ALO Optimized multistage PDF plus (1+PI) controller for AGC of multi-area multi source non-linear power system

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Abstract
The research paper proposes a novel derivative filter based multistage controller and is well known as proportional derivative filter with unit gain complimented PI controller (PDF plus (1+PI) controller) to establish Automatic Generation Control (AGC) in an inter connected complex non-linear thermal and wind generating station based three area power network. Different non-linearity constraints like GDB and GRC are included to make non-linearity to the proposed network. In this proposed work to develop most accurate and close optimum of controller gain values, the proposed controller gain parameters are tunes by nature oriented optimization technique called Ant Lion Optimization (ALO) algorithm. While optimizing different gain parameters to develop least value oriented settling time and over shoot Integral of Time Multiplied Absolute Error (ITAE) has been used as fitness function for this analysis. To depict superior nature of our proposed controller a comparative analysis has been done among few other implemented controllers like conventional I, PI and PID controllers. Again a comparative observation is developed among different techniques like MFO, PSO and GA to impose Excellency of our proposed MFO algorithm. Finally the supremacy of ALO optimized proposed multistage controller is verified through random based step load pattern and are examined through different dynamic responses.

Keywords: Automatic generation control (AGC), Ant Lion Optimization (ALO), Integral of Time Multiplied Absolute Error (ITAE),. Generation Rate Constraint (GRC), GDB (Governor Dead Band)

I. INTRODUCTION

Generated powers from different generating stations are inter linked through different tie lines and delivered to different level of consumers through transmission and distribution lines. The generation amount should always satisfy the net consumer demand and total line loss in order to provide reliable operation of the system. The control mechanism which maintains both active power generation and system frequency in response to total load demand of different consumer is known as automatic generation control (AGC) or automatic load frequency control (ALFC)[1-2]. AGC of multi area non-linear system is very important and also gives challenges to the power engineers. In this research article a complex wind thermal based three area model is considered for AGC analysis. In the research scenario of power system to develop AGC in three area system different secondary controllers [3] have been utilized for control mechanism purposes. Different advanced controllers like classical controllers PI , PID [4,5,6,7] , Sliding mode controller(SMC)[8] and fuzzy logic controller[9,10] have been applied to reduce different error signals of the network for creating AGC in power network. In this research article a novel derivative filter based multistage unit gain oriented PDF plus (1+PI) controller is applied for AGC analysis. In optimized research scenario to tune the gains of different implanted secondary controllers advanced optimization techniques like DE [11], CSA [12], TLBO 13[], Bat algorithm [14], Flower Pollination Algorithm[15], GA [16], hybrid PSO [17], have been utilized to tune the different controller gain values. Th main frame work of this proposed research work is as follows

a) A novel advanced derivative filter oriented unit gain added PI controller is proposed for controlling different error signals of three area network model for AGC analysis.

b) The above proposed controller gain variables are tuned by implementing nature oriented population based Ant Lion Optimization (ALO) technique.

SYSTEM INVESTIGATED

The considered network model for AGC analysis in this research article is a wind thermal based three area complex electrical networks. In this huge network each area consists of single thermal and renewable energy based wind power conversion system. Each are each is assigned with a power rating of 2000MW where from total capacity thermal system is responsible for 80% and renewable energy based wind energy based power generation system participates for rest 20% for power generation. The system is considered as non-linearity in nature by introducing GDB , GRC and Boiler dynamics in the network 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 are 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 proposed derivative filter based multistage controller and for comparison additional controllers like I, PI controller and PID controllers are taken individually. For analysis and supremacy variety of responses are developed in consideration with a step type load(SLP of 2%)at area one only. The model developed for this analysis is designed in simulation based MATLAB environment and simulated through linked optimization programming written in editorial window with .m file. The detailed model along with proposed controller is depicted in fig.1(a). The aim of this research is to maintain both system frequency and inter line power flow by implementing suitable intelligent techniques. 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

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

Equation (2) depictsHydraulic actuator (Governor) Transfer function.

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

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

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

The dynamic nature based power system has been energised through generating system is expressed by equation (4)

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

Here,

ΔP_g = Regulated governor output power

ΔP_{ref} =Regulated governor reference power

Δf = Variation in frequency

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

H= Constant for inertia, T = Tie-line power coefficient.

