MFO OPTIMIZED MULTISTAGE PDF PLUS (1+PI) CONTROLLER FOR AGC OF MULTI-AREA MULTI SOURCE NON-LINEAR POWER SYSTEM

***Abstract:** In this research work the automatic generation control (AGC) of a three equal area and each area having one thermal unit with reheat type turbine and a Generation Rate Constraint (GRC) of 3% per min is taken for each area. Various controllers like I, PI, PID, and multistage PDF plus (1+PI) controller are used to improve the frequency and tie-line power constancy of interconnected power system. The controller parameters are tuned by applying a nature inspired optimization technique named Moth Flame Optimization (MFO) technique and for this the required objective function ITAE .The variation step load by 1% is considered for area one only while other area doesn't have any load variation for this analysis. The deviation in system frequency and tie-line power signals of above said controllers are compared and it is seen that MFO technique based and multistage PDF plus (1+PI) controller having excellent performance over other in regards for settling time, peak overshoot and undershoot with reduced oscillation.*

***Keywords:** Automatic generation control (AGC), Moth Flame Optimization (MFO), Integral of Time Multiplied Absolute Error (ITAE),. Generation Rate Constraint (GRC), GDB (Governor Dead Band)*

1. Introduction

Automatic Generation Control (AGC) has vital role in the area of large scale power system. Due to the dynamic nature of load, it is necessary to maintain the balance between generation and load demand .There by improving the performance of the generating unit the frequency and tie line power should be maintained in prescribed limit is known as Automatic generation control (AGC) [1]. Many researchers have been applied many secondary controllers[2-3] in automatic generation control (AGC) system such as multistage PDF plus(1+PI) controller, classical controllers PI , PID [4,5,10,12] , Sliding mode controller(SMC)[6] and fuzzy logic controller[8,9]. Many intelligence technique like Differential evolution(DE) [4], Cuckoo search algorithm[2],Teaching learning based optimization (TLBO) [6,10],Bat algorithm[11],Flower pollination algorithm(FPA)[7],Genetic Algorithm(GA)[13] and hybrid PSO-PS[8,14] have been applied to optimize the gains and parameters of the controllers . The vital important of the present work are:

a) Optimization of the controller gains of multistage PDF plus (1+PI) controller, PI controller and PID controllers in a three area wind thermal system using MFO algorithm.

b) Comparing the dynamic response obtained by MFO with Genetic algorithm (GA) and Cuckoo search algorithm(CSA).

c) System Investigated

The system model consist of three equal area having capacity 2000MW each. Each area has one reheat type thermal system and wind system in which thermal participate 80% and wind participate 20%.The system is considered as non linearity in nature by introducing GDB(Governor Dead Band) , GRC(Governor Rate Constraint) and Boiler dynamics in the system model shown in fig1(a,b). In the proposed model GRC of thermal unit is $\pm$3% per min is considered. The values of GDB is 0.05% is considered for thermal unit. In the present study back lash non-linearity is consider as GDB which produce oscillation for the natural period of 2 second. In this paper for stabilization multistage PDF plus (1+PI) controller,PI controller and PID controllers are taken individually . A step load perturbation (SLP) 2% is considered in area-1 while taking different dynamic responses. Simulation has been done in Matlab 2010/SIMULINK environment.Matlab Simulink model is shown in Fig.1(a). The main objective of ALFC loop is to improve the frequency and tie line power deviation with different load perturbation. In this three area inter connected power system the governor, reheat type turbine of thermal station and power system are expressed by their single time constant transfer function. Also individual blocks of wind power generation are expressed by their transfer function. According to this the transfer functions are expressed through different equations. Here equation(1) depicts the power balance equation of AGC. According to this

$$\Delta P_g(s) = \Delta P_{ref}(s) - \frac{\Delta f(s)}{R} \qquad (1)$$

Equation (2) depicts Hydraulic actuator (Governor) Transfer function.

$$G_H(s) = \frac{\Delta P_V(s)}{\Delta P_g(s)} = \frac{1}{1+T_H s} \qquad (2)$$

Equation (3) depicts Turbine dynamics Transfer function .That is

$$G_T(s) = \frac{\Delta P_T(s)}{\Delta P_V(s)} = \frac{1}{1+T_T(s)} \cdot \frac{1+sT_r K_r}{1+sT_R} \qquad (3)$$

Generator output is given to power system which is modelled by its transfer function as

$$G_P(s) = \frac{K_P}{1+sT_P} \qquad (4)$$

Where,

ΔP_g = deviation in governor output power

ΔP_{ref} =deviation in governor set point power

Δf = deviation in frequency

R = Regulation = $\frac{\Delta f}{\Delta P}$ $K_P = \frac{1}{D}$, $D = \frac{dP_D}{df}$, $T_P = (\frac{2H}{FD})$

H=Inertia constant, T = Synchronizing Co-efficient.

