Automatic Generation Control of Multi area Thermal Systems by Using Fractional Order Controllers

K. Vasu [1], G. Bhanu Chandar[2] and V. Ganesh[3], *Member, IAENG*

***Abstract* — In this work, Fractional Order Proportional Integral Derivative (FOPID) controller is used to control the operation of interconnected three area unequal thermal systems by considering appropriate Generation Rate Constraints (GRC). The main concept of fraction order controller is to minimize the cost function. ISE (Integral square error) method is used in designing the optimal controller by assigning fixed frequency bias. The parameters in FOPID are tuned by PSO (particle swarm optimization) algorithm. These parameters are used in simulation process with 1% step load perturbation in area 1, area 2 and area 3. The robustness of FOPID controller was examined with different loading conditions and the results are compared with PI and PID controller The simulation results of FOPID controller are distinguished with various classical controllers. FOPID controllers are proven as better in terms of settling time, reduction in frequency of oscillations, change in tie line power.**

***Index Terms* — Area control error, automatic generation control, generation rate constraints, particle swarm Optimization.**

I.NTRODUCTION

The sufficient operation of inter connected power system requires matching of total load demand associated with the losses. The operating point of power - system must be stable for the efficient working of the power system. Otherwise Power system experiences deviations in normal system frequency and scheduled tie line power exchanges to the other areas, which may cause undesirable effects [1]. There are two variables of interest in power system, namely frequency and tie-line power exchange. The combination of the variations in both parameters is called area controller error. Automatic generation controller design strategies have become an emerged area of research. The main aim of automatic generation control (AGC) is to control the mismatches in the system parameters at abnormal conditions. So many investigations and efforts have been carried out to design an optimal automatic generation controller to enhance stability and security of the system. Dynamic performance of all the conventional classical Integer Order (IO) controllers [2] like Integral, Proportional plus Integral , Proportional plus Integral plus Derivative controllers etc. has been reported in the Areas of AGC [3]-[5]. To obtain zero steady state error a number of optimization methods like artificial neural networks, Fuzzy logic controller etc have been employed for control and optimization purpose in AGC. For more settling time and high frequency of oscillations, most of these methods in control of AGC are not efficient in unequal area systems. To overcome this, a Fractional Order controller (FO) is implemented in addition to Proportional-Integral-Derivative controller.

The effects of FO controllers are introduced in the area of automatic generation control for single as well as interconnected systems. In this paper, FOPID controllers are used to improve the dynamic Performance of automatic generation control of three area thermal systems. The main aim of this work is to apply particle swarm optimization algorithm to tune the parameters of the FOPID controllers in an interconnected three area unequal power system. In the view of the above discussion, the main objective investigates as follows:

- To optimize the parameters of FOPID controllers using particle swarm optimization algorithm.
- To compare the performance of PSO FOPID with conventional integer order controllers in automatic generation control of three areas interconnected thermal systems.

The fractional order controller improves the dynamic characteristics such as zero steady state error [6]-[8] and reduces the change in frequency and change in tie line power when compared with classical order controllers like PI & PID in a three area unequal thermal power systems by taking an appropriate constraints.

II. FOPID CONTROLLERS:

The FO controllers were proposed by podlubny. The fractional calculus [9] is a generalization of integral and differential integer order fundamental operator. The integral differential operator is given by

$$aD_t^{\alpha} = \begin{cases} \dfrac{d^q}{dt^q}, R(q)>0 \\ 1, R(q)=0 \\ \int_a^t d\tau^{-q}, R(q)<0 \end{cases} \quad (1)$$

The commonly used definition for fractional differ-integral is given by Riemann-Lowville (RL) definition is as follows.

Received August 4 2015 and Revised August 15 2015.

K. Vasu is with the MITS , Madanapalli,517325, Andhra Pradesh, INDIA

G. Bhanu Chandar is with JNTUA College of Engineering Pulivendula,516390,Andhra Pradesh, INDIA

Ganesh Vulasala is with JNTUA College of Engineering Pulivendula, 516390, Andhra Pradesh, INDIA, e-mail:ganivg@gmail.com.