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, $\Delta f(s) = G_P(s)(\Delta P_T(s) - \Delta P_D(s) - \Delta P_{tie})$.

Tie-line power between ar1 and ar2 for this proposed model is depicted inequation (8)

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

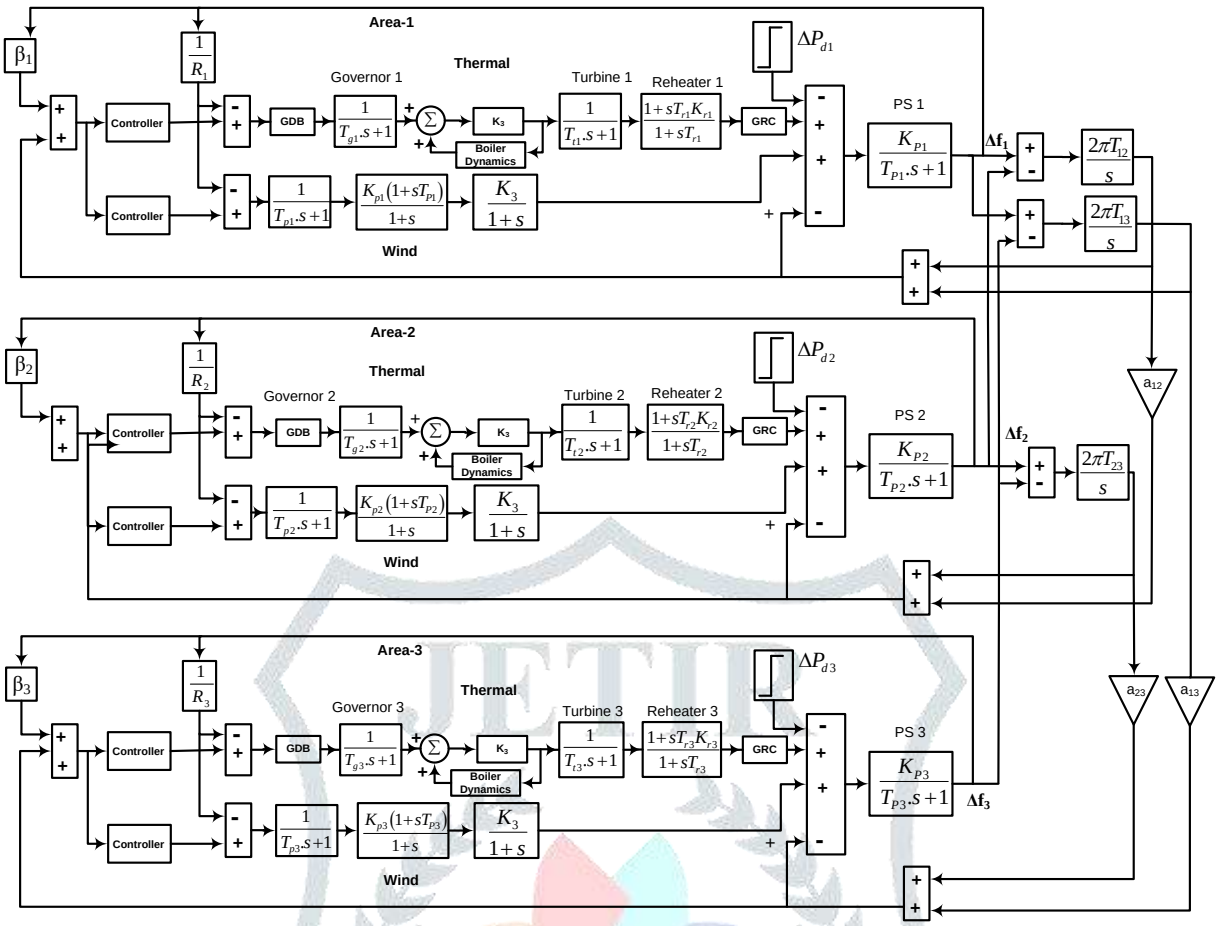
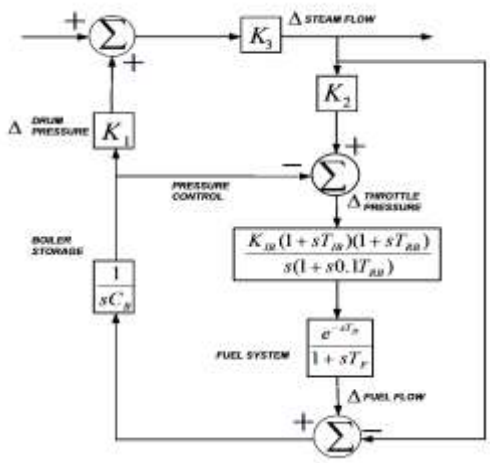


