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Design of PSO based Fractional order Load Frequency controller for two area power system

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Abstract: *This paper presents the development and application of Fractional order PID controller based on particle swarm optimization (PSO) for load frequency control of two-area inter connected power system. The dynamic response of the system has been studied for 1% and 10% step load perturbations in area2. The performance of the proposed FOPID controller is compared against the traditional PID controller based on PSO technique. Comparative analysis demonstrates that proposed FOPID controllers based on PSO reduces the settling time and overshoot effectively against small step load disturbances. Simulations have been performed using MATLAB/Simulink.*
Keywords: *Fractional Order PID Controller (FOPID), Integer Order PID controller (IOPID), Load Frequency Control (LFC), Particle Swarm Optimization (PSO).*

I. Introduction

In an interconnected power system Automatic Generation control or Load frequency control is important in Electrical Power System design and operation. Large scale power system comprises of interconnected subsystems (control areas) forming coherent groups of generators, where as connection between the areas is made using tie-lines [1-2]. Each control area has its own generation and is responsible for its own load and scheduled interchanges with neighbouring areas. The load in a given power system is continuously changing and consequently system frequency deviates from the desired normal values. Therefore to ensure the quality of power supply, a load frequency controller is needed to maintain the system frequency and inter-area flows at the desired nominal values.

The PI and PID controllers are well-known and widely used in power system control applications as they are simple to realize, easily tuned and several rules were developed for tuning their parameters [15]. These controllers are commonly used to dampen system oscillations, increase stability and reduce steady-state error. These controllers are integer order controllers as power of derivative or integral in these controllers is one.

In recent years, researchers reported that controller making use of fractional order derivatives and integrals could achieve performance and robustness, superior to those obtained with conventional controllers. Fractional calculus deals with the concept of differentiation and integration to non-integer order. It is an extension of the concept $d^n y(t)/dt^n$ with n is an integer number to the concept $d^\alpha y(t)/dt^\alpha$ where α is non-integer number with possibility to be complex [15]. The classical IO controllers are particular cases of FOPID controllers. As the FOPID has two more extra tuning knobs than the classical IOPID controller, it gives more flexibility for the design of a control system and gives better opportunity to adjust system dynamics especially if the original system to be controlled is a fractional system. In many cases, fractional calculus can be applied to improve the stability and response of such a system through the use of non-integer order integrals and derivatives in place of the typical first order ones.

The fractional control theory extends traditional integer order to the fractional-order and plural order. Fractional PID controller not only has three parameters K_p, Ki, Kd but also has integral order λ and differential order μ which are two adjustable parameters [8]. The application of fractional control theory yields performance better than IOPID.

In this paper a fractional $PI^\lambda D^\mu$ controller is designed for AGC of a two area power system. The parameters K_p, K_i, K_d, λ, μ were optimized using Particle Swarm Optimization [8]. Simulation results showed that fractional order controller based on PSO had better performance than integer order PID controller based on PSO.

II. Configuration Of Two-Area Power System

1. Plant model description

The two-area inter connected power system is taken as a test system in this study. The model of the system under consideration is as shown in fig1 where symbols have their usual meanings. The conventional AGC has two control loops the primary control loop, which control the frequency by self-regulating feature of the governor, however, frequency error is not fully eliminated and the supplementary control loop which has a controller that can eliminate the frequency error. The main objective of the supplementary control is to restore balance between each control area load and generation after a load perturbation so that the system frequency and tie-line power flows are maintained at their scheduled values. So the control task is to minimize the system frequency deviations in the two areas under the load disturbances ΔP_{d1} or ΔP_{d2} in two areas. This is achieved conventionally with the help of suitable integral control action. The supplementary control of the i[th] area with integral gain K_i is therefore made to act on ACE_i given by equation (1) which is an input signal to the controller [15-17].