The above Transfer function equations are for Thermal power station. Like this the wind generating station is modelled by its Transfer function equations.

The first stage Transfer function equation of wind generating station is described in equation (5)

$$G_1(s) = \frac{1}{T_{Di}.s+1} \tag{5}$$

Like this the second stage transfer function equation of wind generating station is described in equation (6)

$$G_2(s) = \frac{K_{Di}(1+s.T_{Di})}{1+s} \tag{6}$$

Like this the Third stage transfer function equation of wind generating station is described in equation (7)

$$G_3(s) = \frac{K_3}{1+s} \tag{7}$$

Finally, $\Delta f(s) = G_p(s)(\Delta P_T(s) - \Delta P_D(s))$ for single area system. For multi area system there is a tie-line power, which is derived by (Tie-line power between ar1 and ar2) equation (8)

$$\Delta P_{12}(s) = \frac{2\pi T}{s}(\Delta f_1(s) - \Delta f_2(s)) \tag{8}$$

Nomenclature & Values of the parameters

R_i	Regulation of governor = 2.4 Hz/P.uMW
β_i	Frequency bias parameter = 0.425
T_{gi}	Time constant of the governor = 0.08 Sec
K_{ri}	Gain of the re-heater = 0.3
T_{ri}	Time constant of the re-heater = 10 Sec
T_{ti}	Time constant of turbine =0.3
T_{D1}	Hydraulic pitch actuator time constant = 0.041
K_{pi}	Hydraulic pitch actuator gain = 1.25
T_{pi}	Hydraulic governor time constant = 0.6
K_3	(wind) Data fit pitch response gain = 1.40
K_{Pi}	Power system gain = 120
T_{Pi}	Time constant of power system = 20 Sec
ΔP_D	Step load perturbation = 0.01 P.u
$.a_{12}$	constant of value -1, $\Delta P_{21} = a_{12}*\Delta P_{12}$
$.a_{13}$	= -1 , $\Delta P_{31} = a_{13}*\Delta P_{13}$

a_{23} = -1 , $\Delta P_{32} = a_{23}*\Delta P_{23}$

Boiler Dynamics data

K_1= 0.85; K_2=0.095; K_3=0.92; K_{IB}=0.03;
T_{IB}=26 Sec; T_{RB}=69; C_B=200; T_D=0; T_F=10;