Fig.1 (a) Three area thermal wind system



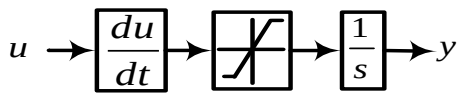


Fig.1 (b) Boiler Dynamics& GRC

1. Pdf Plus (1+Pi) Multistage Controller

The most favored controller in the area of engineering research is PID controller which is expressed though transfer function and

is

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

In complex and time variant non-linear network the conventional PID controller is unable to give superior performance due to some limitations .Though integral gain helps to reduce the steady state error of the response but presence of integral gain makes slower to the system and also reduce stability of the system in system transient conditions. So while designing controller proper selection of gain parameter with adequate tuned value is so important. So to give better output responses the parameter should be activated at proper time duration. It is required to inactive in integral gain of the controller during transient period to develop the dynamic response. To achieve such performance a derivative filter based unit gain oriented PDF plus (1+PI) controller is proposed in this article. In this controller the first stage includes a filter oriented PD controller and second stage includes unit gain based PI controller which is depicted in fig.2

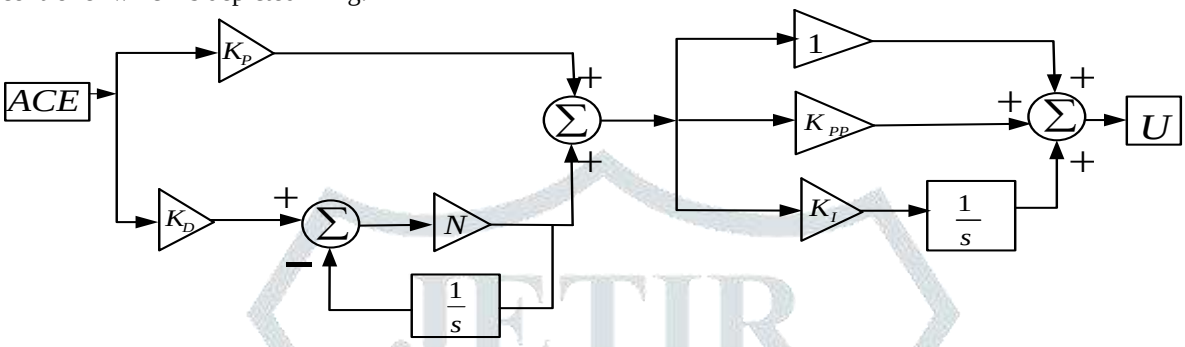


Fig2. Multistage PDF plus (1+PI) controller

II. Fitness function

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

Optimization of controller gain parameter is associated with their corresponding fitness functions. The proposed fitness function helps to develop most superior responses in terms of their settling time and over shoot. From literature survey it has been studied that variety of fitness functions like ITAE (Integral of Time Multiplied Absolute Error) , IAE (Integral of Absolute Error) and ISE(Integral of Squared Error) have been proposed in optimization scenario. This article has implemented ITAE as fitness function and is expressed through equation (10)

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

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.

III. Ant Lion Optimizer (ALO)

ALO is a population based nature oriented optimization technique whose technique of operational principle is specially depends on the hunting action of ant lions in natural environment. On their life period ant lions specially go through two different stages . The preliminary stage is larva phase and the second or terminated stage is adult phase. In the nature the larva phase is associated with the hunting behavior of ant lion and the followed adult phase is largely responsible for reproduction of ant lion. In the living style of ant lion to catch ants designed and smoothed cone shape holes are dug by the ant lions on the muddy earth surface. The holes are designed in such a way that once the ant felt down in the hole it will be easily caught by the lion at bottom of the hole. The principal operation of ALO technique is followed by five different steps. These steps are ants random movement, Hole structure, Trapping action of ants, catching to ants and Re build up of holes.