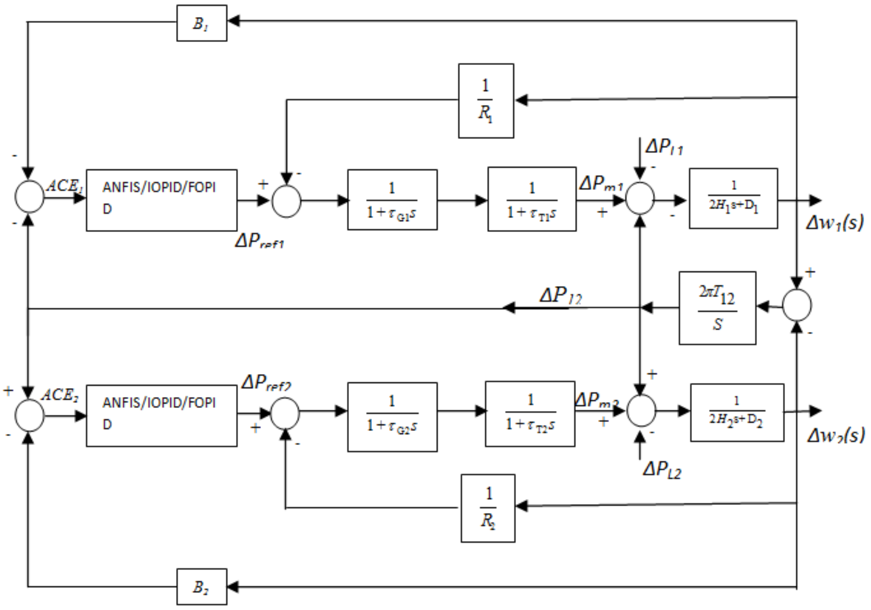

Fig.1 Block diagram of AGC for Two area system with secondary loop

$$ACE_i = \sum_{j=1}^{n} \Delta P_{tie,ij} + B_i \Delta f_i \qquad (1)$$

Where ACE_i is area control error of the i[th] area

Δf_i = Frequency error of i[th] area

$\Delta P_{tie,ij}$ = Tie-line power flow error between i[th] and j[th] area

B_i = frequency bias coefficient of i[th] area

III. Integer Order PID Controller

The PID control is a widely used approach for designing a simple feedback control system where in three constants are used to weigh the effect of the error (the P term), the integral of the error (I term) and the derivative of the error(the D term). A typical structure of classical IOPID controlled system [15] is shown in Fig.2

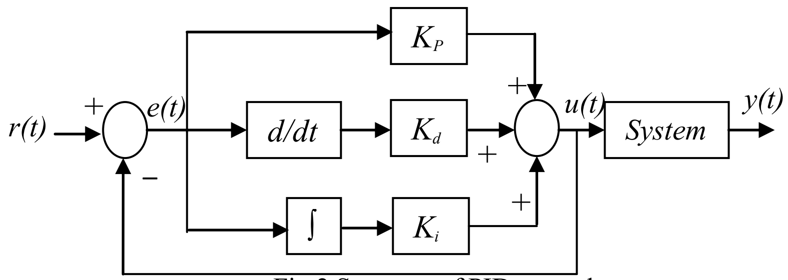

Fig.2 Structure of PID control

To implement a PID controller that meets the design specifications of the system under control, the parameters [K_p, K_i, K_d,] must be determined for the given system. An IOPID controller is designed for frequency control in power system in this paper, whose parameters were optimized using Particle swarm optimization.

IV. Fractional Calculus

Fractional calculus can have different definitions in different perspectives [15]. There are two commonly used definitions for fractional calculus so far, that is Grunwald-Letnikov definition, Reiman-Liouville definition.

$$ {}_aD_t^\alpha f(t) = \lim_{h\to 0} \frac{1}{\Gamma(\alpha)h^\alpha} \sum_{K=0}^{[(t-a)/h]} \frac{\Gamma(\alpha+K)}{\Gamma(K+1)} f(t-Kh) \qquad (2) $$

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

Grunwald-Letnikov definition is perhaps the best known one due to its most suitability for the realization of discrete control algorithms. The m order fractional derivative of continuous function f(t) is given by [10]

$$ D^m f(t) = \underset{h\to 0}{Lt}\, h^{-m} \sum_{j=0}^{[x]} (-1)^j \binom{m}{j} f(t-jh) = \frac{d^m f(t)}{dt^m} \qquad (4) $$