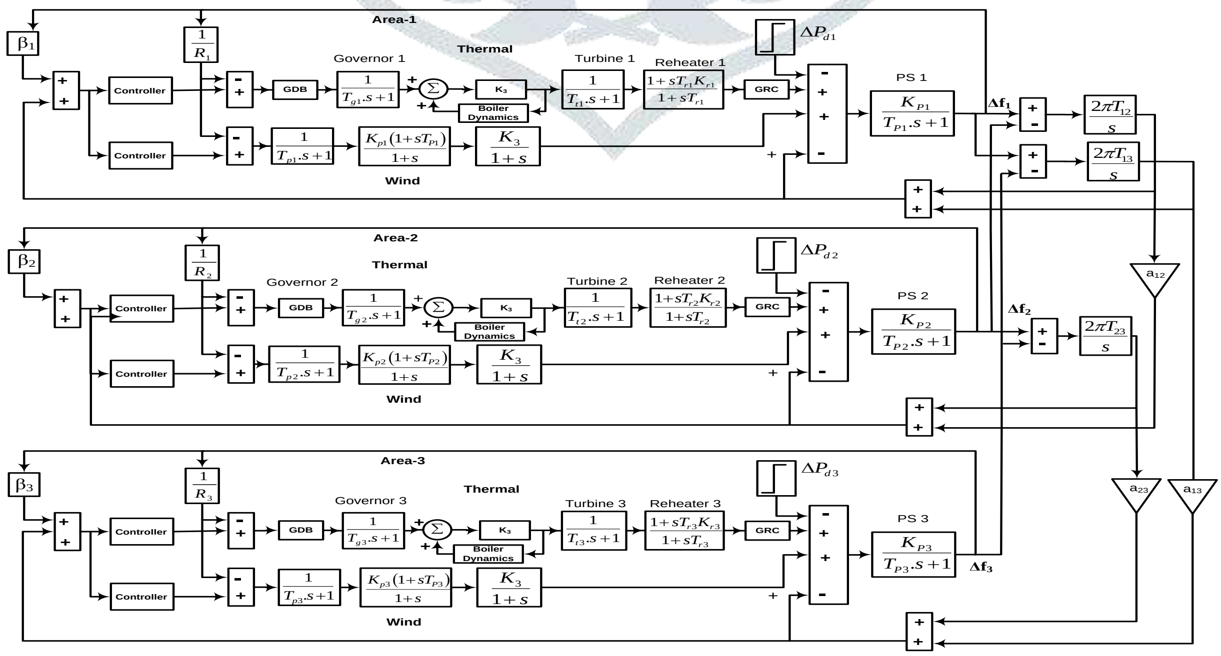


Fig.1 (a) Three area thermal wind system

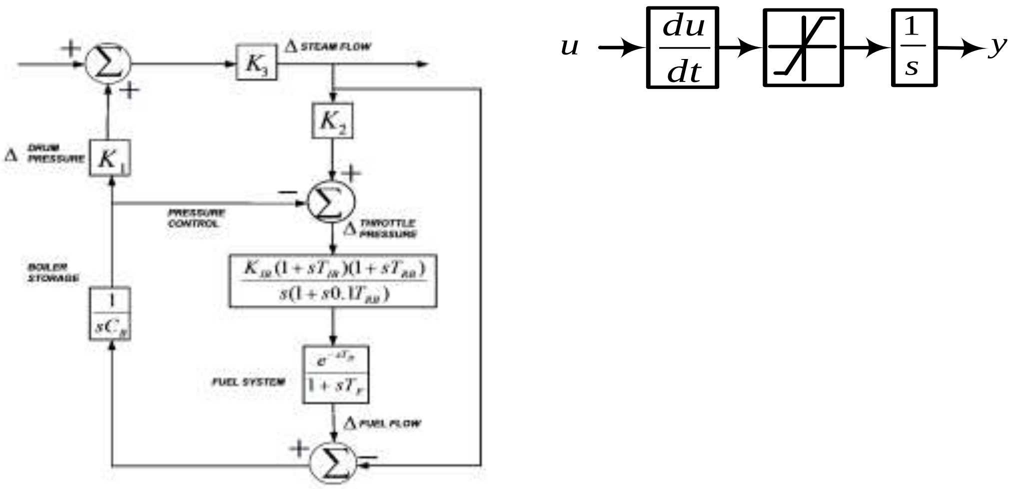


Fig.1 (b) Boiler Dynamics & GRC

2. Multistage PDF plus (1+PI) controller

The classical PID controllers still remain the simplest, effective, robust, and easily implementable control methods. The transfer function of PID controller is as follows:

$$Tf_{PID} = K_P + \frac{K_I}{s} + K_D s \tag{9}$$

The design of a simple PID controller is difficult to get optimal performance in terms of transient and steady state performance. When integral gain is increased to remove steady-state error the transient performance of the system suffers. The presence of integral part reduces speed and stability of the system during the transient conditions. The integral term should be inactive in the transient portion to improve the transient response. This can be realised by a two stage PD –PI controller which consists of a first stage PD controller and a second stage PI controller. In automatic control system noise are produced by sensors.

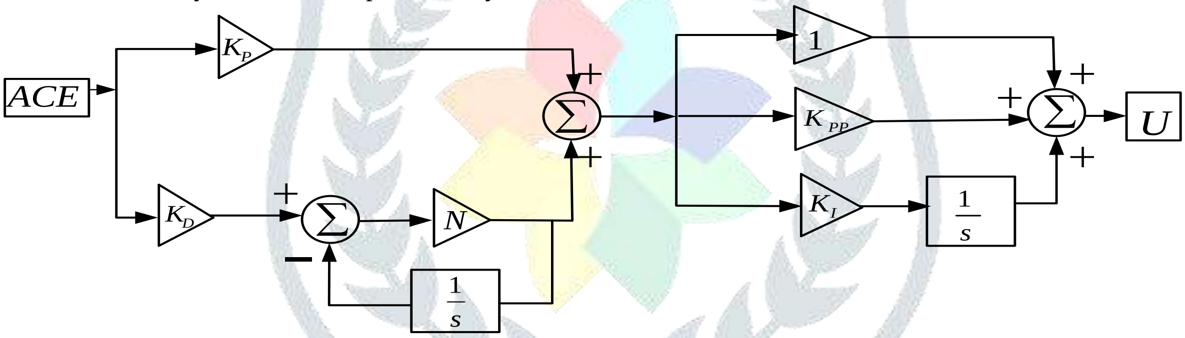


Fig2. Multistage PDF plus (1+PI) controller

3. Fitness function

The purpose of the Fitness function is to find the best parameters of controller which minimizes the frequency deviation.

Some of the popular and effective objective functions generally taken in controller design are ITAE (Integral of Time Multiplied Absolute Error), ISE (Integral of Squared Error), ITSE (Integra of Time Multiplied Squared Error), IAE (Integra of Absolute Error). In this research work ITAE is taken as objective function to design the gains of the proposed controllers. ITAE reduces settling time and also peak overshoot. Equation (10) shows expression of ITAE objective function.

$$J = \int_0^{tsim} \left(|\Delta f_1|\right) + \left(|\Delta f_2|\right) + \left(|\Delta f_3|\right) + \left(|\Delta P_{tie}|\right) t.dt \tag{10}$$

Where Δf_1 = frequency deviation in area1
Δf_2 = frequency deviation in area2
Δf_3 = frequency deviation in area3
ΔP_{tie} = Incremental change in tie line power
tsim = time range of simulation.