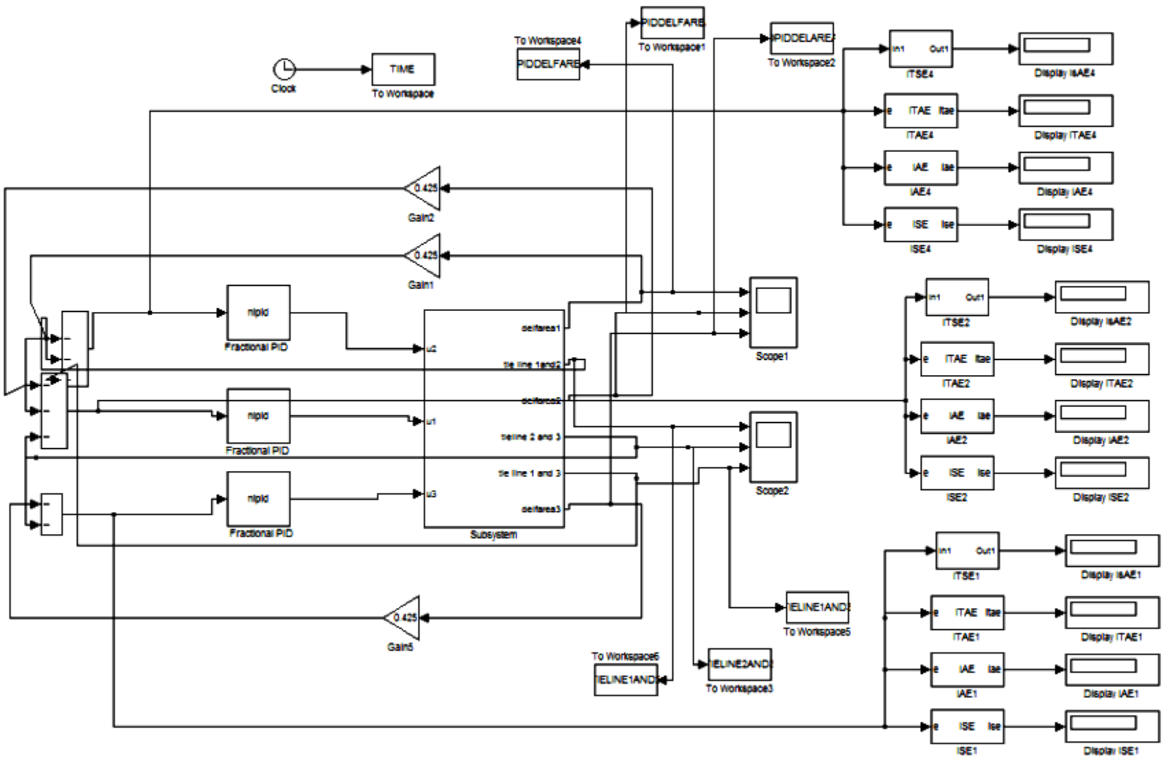

Fig 1 : Schematic diagram of three area interconnected reheat thermal system with GRC.

$$ {}_aD_t^{\alpha} f(t) = \frac{1}{\Gamma n-\alpha} \frac{d^n}{dt^n} \int_a^t t-\tau^{\,n-\alpha-1} f(t) \tag{2}$$

Where n-1≤α<n, n is an integer and $\Gamma(.)$ is the Eulers gamma functon. The general equation of fractional integral equation is given by

$$ {}_aD_t^{\alpha} f(t) = \frac{1}{\Gamma \alpha} \frac{d^n}{dt^n} \int_a^t t-\tau^{\,\alpha-1} f(t) d\tau \tag{3}$$

Applying the laplace transform to the Riemann-Liouville differentional equation, the above equation becomes,

$$ L({}_aD_t^{\alpha} f(t)) = S^{\alpha} F(s) - \sum_{k=0}^{n-1} S^k \, {}_aD_t^{\alpha-k-1} f(t)\Big|_{t=0} \tag{4}$$

Where, L (f(t)), indicates normal Laplace transformation.