Where [x] is a truncation and $x = \frac{(t-m)}{h}$; $\binom{m}{j}$ is binomial coefficients

$$ \binom{m}{j} = \frac{m(m-1)\ldots(m-j+1)}{j!}, \binom{m}{j} = 1, (j=0), $$

it can be Replaced by Gamma function,

$$ \binom{m}{j} = \frac{\Gamma(m+1)}{j!\Gamma(m-j+1)} . $$

The general calculus operator including fractional order and integer order is defined as [10]

$$ {}_aD_t^\alpha => \begin{cases} d^\alpha / dt & R(\alpha) > 0 \\ 1 & R(\alpha) = 0 \\ \int_a^t (d\tau)^{-\alpha} & R(\alpha) < 0 \end{cases} \qquad (5) $$

Where a and t are the limits related to operation of fractional differentiation, α is the calculus order. The Laplace transform of the fractional derivative of *f(t)* is given by

$$ L\{D^\alpha f(t)\} = s^\alpha F(s) - [D^{\alpha-1} f(t)]_{t=0} \qquad (6) $$

Where *F(S)* is the Laplace transform of *f(t)*. The Laplace transform of the fractional integral of *f(t)* is given as follows.

$$ L\{D^{-\alpha} f(t)\} = s^{-\alpha} F(s) \qquad (7) $$

V. Fractional PID ($PI^\Lambda D^\mu$) Controller

The FOPID (or $PI^\lambda D^\mu$) controller involves an integrator of fractional order λ and a differentiator of order μ, which has the following fractional order transfer function.

$$ G_c(s) = K_p + \frac{K_i}{S^\lambda} + K_d S^\mu \qquad (8) $$

Where λ is the fractional order of the integrator and μ is the fractional order of the differentiator, which both can take any value of complex numbers. The classical controllers are particular cases of the FOPID controller. If λ=μ=1, the classical IOPID controller is obtained. For λ=μ=0, the P controller is obtained, for λ=0, μ=1 the PD controller is obtained. Illustration of different types of integer and fractional order controllers as λ and μ vary as shown [15] in Fig3.

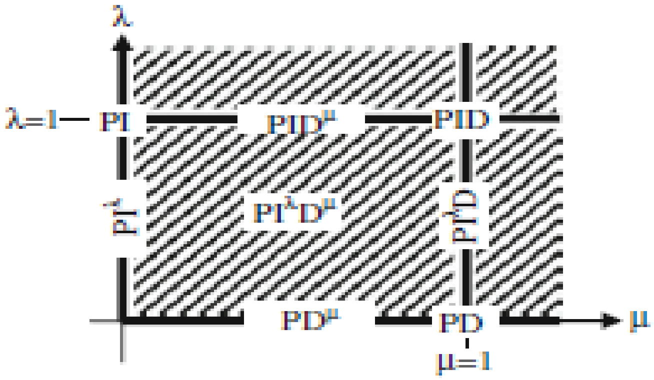

Fig.3 Illustration of IO and FO controllers

As the FOPID has two more extra tuning knobs than the classical integer-order PID controller, the use of fractional controller (λ and μ are non-integers) gives more flexibility for the design of a control system and gives better opportunity to adjust system dynamics if the original system to be controlled is fractional system. In time domain input to the system to be controlled takes the following form.

$$u(t) = K_p e(t) + K_i D^{-\lambda} e(t) + K_d D^{\mu} e(t) \qquad (9)$$

Where λ is the integral order, μ is the differential order *Kp, Ki, Kd* are the parameters of PID controller.

1. Optimization of PI$^{\lambda}$D$^{\mu}$ Controller's parameters

Fractional controller has five parameters and currently there are no practical engineering applications in frequency control of power system. Determine its parameters based on experience like traditional controllers are not possible and so a fast and efficient way to optimize its parameters must be found.

Particle swam optimization (PSO) is a kind of swarm intelligence algorithm, simulating biological predation phenomenon in nature. PSO employs swarm intelligence, which comes from cooperation and competition between particles of a group, to guide the optimization search, with strong convergence, global optimization and computation-efficiency [10, 15].

2. Calculation of fitness function

The design of PI$^{\lambda}$D$^{\mu}$ controller is actually a multi dimensional function optimization problem. The objective of controller parameters optimization is to make the control error tend to zero and there is smaller over shoot and faster response. In order to obtain satisfactory transition of the dynamic characteristic, the paper has used Integral squared error (ISE) performance index for the parameter's minimum objective function. ISE can be expressed as follows [15].

$$ISE = \int_0^t e^2(t)dt \qquad (10)$$

3. Particle swarm optimization

Particle Swarm Optimization is new population based evolutionary computation. The PSO algorithm attempts to mimic the natural process of group communication of individual knowledge, which occurs when such swarms flock, migrate; forage etc in order to achieve some optimum property such as configuration or location.