4. Moth Flame Optimization(MFO)

MFO technique is a nature inspired population based powerful tool. The motivation of this optimization technique is that the moths follows navigation method in nature, which is known transverse orientation. Moths always keep a constant angle with moon while flying in night. This principle helps to moths for travelling them in a straight line for long distances.In this work mathematical model of this mechanism is used to update the controller gain .The chief update mechanism of moth is Logarithm spiral. Here strength of moths is the population size and the fitness value or variable is the position of moth. MFO technique[17] is done through following steps.

Step I: At first the number of moths is specified and which is termed as population size. Each moth can occupy different positions in space and update the positions to get best position.

Initially upper band, Lower band and with their dimensions are specified.

Step II: As MFO is three-tuple i.e MFO = (I,P,T) , function I has to generate primary solutions and calculate objective function values

$$M(i,j) = (ub(i) - lb(i)) * rand + lb(i) \quad (11)$$

Where,

i = 1 ;2;3…….no. of moth .

j = 1;2;3…….no. of flame .

Where, ub(i) is the upper band of ith variable and lb(i) is the lower band of ith variable.

Step III: While each moth searches for getting best position ,it updates new positions to get this best finally as number of search agents are there, their fitness values are passed to an array om,

Om = [om_1; om_2; ……….om_n],

Step IV: The position of each moth will be updated to get to get best fitness value. This is done using equation

M_i is the ith moth , F_j is jth flame and S is for spiral function.

$$S(M_i, F_j) = D_1.e^{bt}.Cos(2\pi t) + F_j \quad (12)$$

Where, b=constant for defining shape of spiral, t= random number, D_i =Distance of ith moth from jth flame, F_j =flame, M_i =moth, D_i =is calculated as $D_i = |F_j - M_i|$

Step V: On their spiral movement no moth should be outside the limit. If the moth is very close to flame with respect to't' by updating previous value with present value, finally best position and fitness value will be displayed. If best position will not be achieved then limit should be checked, if $gen < \max^m gen$ then update generation by $gen = gen + 1$, then move to starting of step-iii. In case $gen < \max^m gen$ is not satisfied go to final step and display the best fitness and best position.

Flow chart of MFO algorithm is given in Fig. 3. An adaptive technique is taken for strength of flames

$$\text{Flame no.} = \text{round}\left(N - 1 * \frac{N-1}{T}\right)$$

Where,

N = maximum number of flame.

L = current number of iteration.

T = maximum number of iteration.

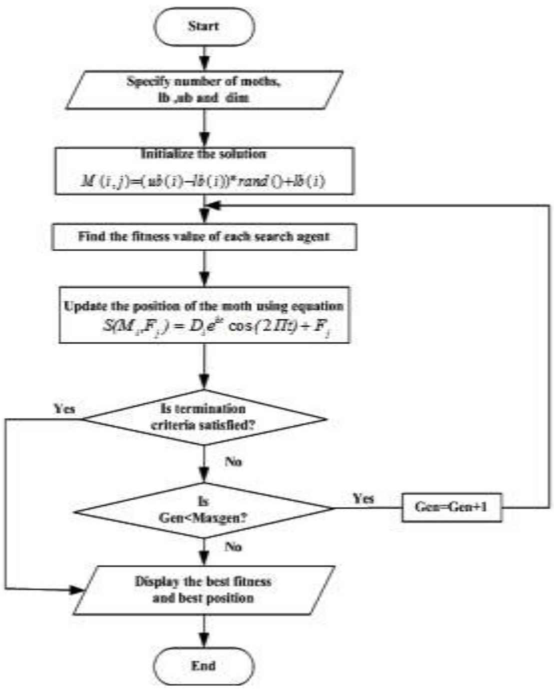
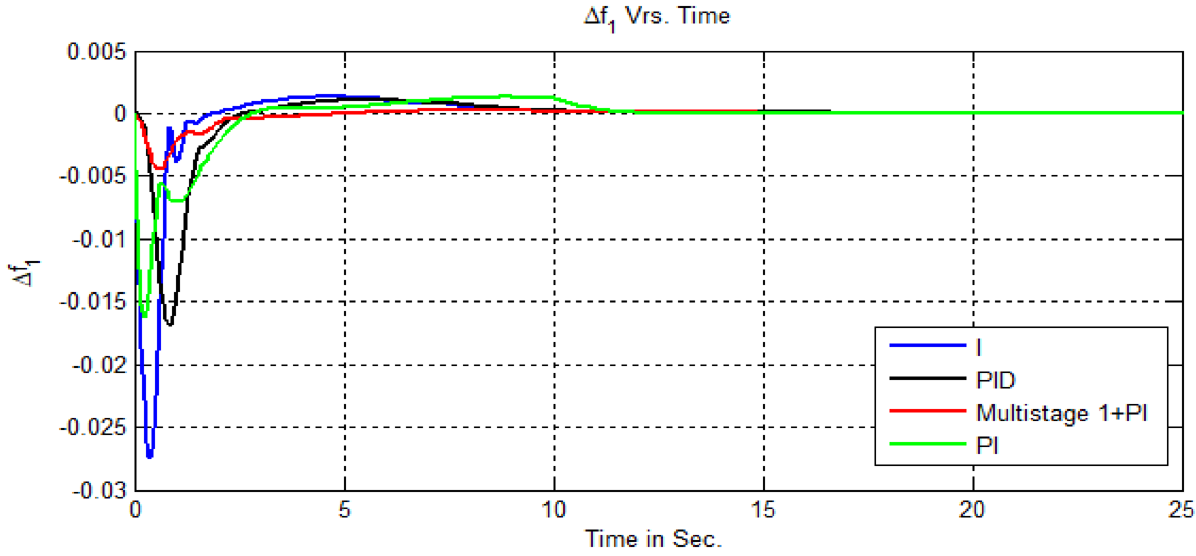


