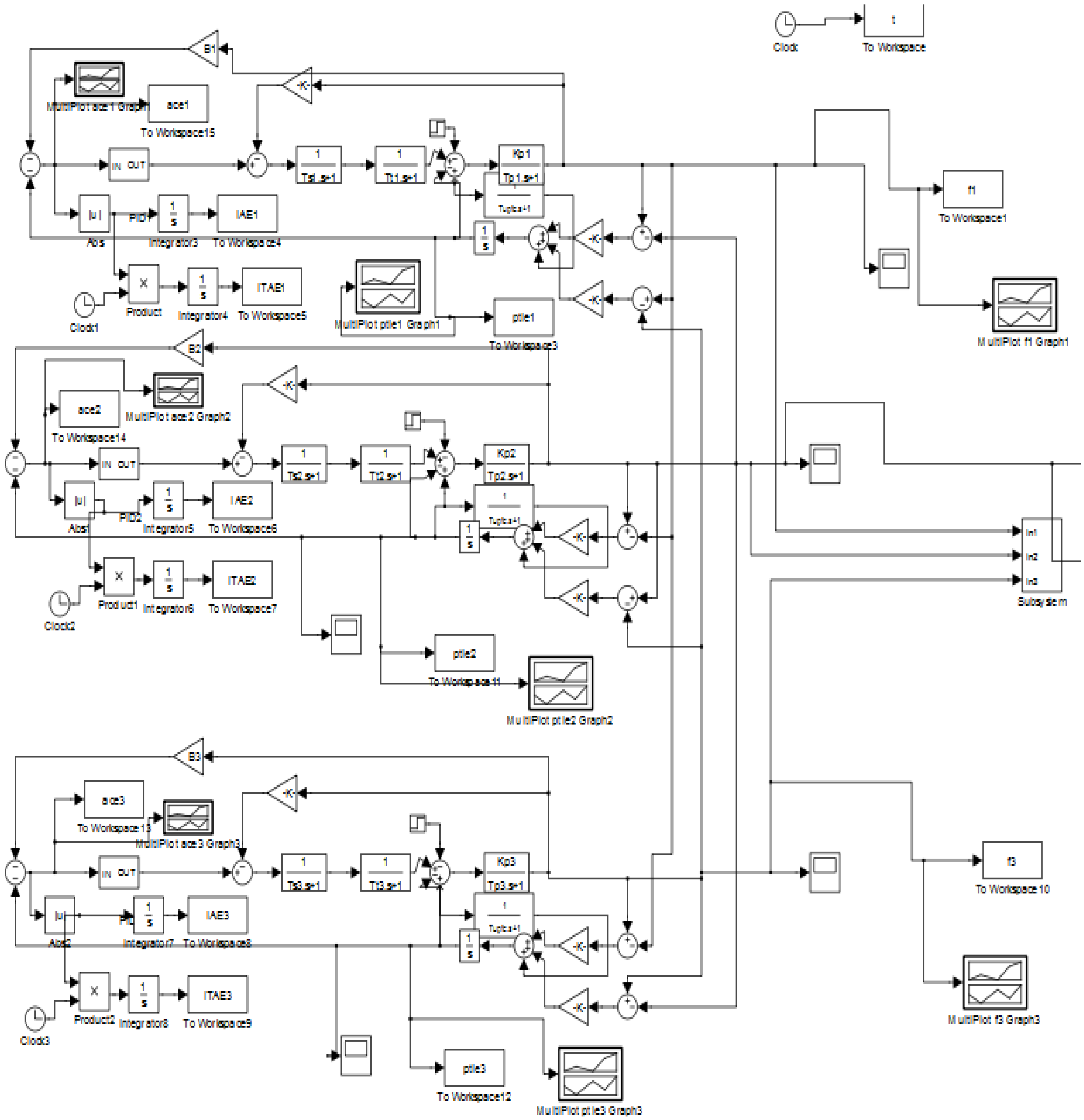

Fig.4. *MATLAB/Simulink model of three-area system with UPFC*

5. Simulation and Results:

The effectiveness of the proposed optimization approach with UPFC, the system is subjected to dynamic load demand. The comparisons of all techniques with UPFC are as follows

Load change in area-1 by 0.2 pu at t=50secs. The dynamic responses of Δf_1 , Δf_2 , Δf_3, ΔP_{tie1}, ΔP_{tie2}, ΔP_{tie3} and ΔACE1, ΔACE2, ΔACE3given in Fig 5(a) - (i) for all the algorithms with UPFC.