In PSO the 'swarm' is initialized with a population of random solutions. Each particle in the swarm is a different possible set of the unknown parameters to be optimized. Representing a point in the solution space, each particle adjusts its flying experience and shares social information among particles. The goal is to efficiently search the solution space by swarming the particle towards the best fitting solution encountered in previous iterations with the intent of encountering better solutions through the course of process and eventually converging on a single minimum error solution [10].

In PSO, a swarm consists of N particles moving around in a D-dimensional search space. The random velocity is assigned to each particle. Each particle modifies its flying based on its own and companion's experience at every iteration.

The formulae (11) and (12) are the particles velocity and position update formulae [11].

$$v_{id}^{t} = \omega \times v_{id}^{t-1} + c_1 \times r_1 \times (p_{id}^{t-1} - x_{id}^{t-1}) + c_2 \times r_2 \times (p_{gd}^{t-1} - x_{id}^{t-1}) \qquad (11)$$

$$x_{id}^{t} = x_{id}^{t-1} + v_{id}^{t} \qquad (12)$$

The ith particle is denoted as $X_i = (x_{i1,}x_{i2},\ldots x_{id})$ whose best previous solution P_{best} is represented as $P_i = (p_{i1,}p_{i2},\ldots p_{id})$ current velocity (position change rate) is described by $V_i = (v_{i1,}v_{i2},\ldots v_{id})$ Finally, the best solution achieved so far by the whole swarm is represented as $P_g = (p_{i1,}p_{i2},\ldots p_{gd})$.

At each time step, each particle moves towards P_{best} and g_{best} locations. The fitness function evaluates the performance of particle to determine whether the best fitting solution is achieved. ω is the inertia weight factor, c_1 and c_2 are acceleration constant. r_1 and r_2 are random numbers between zero and one. ω can be adjusted by the following formula (13),

$$\omega = \omega_{max} - \frac{\omega_{max} - \omega_{min}}{T_{max}}.t \qquad (13)$$

ω_{max} and ω_{min} are maximum and minimum values of inertial weight coefficient, T_{max} is the maximum of iterations, t is the current number of iterations.

4. Design of fractional order PID controller using pso

When $PI^{\lambda}D^{\mu}$ controller's parameters are optimized using particle swarm optimization, the five parameters of the fractional controller can be viewed as a particle that is *K= [Kp, Ki, Kd, λ, μ]*. In order to limit the evaluation value of each individual of the population, feasible range must be set for each parameter as follows

$K_{p1max} = K_{p2max} = 1.5$; $K_{p1min} = K_{p2min} = 0$; $K_{i1max} = K_{i2max} = 1.5$; $K_{i1min} = K_{i2min} = 1$;
$K_{d1max} = K_{d2max} = 1.5$; $K_{d1min} = K_{d2min} = 0$; $K_{p1vmax} = K_{p1max}/10$; $K_{i1vmax} = K_{i1max}/10$; $K_{d1vmax} = K_{d1max}/10$;
$K_{p1vmin} = K_{p1min}$; $K_{i1vmin} = K_{i1min}$; $K_{d1vmin} = K_{d1min}$;
$\lambda_{1max} = \lambda_{2max} = 2$; $\lambda_{1min} = \lambda_{2min} = 0$; $\mu_{1max} = \mu_{2max} = 2$; $\mu_{1min} = \mu2_{min} = 0$;
$\lambda_{1vmax} = \lambda_{1max}/10$; $\lambda_{1vmin} = \lambda_{1min}$; $\mu_{1vmax} = \mu_{1max}/10$; $\mu_{1vmin} = \mu_{1min}$;
$K_{p2vmax} = K_{p2max}/10$; $K_{i2vmax} = K_{i2max}/10$; $K_{d2vmax} = K_{d2max}/10$;
$K_{p2vmin} = K_{p2min}$; $K_{i2vmin} = K_{i2min}$; $K_{d2vmin} = K_{d2min}$;

Now the design steps are as follows [11-14]:

1. Randomly initialize the individuals of the population including position and velocities in the feasible range.
2. For each individual of the population, calculate the values of the performance criterion in (10).
3. Compare each individual's evaluation value with its personal best P_{id}. The best evaluation value among all P_{id} is denoted as Pg.
4. Modify the member velocity of each individual according to (11) where the value of ω is set by equation (13).
5. Modify the member position of each individual according to (12).
6. If the number of iterations reaches the maximum, then go to step 7 otherwise go to step2.
7. The latest Pg is the optimal controller's parameters.