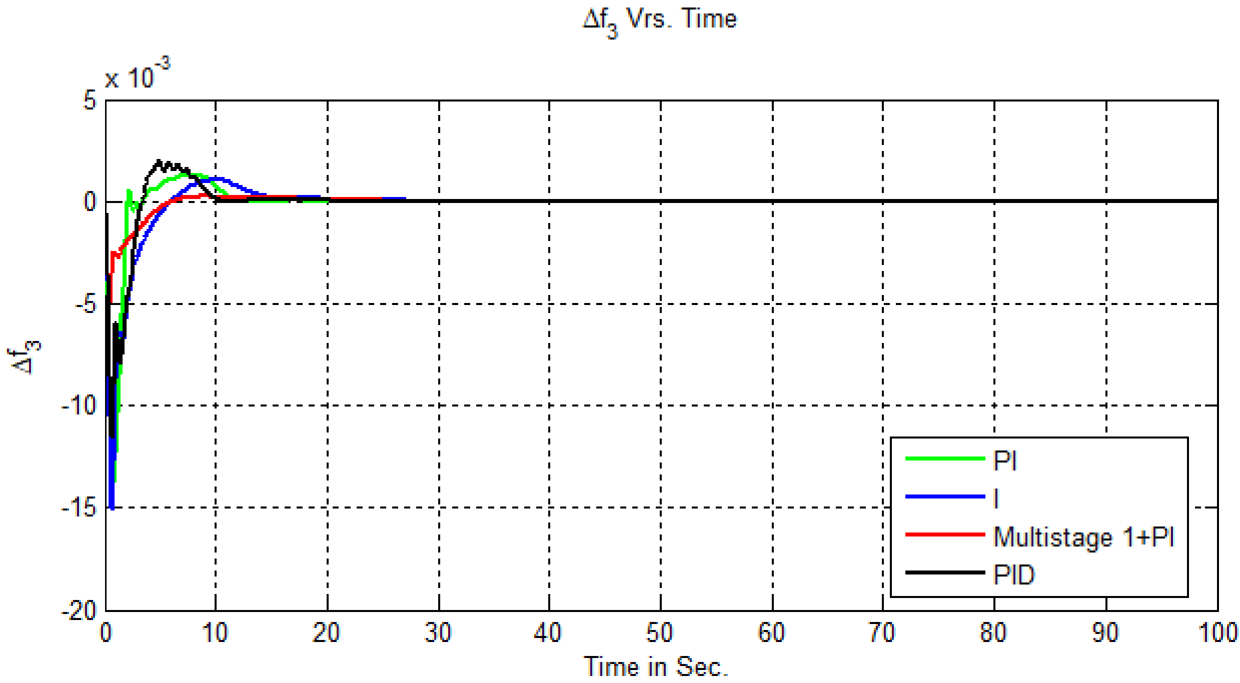
Fig.3 Flow chart of MFO algorithm

5. Result & Analysis

In this paper MFO algorithm is implemented the parameters of I, PI, PID and multistage PID(1+PI) controller for AGC of multi source interconnected system. In this paper A three area interconnected power system which contains thermal, wind system with appropriate nonlinearities such as Generation Rate Constraint (GRC), Governor Dead Band (GDB) and boiler dynamics is considered.. Simulation result reveals that proposed multistage-PID controller provides better result as compared to PI and PID controller for the critical parameters like over shoot, under shoot in frequency, settling time and tie line power deviation. MFO technique superiority over GA and PSO techniques has also been established. Lastly, sensitive analysis has been carried .it is seen that the proposed methodology is sturdy and the controller parameters need not be retuned under shifted conditions.