Stage-1 Ant's random movement

Ants always move randomly on their way to search different foods until to get suitable food. The random movement helps them to find food easily. The below equation depicts the random walking nature of ant.

$$X(k) = [0, csum(2r(k) - 1, csum(2r(k_2) - 1).....csum(2r(k_n) - 1)]$$

Here k = size of step, n = maximum number if ants, csum = cumulative sum.

Different matrixes are used to hold the corresponding fitness value and positions . For this analysis matrix P_P and matrix Q_f are notated to store their positions and fitness values respectively.

$$P_P = \begin{array}{|c|c|c|c|c|} \hline f([PL_{1.1} & PL_{1.2} & PL_{1.3} & \dots & PL_{1.d}]) \\ \hline f([PL_{2.1} & PL_{2.2} & PL_{2.3} & \dots & PL_{2.d}]) \\ \hline f([PL_{3.1} & PL_{3.2} & PL_{3.3} & \dots & PL_{3.d}]) \\ \hline . & . & . & . & . \\ f([PL_{n.1} & PL_{n.2} & PL_{n.3} & . & PL_{N.d}]) \end{array}$$

$$Q_f = \begin{array}{|c|c|c|c|c|} \hline f([QL_{1.1} & QL_{1.2} & QL_{1.3} & \dots & QL_{1.d}]) \\ \hline f([QL_{2.1} & QL_{2.2} & QL_{2.3} & \dots & QL_{2.d}]) \\ \hline f([QL_{3.1} & QL_{3.2} & QL_{3.3} & \dots & QL_{3.d}]) \\ \hline . & . & . & . & . \\ f([QL_{n.1} & QL_{n.2} & QL_{n.3} & . & QL_{N.d}]) \end{array}$$

Step- 2 Hole Construction

Initially a fittest ant lion is selected with the use of roulette wheel mechanism. The construction of hole is done in such a way that in such a manner that once the ant comes near the hole it slips down towards its bottom immediately. The sliding behaviour of the ant is expressed through different equations i.e

$$C^k = \frac{C^k}{I}, \qquad I = 10^W \frac{i}{s}, \qquad d^k = \frac{d^k}{I}$$

Here k = current iteration, s = maximum iteration of process

$$W = \left\{ \begin{array}{c} 2, \text{if} : t > 0.15 \\ \hline 3, \text{if} : t > 0.55 \\ \hline 4, \text{if} : t > 0.755 \\ \hline 5, \text{if} : t > 0.95 \\ \hline 6, \text{if} : t > 0.955 \end{array} \right\}$$

Step-3 Ant's trapping behaviour

Whenever the ants are felt down in the cone shaped holes these are trapped by the Lions .The trapping behaviour is expressed through different equations.

$$C_m^k = Ant - lion_n^k + C^k$$
$$d_m^k = Ant - lion_n^k + d^k$$

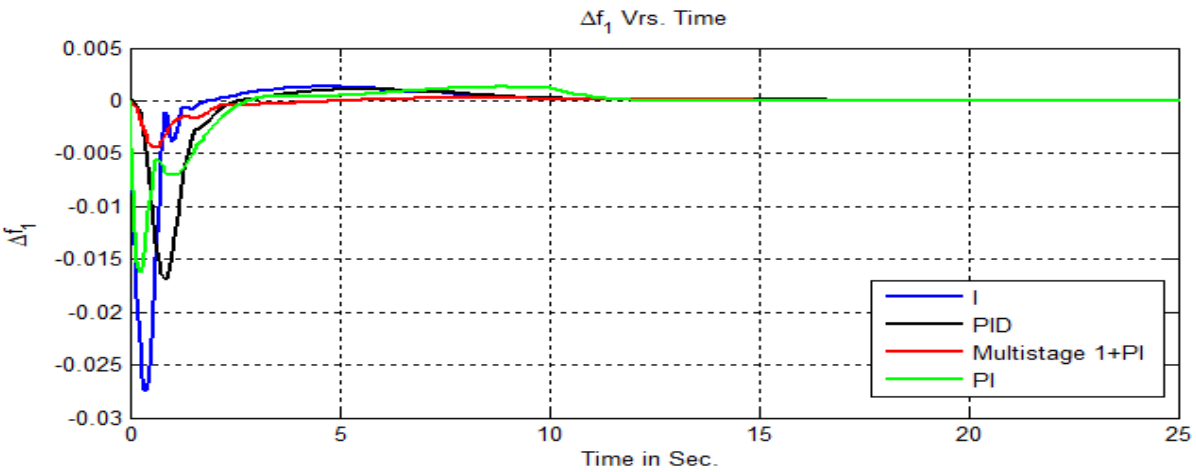
Step-4 & 5 Catching and Re-build up holes