In this study optimal parameters of fractional controller for 1% and 10% step load perturbations are

K_{p1}=0.2819, K_{i1}=1.5, K_{d1}=1.2618, λ_1=1.1869, μ_1=0.5524.
K_{p2}=1.3213, K_{i2}=1.5, K_{d2}=1.1813, λ_2=0.8336, μ_2=1.0770.

VI. Results and Discussions

In the present work Automatic Generation Control of two area interconnected power system has been developed using PSO based IOPID Control, PSO based FOPID controller using Matlab/Simulink package. Figs 4 to 7 respectively represent the plots of change in system frequency for 1% and 10% step load variations in area1. The results obtained are also given in Tables 1and 2.

Case I: For 1% Step load Perturbation

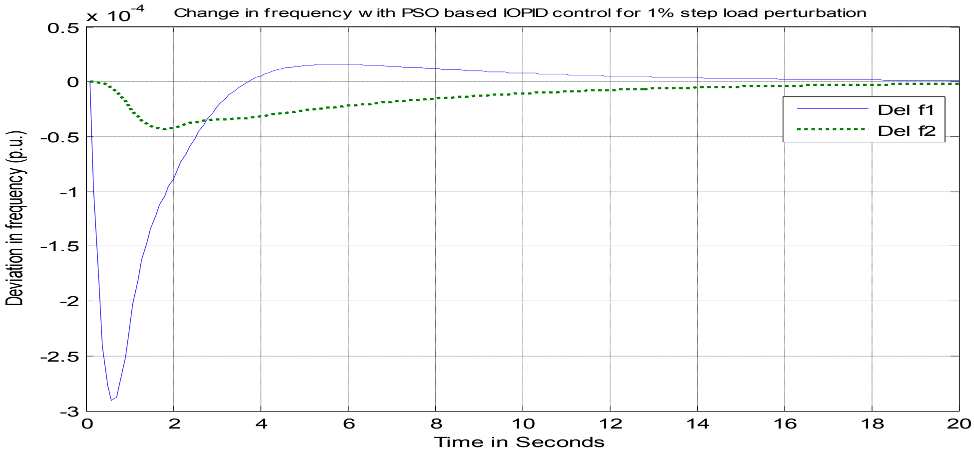

Fig4. Frequency deviations $\Delta f_1, \Delta f_2$ with **PSO** based IOPID control

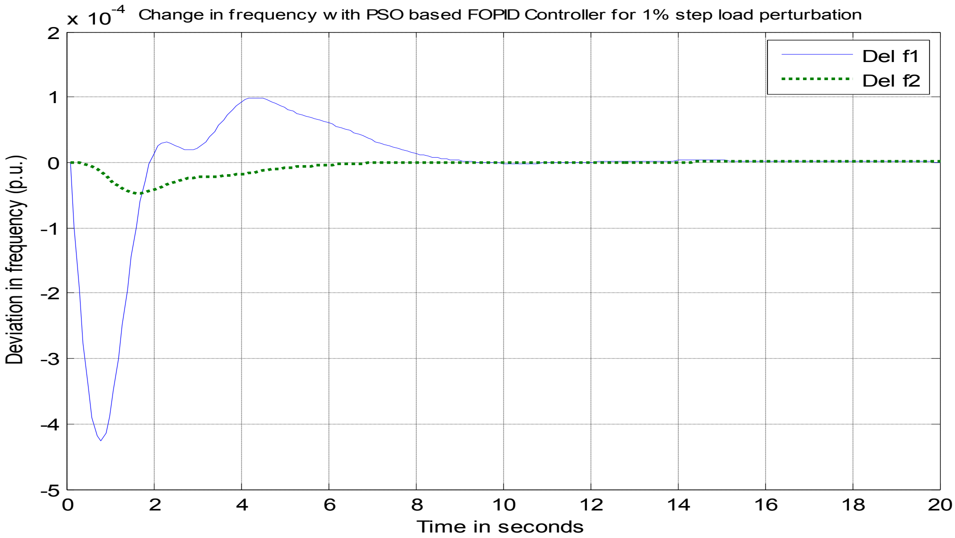

Fig5. Frequency deviations $\Delta f_1, \Delta f_2$ with **PSO** based FOPID controller