4 (a)



4 (b)

Fig.4 Frequency deviation of (a) area-1 and (b) area-3 with different controllers having 2% step load perturbation in area-1

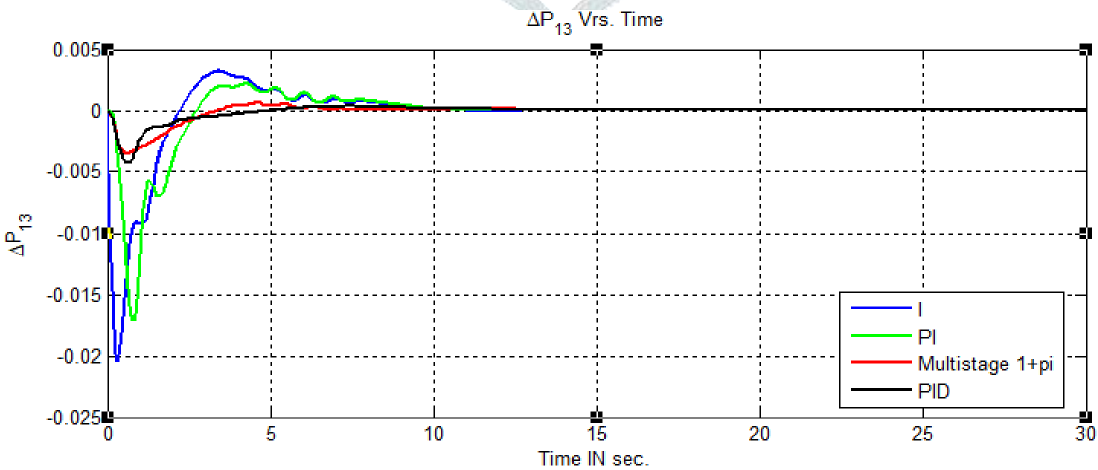


Fig.5 Deviation of tie-line power between area-1 and area-3 with different controllers having 2% SLP at ar-1