The behavior of the systems can be found by assuming zero initial conditions to differential equations and fractional derivatives which give the transfer function of a fractional order of system with a fractional order of s.

In Simulation & Hardware implementations of transfer function of system, it is required to round off them with classical order transfer functions. The perfect fractional order transfer function consists of an infinite number of poles and zeros. Inspite of that, it is possible to get logical approximations with a finite number of zeroes and poles. The fractional derivative or integral is represented by s^{α} can be approximated in proper range $[W_l, W_h]$ as

$$ S^{\alpha} = K \prod_{n-1}^{N} \frac{1 + S/\omega_{z,n}}{1 + S/\omega_{p,n}} \tag{5}$$

Where, K is adjustable gain and
N is the number of poles and zeors .

The transferfunction of the fractional order controller (FOPID) is,

$$ G(s) = K_p + \frac{K_i}{S^{\lambda}} + K_d S^{\mu} \tag{6}$$

The main advantage of FOPID is the extra 2 tuning parameters compared to classical order controllers that achive more flexibility in the control objects.

A. Optimization Method (PSO):

In this paper, particle swarm optimization method is proposed which consists of particles which represents a solution of the problem.

Procedure for PSO:

- First initializes a population of particles with randomness of both possition and velocities.
- Each particles adjust its velocity dynamically corresponding to its flying experience.
- From this, best position of particle is selected and it can be taken as pbest. The performance of best particle among all the particles is taken as the global best. The updated velocity and each particle position can be represented as,

$$ V_i^{(t+1)} = w.V_i^{t} + C1.rand\,1.(pbest_i - p_i^{t}) + C2.rand\,(rand\,2.(gbest_i - p_i^{t}) \tag{7}$$

$$ p_i^{(t+1)} = p_i^{t} + V_i^{(t+1)} \tag{8}$$

In equation.(7) ‘w’ represents the inertia weight parameter, controls both global and local possition of the particle and C_1, C_2 are the accelaration constants. Rand1 and rand2 are the random numbers, different for different iterations. The best position of the swarm is the solution of the problem.

The flow chart for particle swarm optimization is used for tuning the controller parameters in finding the best results. The flowchart diagram of the particle swarm is given in Figure 2.

After PSO optimization, tuning values are obtained given in table 1, which are used in the simulation process given in figure 1. By giving these tuned values to the simulation we get the simulation results from fig3-8

TABLE I
CONTROLLER PARAMETERS

		Kp	Ki	Kd	λ	μ
Area1	PI	0.0021	0.7750	0	0	0
	PID	0.3003	0.6376	0.0024	1	1
	FOPID	0.1270	0.6324	0.8147	0.2785	0.957
Area2	PI	0.0078	0.1040	0	0	0
	PID	0.3865	0.1979	0.1118	1	1
	FOPID	0.7962	0.3453	0.0573	0.5202	0.073
Area3	PI	0.0633	0.4213	0	0	0
	PID	0.3922	0.6538	0.0992	1	1
	FOPID	0.8466	0.1692	0.0774	0.4162	0.406