Whenever the ant comes down to the bottom of the hole it is easily caught by the lion . For next operation and for new hunting process the ant updates its position along with re-building the new holes. The entire process is developed through mathematical equations

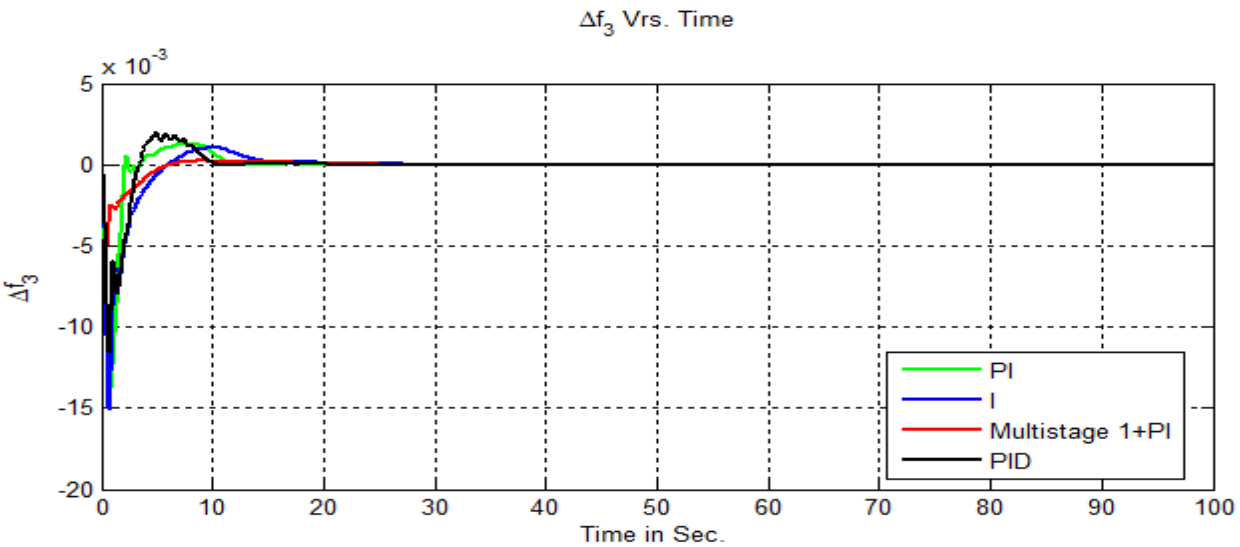
$$Ant\_Lion_n^k = Ant_m^k if(Ant_m^k \geq f(Ant\_Lion_j^k))$$

IV. Result & Analysis

Frequency variation of area-1, area-2& area-3 along with tie-line power variation (ΔP_{13}) are plotted with different intelligence technique and with different controllers which shows the superiority of ALO based Multistage PDF plus (1+PI) controller



4 (a)



4 (b)

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

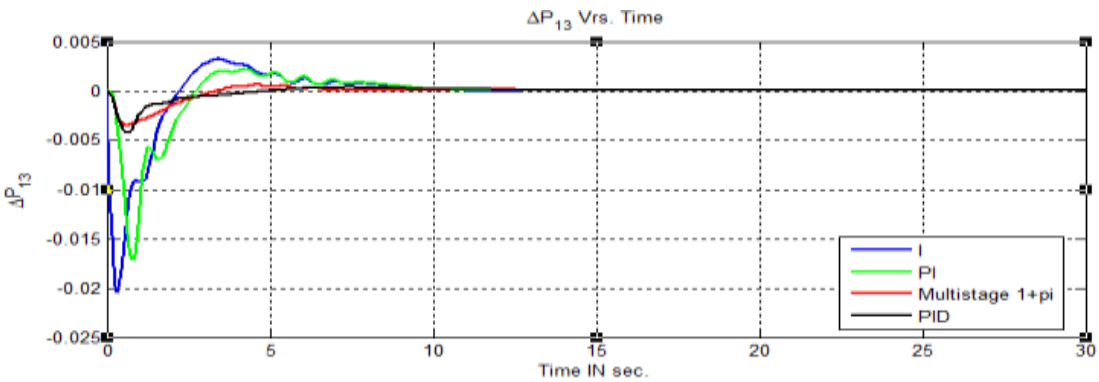


Fig.5 Deviation of tie-line power between area-1 and area-3 with different controllers having 2% SLP at ar-1