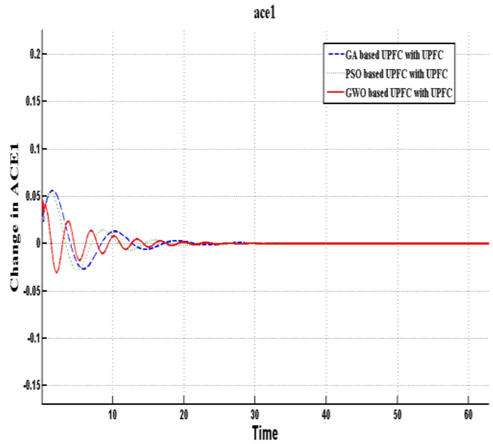

Fig. 5(a). *Change in* ACE_1 *of first area for change in 0.2 p.u change in area 1 at t=50 secs*

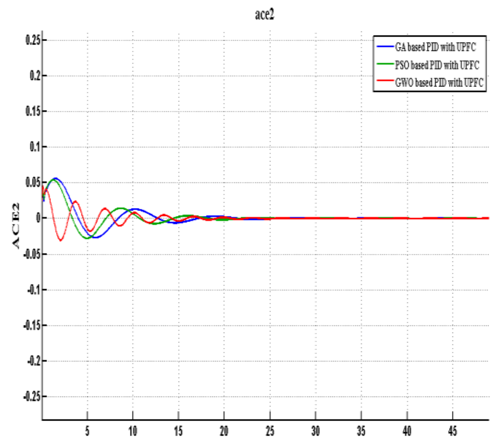

Fig. 5(b). *Change in* ACE_2 *of second area for change in 0.2 p.u change in area 1 at t=50 secs*

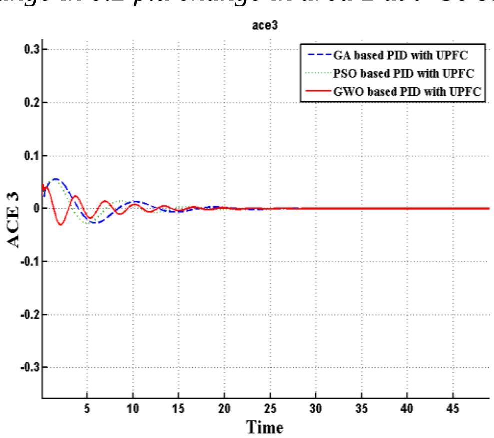

Fig. 5(c). *Change in* ACE_3 *of third area for change in 0.2 p.u change in area 1 at t=50 secs*

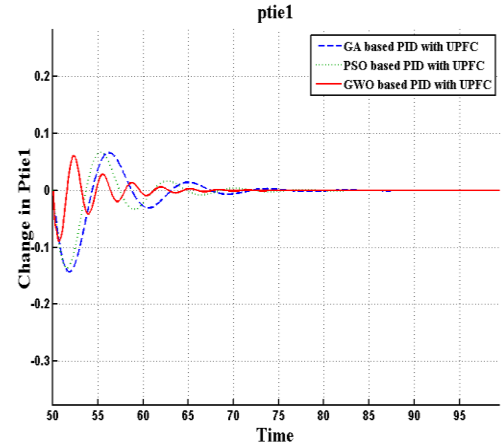

Fig. 5(d). *Change in* ΔP_{tie1} *of first area for change in 0.2 p.u change in area 2 at t=50 secs*

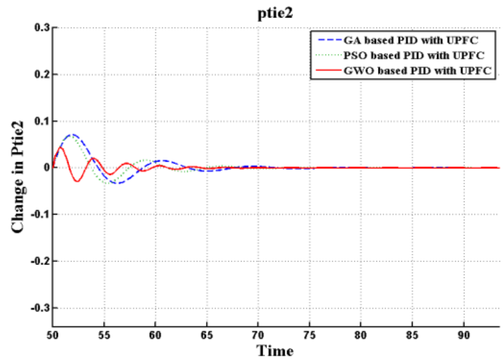

Fig. 5(e). *Change in* ΔP_{tie2} *of second area for change in 0.2 p.u change in area 2 at t=50 secs*