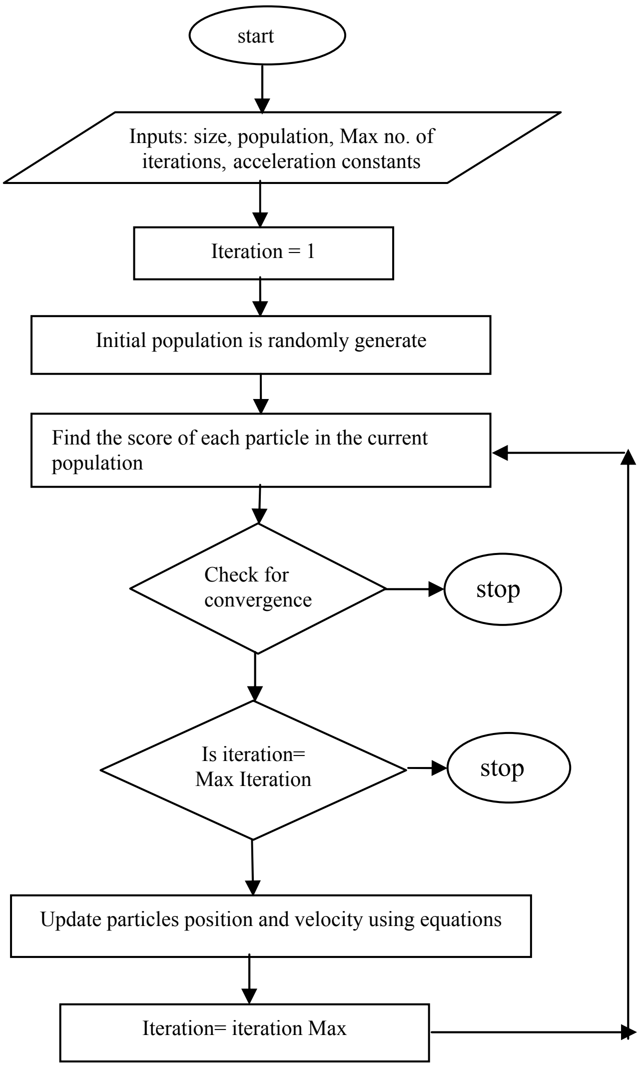

Fig 2: Flow chart for Particle swarm optimization

III. SIMULATIN RESULTS AND ANALYSIS

PSO FOPID method:

Three cases are considered in simulation analysis with a 1% step load perturbation is applied in any one of three areas; with reheat generating system, the change in frequency deviation and change in deviation of tie line power as follows.

Case I:

In the first case, a 1% step load perturbation is applied in the demand of area 1, with reheat generating system, the change in frequency deviation of area 1 and change in deviation of tie line power is as shown in figure 3 and figure 4.

It is observed from the simulation results that the system frequency deviation of PSO FOPID controller compared with the PI and PID controllers is improved by 45.78% and 40% respectively and tie line power deviation of PSO FOPID controller is improved by 40.15% and 21.48% respectively.

Case II:

In the second case, a 1% step load perturbation is applied in the demand of area 2, with reheat generating system, the change in frequency deviation of area 2 and change in deviation of tie line power is as shown in figure 5 and figure 6.

It is observed from the simulation results that the system frequency deviation of PSO FOPID controller compared with the PI and PID controllers is improved by 31.26% and 12.85% respectively and tie line power deviation of PSO FOPID controller is improved by 35% and 43% respectively.

Case III:

In the third case, a 1% step load perturbation is applied in the demand of area 3, with reheat generating system, the change in frequency deviation of area 3 and change in deviation of tie line power is as shown in figure 7 and figure 8.

It is observed from the simulation results that the system frequency deviation of PSO FOPID controller compared with the PI and PID controllers is improved by 30.26% and 12.05% respectively and tie line power deviation of PSO FOPID controller is improved by 34% and 42% respectively.

From these simulation results, the FOPID controller has the enchanced in terms of frequency of oscillations, tie line power deviation compared to the classical controllers, with the values shown from figure 3-8.

TABLE 2
NOMINAL PARAMETERS OF ASYSTEM

Nominal frequency F	50 Hz
Governor time constant	Tg1= Tg2 =Tg3= 0.08 sec
Max tie Line power Ptie Max	200 Mw
Reheat time constant	Tr1 = Tr2 =Tr3= 10 sec .
Reheat system gain	Kr1 = Kr2 =Kr3= 0.5
Turbine constant	Tt1 = Tt2 =Tr3= 0.3 sec
Power system gain	Kp1 = Kp2 =Kp3= 120 Hz/puMw
Power system time constant	Tp1 = Tp2 =Tp3 20sec
a12 =, a23 = a31	0.0707
frequency bias constants	0.425Mw/Hz