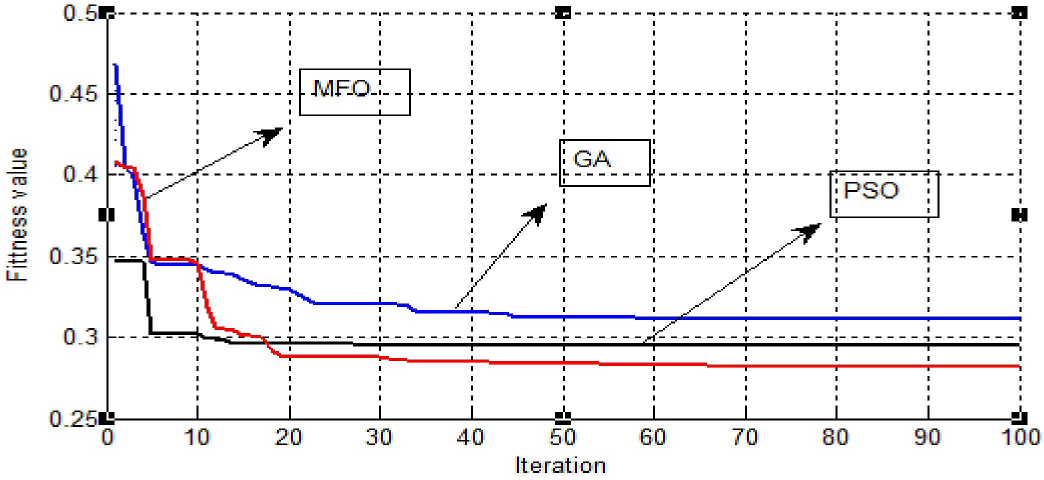


Fig.6 Convergence curve

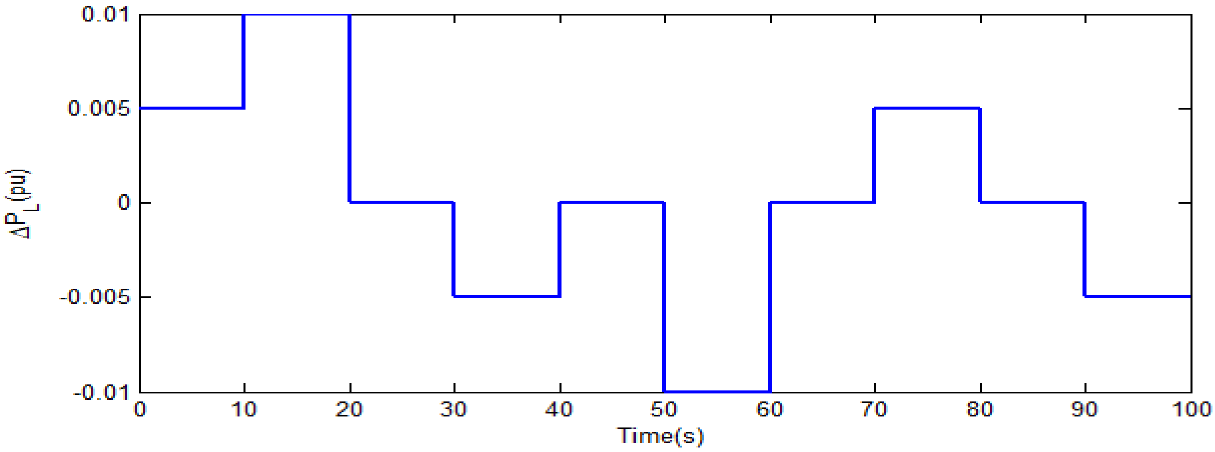


Fig.7 (a) Random load pattern

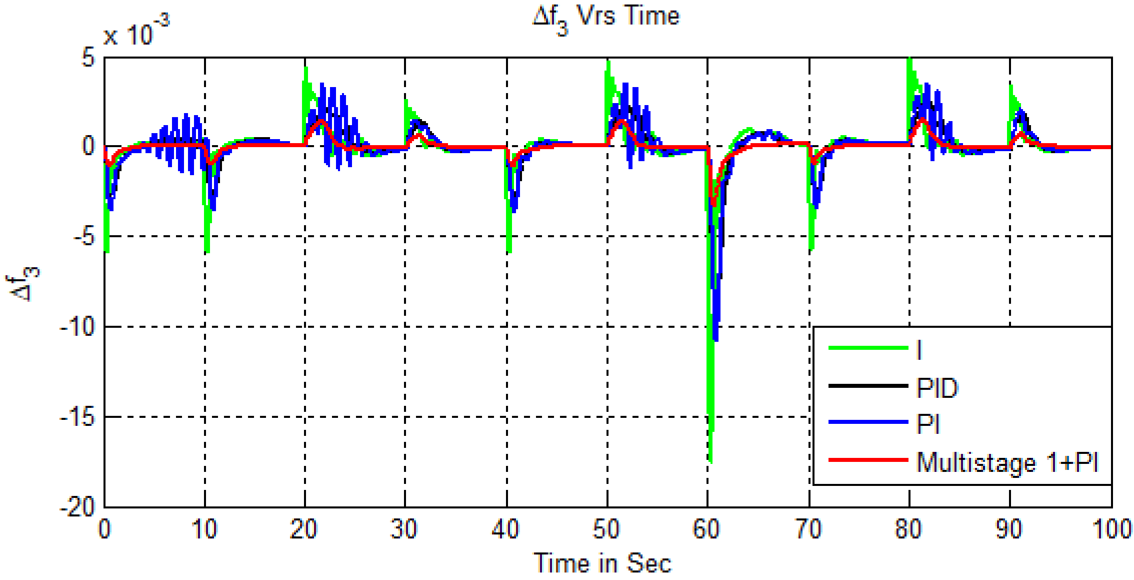


Fig.7(b) Deviation of frequency in area.3 due to RLP at area.1 only

Table1: Settling Time, Peak Overshoot and Peak Undershoot of ΔP_{12} with different controllers and different Algorithms

Controller / Algorithm	PI	PID	Multistage 1+PI	Remark
GA	15.0202	14.8802	13.2628	Settling Time
	0.00058	0.00054	0.00048	Peak Overshoot
	-0.0058	-0.00568	-0.00462	Peak Undershoot

PSO	14.2122	13.8288	12.6208	Settling Time
	0.00030	0.00028	0.00021	Peak Overshoot
	-0.0034	-0.0027	-0.0028	Peak Undershoot
MFO	13.9872	11.0256	10.8600	Settling Time
	0.00020	0.00018	0.0001	Peak Overshoot
	-0.0032	-0.0026	-0.0011	Peak Undershoot

Table2: Optimized values of different controller parameters with MFOTechnique

Controller	Multistage PID Controller					PID Controller			PI Controller	
Parameters	K_P	K_{PP}	K_I	K_D	N	K_P	K_I	K_D	K_P	K_I
AREA1	-1.9986	1.9767	0.3992	-1.9971	76.6982	-1.6156	-1.9215	-1.9013	0.3034	-1.1639
AREA2	-0.2353	1.8408	0.1285	-1.9964	15.7962	-0.5681	-0.0327	-0.4573	-0.4668	-0.0350
AREA3	-1.9962	-0.7845	1.5415	-0.2862	87.9471	-0.6504	1.8382	-0.4641	0.4819	-1.6653
ITAE value	41.68×10^{-2}					86.97×10^{-2}			131.54×10^{-2}	

Table3: Performance analysis of different optimization techniques with different signals and fitness function