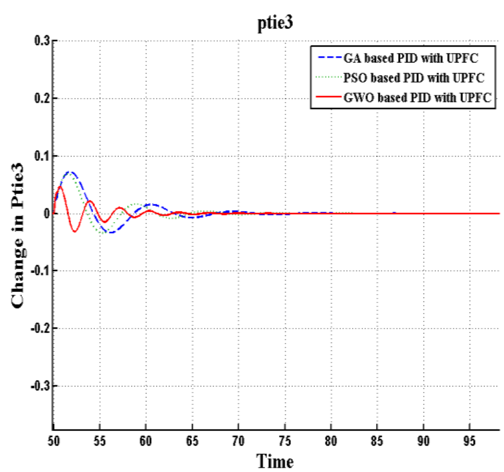

Fig. 5(f). *Change in* ΔP_{tie3} *of third area for change in 0.2 p.u change in area 2 at t=50 secs*

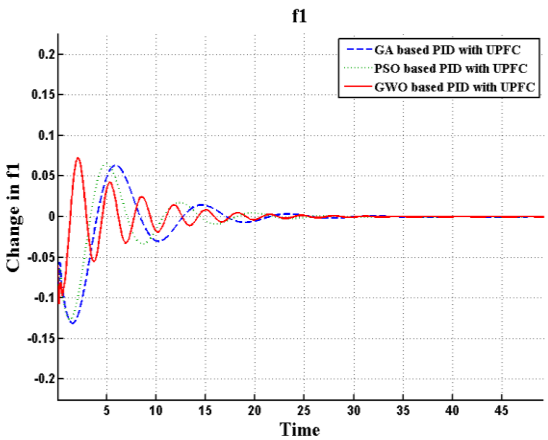

Fig. 5(g). *Change in* Δf_1 *of first area for change in 0.2 p.u change in area 2 at t=50 secs*

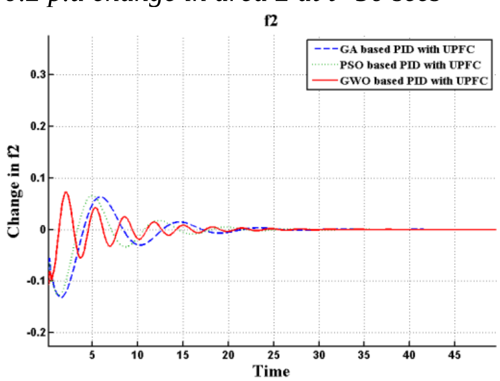

Fig. 5(h). *Change in* Δf_2 *of second area for change in 0.2 p.u change in area 2 at t=50 secs*

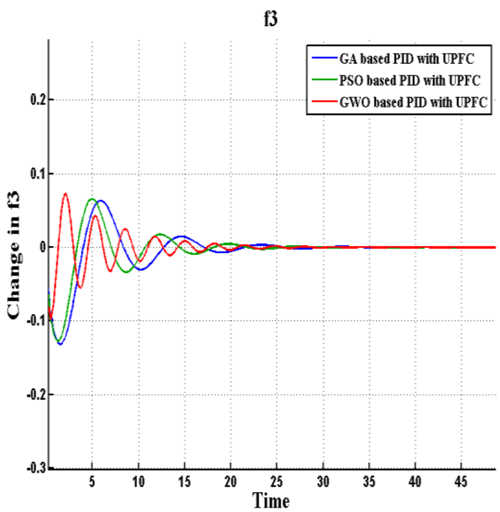

Fig. 5(i). *Change in* Δf_3 *of third area for change in 0.2 p.u change in area 2 at t=50 secs*

Table 2 Tie Line Power Deviation Comparison

Parameters	Area 1		
	GWO based PID with UPFC	PSO based PID with UPFC	GA based PID with UPFC
Peak Power (pu MW)	-0.06	-0.08	-0.09
Settling time (secs)	67	73	75
Steady state error (pu MW)	0.001	0.002	0.002

5. Conclusion

GWO based PID controllers with UPFC for controlling the load frequency (LFC) in Automatic Generation Control (AGC) of three area interconnected power system. By the addition of UPFC, simulation results shows a better performance of GWO based PID controller with respect to the GA based PID and PSO based PID controllers. Steady stare error, settling time and dynamic response of the simulated power system has improved significantly by applying the proposed system.

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