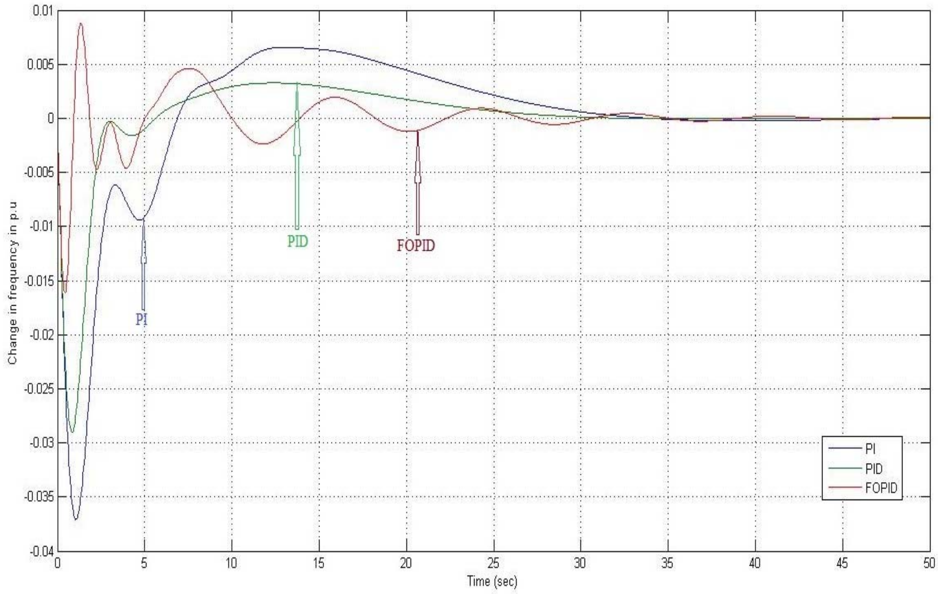

Fig 3: change in frequency deviation of Area 1

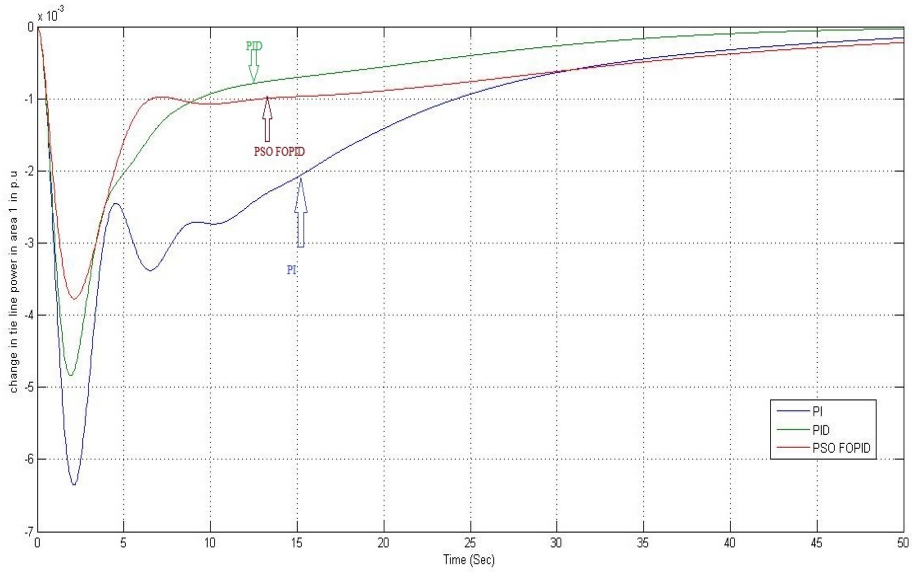

Fig 4: change in Tie line power of Area 1 and 2

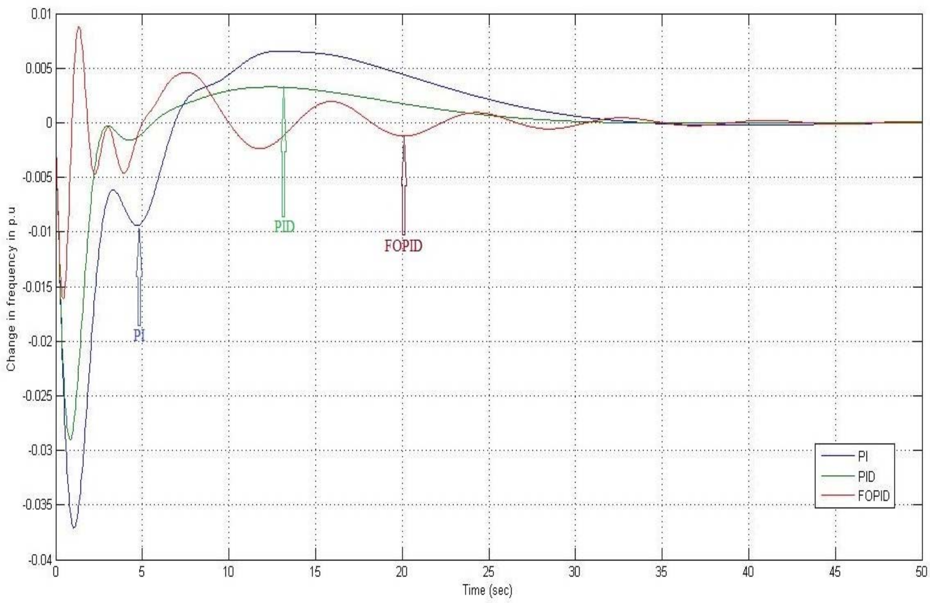

Fig 5: change in frequency deviation of Area 2

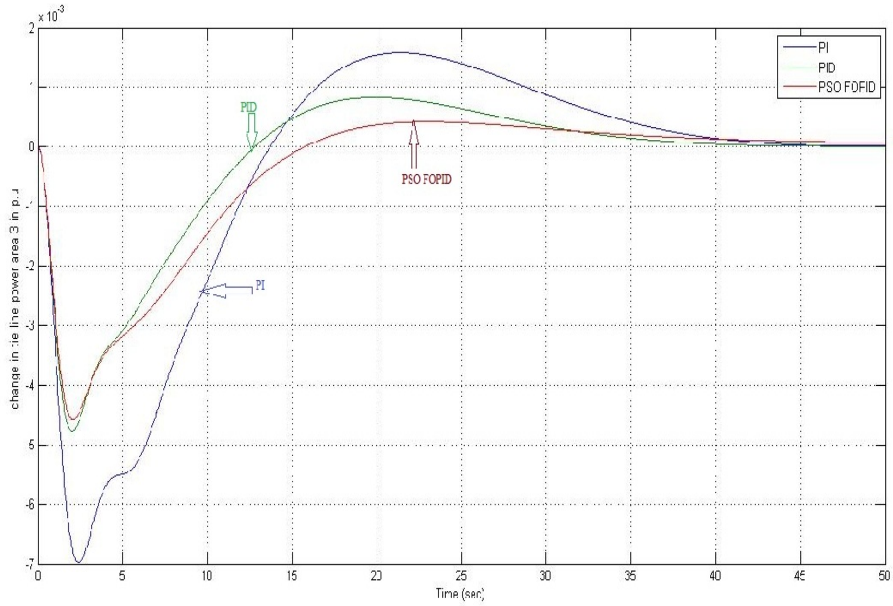

Fig 6: change in tie line power of area 2 and 3

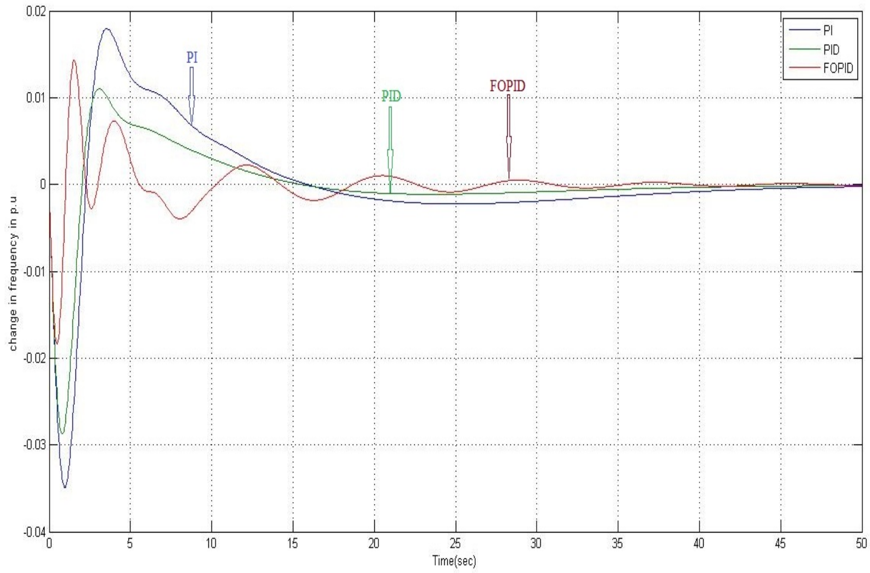

Fig 7: change in frequency deviation of Area 3

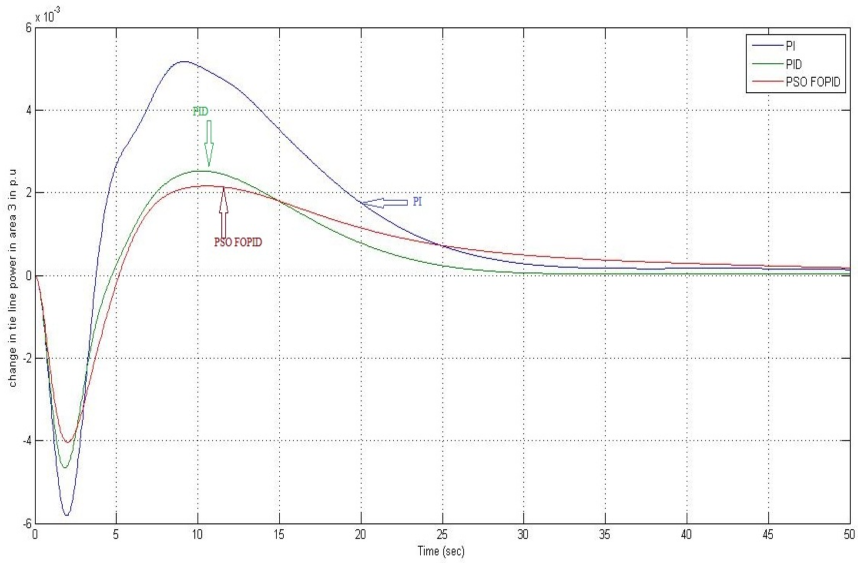

Fig 8: change in tie line power of Area 3 and 1

ISBN: 978-988-14047-1-8
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

IV. THREE AREA SYSTEMS

The investigated system as shown in figure 1, was a three area thermal system with reheat turbine this power system should be modeled as a multivariable system is obtain from the particle swarm optimization. The parameters of the studied systems are given in above table 1.simulaton studies were performed on a three area thermal system with reheat systems for 1% step load perturbation .several different comparative cases were performed to show the effectiveness of fractional order controllers FOPID tuned by particle swarm optimization PSO for load frequency control in the power system. It was compared with the conventional PI and PID controller designed by the same method. By using these fractional order controllers we can control the settling time, maximum change in frequency deviation and change in tie line power of the system As compared with the classical order controllers like PI and PID.

Nomenclature:

H=Inertia constant (sec).

f_i = Nominal system frequency of area i (Hz)

R_i =Regulation of Speed constant of i^{th} unit (Hz/p.u.)

T_{t1} =Area 1 Turbine time constant (sec).

T_{t2} =Area 2 Turbine time constant (sec).

T_{t3} =Area 3 Turbine time constant (sec).

T_{g1} = Governor Time constant of Area 1 (sec).

T_{g2} = Governor Time constant of Area 2 (sec).