Technique/ Performance	Multistage (1+PI) (MFO)			PID(MFO)			PI(MFO)		
	Settling Time in Sec.	Over Shoot in Pu. $*10^{-3}$	Under Shoot in Pu $*10^{-3}$	Settling Time in Sec.	Over Shoot in Pu. $*10^{-3}$	Under shoot in Pu $*10^{-3}$	Settling Time in Sec.	Over Shoot in Pu. $*10^{-3}$	Under shoot in Pu $*10^{-3}$
ΔF1	8.4523	0.4500	-1.9200	9.2020	1.2202	-3.1200	12.2747	2.6502	-5.3224
ΔF2	12.1634	0.3264	-0.6256	12.8788	0.6244	-2.6200	15.2530	1.4166	-3.8644
ΔF3	11.6218	0.3824	-0.8256	12.2000	0.9234	-2.5466	13.3288	1.4286	-3.9654
ΔP13	8.3244	0.8654	-6.6232	9.6086	0.9264	-8,4090	10.6208	1.1088	-11.1022
ΔP23	9.0876	0.9292	-7.1004	10.6544	0.9876	-8.2200	11.9876	1.1244	-10.8654
ITAE value	41.68×10^{-2}			42.80×10^{-2}			102.74×10^{-2}		

4. Conclusion

Three area six units thermal-wind system has been taken into consideration for the analysis of AGC system. Dynamic analysis has been carried out by giving 2% step load perturbation in area-1 with different secondary controllers like multistage PDF plus(1+PI)controller,PID controller,PI controller and I controller. It is observed from different figures and tables that Multistage PDF plus(1+PI)controller shows better performance in terms of settling time, over shoot and under shoot. Also it is not necessary to update the controller gains again while changing the different system parameters which reflect robust nature of the multistage controller. Besides this a Random Load Pattern (RLP) and a Noise load pattern is implemented in area1 only for analysis of different system responses. Controller gains are simultaneously optimized with different meta-heuristic optimization techniques like MFO, PSO and GA which unveils the superior performance of MFO.

Reference

[1]Elgerd. O.I and Fosha.C .1970. Optimum megawatt frequency control of multi-area electric energy system. IEEE Transactions on power apparatus and system, PAS – 89: 556-563.

[2] Dash,P, Saikia,L.C. and Sinha.N . 2014. Comparison of performances of several cuckoo search algorithm based 2DOF controllers in AGC multi-area thermal system. Electrical Power and Energy systems.55: 429-436.

[3] Debbarma.S , Saikia,L. C. and N. Sinha.N 2014. Automatic generation control of two degree of freedom controller fractional order PID controller. Electrical power and energy system 58: 120-129.

[4] Mohanty.B , Panda,S and Hota,P. K. 2014. Differential evolution algorithm based automatic generation control for interconnected power system with non-linearity"AlexandriaEngineering journal, 53: 537-552.

[5] Saikia,L.C, Nanda, J and Mishra,S. 2011. Performance comparison of several classical controllers in AGC for multi-area interconnected thermal system. Electrical Power and Energy systems.33: 394-401.

[6] Mohanty,B. 2015. TLBO optimized sliding mode controller for multi-area multi-source non-linear interconnected AGC system. Electrical Power and Energy systems.73: 872-881.

[7] Yang, X-S. 2012. Flower pollination algorithm for global optimization. Unconventional computation and natural computation.vol.7445: 240-249.

[8] Sahu,R.K , Panda,S and Chandra Sekhe,G.T. 2015. A novel hybrid PSO-PS optimized fuzzy-PI controller for AGC in multi-area interconnected power systems. Electrical Power and Energy systems.64, 880-893.

[9] Bevrani, H and Daneshmand,P. R. 2012. Fuzzy logic-based load-frequency control concerning high penetration of wind turbines. IEEE systems journal, 6: 173-180.

[10] Barisal, A. K. 2015. Comparative performance analysis of teaching learning based optimization for automatic load frequency control of multi-source power systems. Electrical Power and Energy system, 66: 67-77.

[11] M-Abd-Elazim ,S and Ali,E.S. 2016. Load frequency controller design via BAT algorithm for non-linear interconnected power system .Electrical Power and Energy systems.77: 166-177.

[12]Das, D, Aditya.S.K and Kothari,D.P. 1999. Dynamic of diesel and wind turbine generators on an isolated power system. Electrical Power and Energy systems.21:183-189.

[13] Ghoshal, S. P and Goswami, S.K.2003. Application of GA based optimal integral gains in fuzzy based active power-frequency control of non-reheat and reheat thermal generating systems.Electric Power Systems Research 67.2 79-88.

[14] Ghoshal, Sakti Prasad.2004. Optimizations of PID gains by particle swarm optimizations in fuzzy based automatic generation control. Electric Power Systems Research 72(3): 203-212.

[15] Yang, XS.2014. Flower pollination algorithms. Nature-inspired optimization algorithms; 155–73 [chapter 11].

[16] Yang XS, Karamanoglu, M and He, X.2013. Multi-objective flower algorithm for optimization. Procedia Comput Sci;18:861–8.

[17] Mirjalili, S.2015. Moth flame optimization algorithm: A novel nature inspired heuristic paradigm Knowledge based system ,89:228–249,