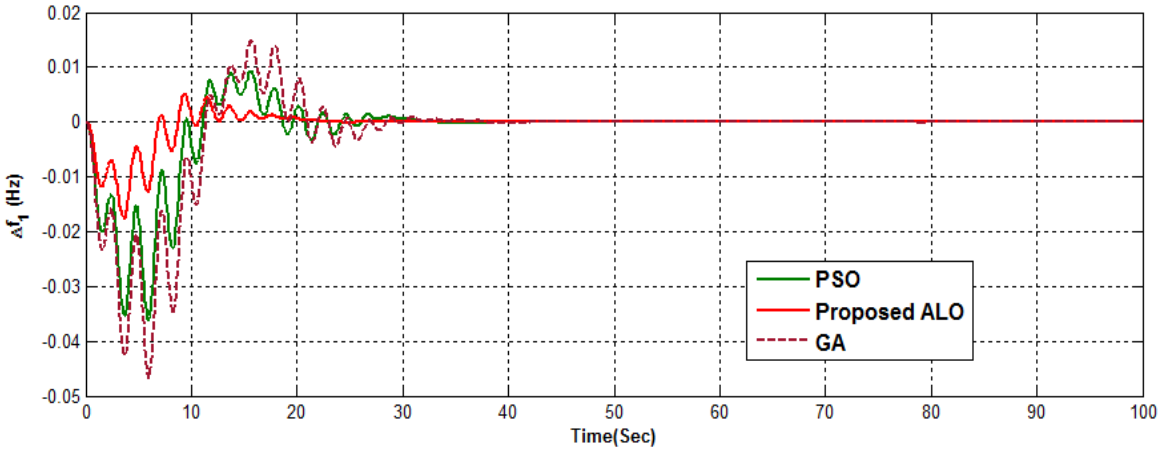


Fig.6 (a) Frequency deviation of (a) area-1 with different algorithms having 2% step load perturbation in area-1