T_{g3} = Governor Time constant of Area 3 (sec).

Tp_1 = Area 1 Power system time constants (sec).

Tp_2 = Area 2 Power system time constants (sec).

Tp_3 = Area 3 Power system time constants (sec).

K_{p1} =Area 1 Power systems gains (Hz/p.u).

K_{p2} =Area 2 Power systems gains (Hz/p.u).

K_{p3} =Area 3 Power systems gains (Hz/p.u).

T_i= Synchronizing time constant (p.u MW/Hz).

B_i = Frequency biasing (p.u MW/Hz).

K_{ri} = Gain constant of Reheat system (Hz/p.u).

a_i= Tie line power constant

Δf_i = Change in frequency of i^{th} area (Hz).

ΔP_{tiline} = Change in tie line power of i^{th} area (MW).

ACE = Area control error.

ΔP_l = Change in load perturbation.

ΔP_{gi}= Change in governor valve position.

V. CONCLUSION

This paper investigates the performance of PSO FOPID controller for Automatic generation Control of multi-area interconnected Power system with unequal reheat thermal constants. Gains for all the controllers are optimized using particle swarm optimization technique minimizing the steady state error to zero. Performances of several classical order controllers such as Integral, Proportional plus integral and proportional plus integral and derivative controllers are investigated for three area thermal system and compared with PSO FOPID controller. Simulation Results states that PSO FOPID controller is improved and effective than Integral order controllers in enhancing system dynamic performances with reduced change in frequency and change in tie-line power deviations.

REFERENCES

[1] O.I Elgerd and C.E Fosh ,"Optimum megawatt frequency control of multi area electronic energy system" IEEE Trans. power Apparatus .Syst.,vol.PAS-89,no.4,556-563,Apr.1970

[2] C.Concordia and L.K Kirchmayer," tie line power frequency control of Electronic power system: Part II" AISE Trans, III-A, vol 73, pp.133-146, April 1954

[3] Naresh kumari and A,N Jha "Effect of generation rate constraints on load frequency control of multi Area interconnected thermal systems" JEEER, vol 5(3).pp.44-49 September 2013

[4] C.Concordia and L.K Kirchmayer," tie line power frequency control of electronic power system" AIEE Trans, III-A, vol 72,pp.562-572,june 1953

[5] Khodabakhshian A, hoosmand R.A new PID controller design for Automatic generation control of interconnected power system.int J Electric power Energy system 2010:32: : 375-82.

[6] Igor podlubny," fractional –orde systems and Controller", IEEE Trans, Automatic control, vol 44 no.1, 1999,pp 208-214

[7] Podlubny, I.Petras, B.M, Vinagre, P.O'Leary, L.Doracak, "Analogue Realizations of Fractional Order Controllers", Faculty BERG, TU Kosice, 2002, pp , .84.

[8] Podlubny I (1994) "The Laplace transform method for linear Differential equations of the fractional institute of experimental physics", The Slovak academy of sciences, UEF-02-94, Kosice

[9] C.E Fosha and O.I elgerd "The mega watt-frequency control problem-a new approach via optimal control theory," IEEE Trans. Power apparatus. Syst., vol PAS-89, no.4 (Apr.1970) 563-577

[10] K.M Passino "Biomimicry of bacterial foraging for disturbed optimization and control," control system magazine, IEEE, June 2002, volume 22,issue3,pages(s):52-67

[11] B .Anand, A.E. Jeyakumar, "load frequency control inter connected hydro-hydro system with Fuzzy logic controller,"

[12] N.Jaleeli, LS, vanslyck, DN Ewart, LH Fink, AG Hoffmann "understanding automatic generation control," IEEE Trans power on power system,1992,7(3).PP 1106-1121.

[13] Lalit Chandra saikia, J.Nanda, S.Mishra," Performance comparison of several classical controllers in AGC for multi area interconnected thermal system" International Journal of Electrical Power &energy systems, volume 33,issue 3,March 2011,pages 394-401

ISBN: 978-988-14047-1-8
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)