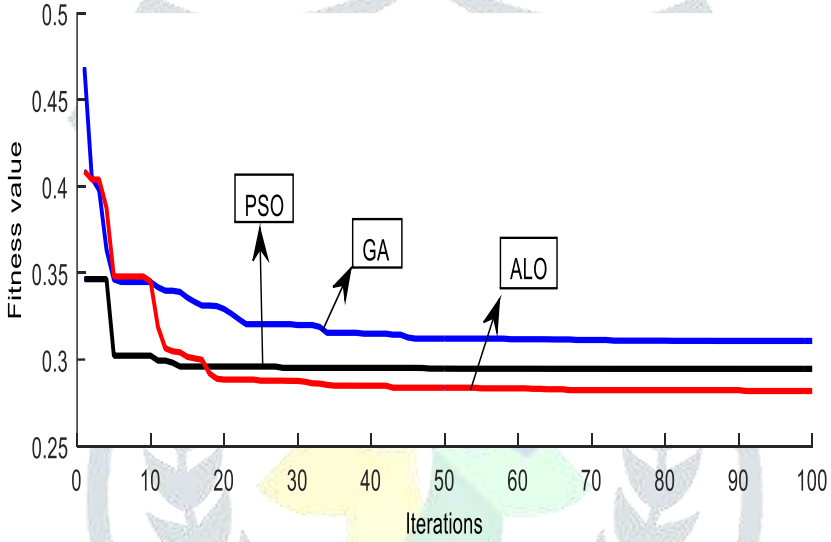


Fig.6(b) Convergence curve

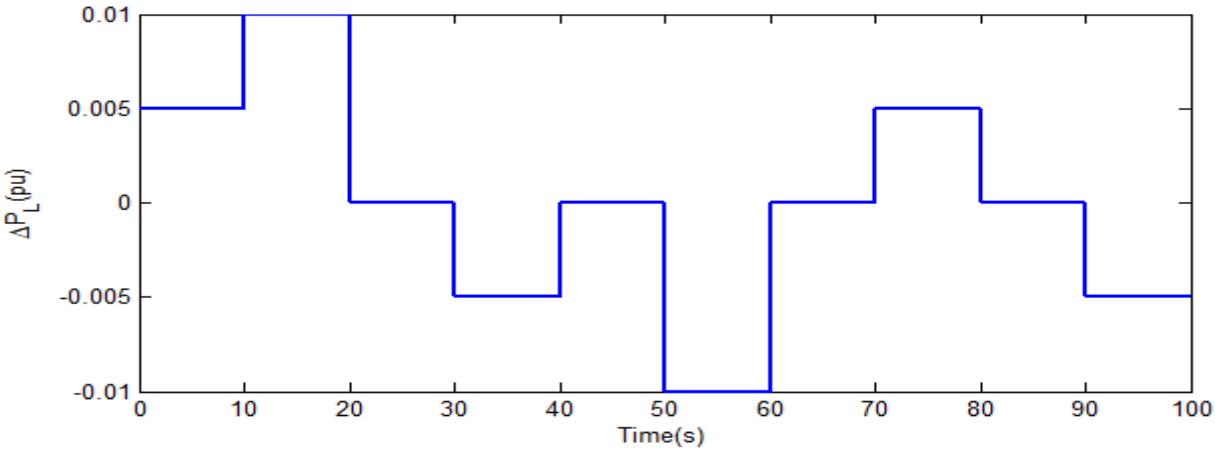


Fig.7 (a) Random load pattern

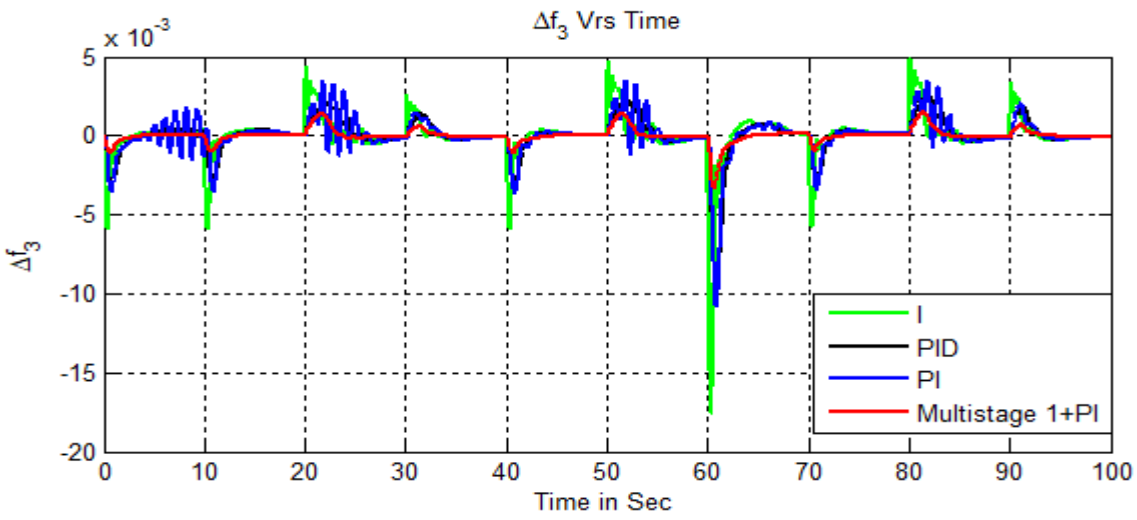


Fig.7 (b) Deviation of frequency in area.3 due to RLP at area.1 only

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
ALO	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) (ALO)			PID(ALO)			PI(ALO)		
	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}		

V. Conclusion

In this proposed work AGC is developed in complex non-linearity based wind thermal oriented three area inter connected power network with introducing GDB and GRC non-linearity constraints. The analysis is done through matlab software and implementing different 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 ALO, PSO and GA and finally it observed that ALO depicts superior performance

APPENDIX

Nomenclature & Values of the parameters

R_i Governor regulation = 2.4 Hz/P.uMW
β_i Biasing for frequency = 42.5×10^{-2}
T_{gi} Governor constant(time)= 8×10^{-2} Sec
K_{ri} Re-heater gain= 0.3
T_{ri} Re-heater constant (time) = 10 Sec
T_{ti} Turbine constant (time) =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} Gain of rotary mass = 120
T_{Pi} Rotary mass time constant = 20 Sec
ΔP_D Variation in disturbalce = 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;

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