Case II: For 10% Step load Perturbation

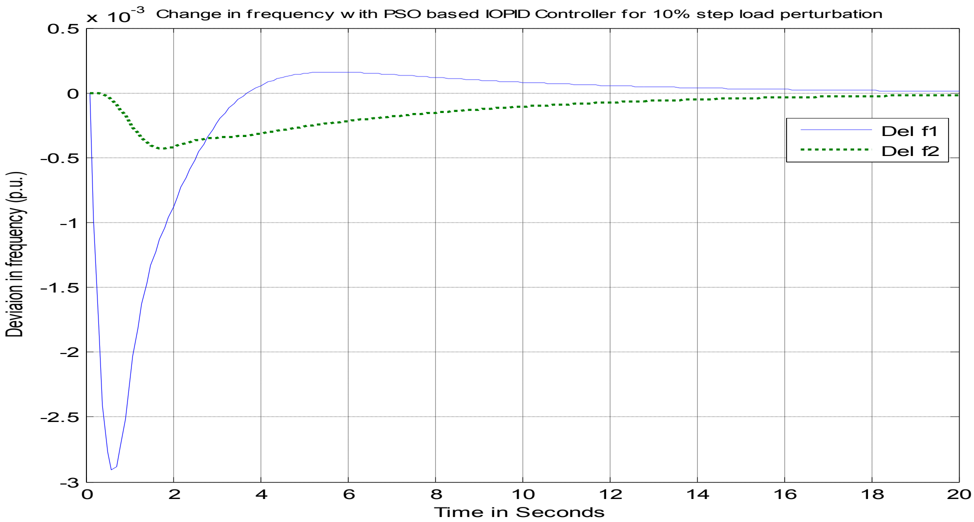

Fig6. Frequency deviations $\Delta f_1, \Delta f_2$ with **PSO** based IOPID Control

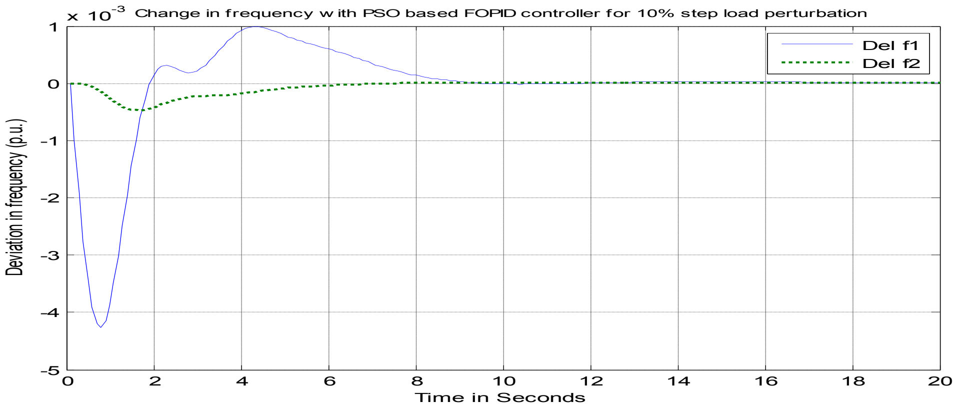

Fig7. Frequency deviations Δf_1, Δf_2 with **PSO** based FOPID controller

VII. Conclusion

This paper presents a fractional $PI^{\lambda}D^{\mu}$ frequency controller for a two area interconnected system, whose parameters are optimized using PSO algorithm.The paper presents the comparative analysis of PSO based IO controller, PSO based FO controllers of interconnected systems. The paper has shown that a FOPID, which has two more extra tuning knobs than the classical IOPID controller, gives more flexibility for the design of a control system and gives better opportunity to adjust system dynamics. Simulation results shows that the proposed Fractional controller has better dynamic performance than the Integer order controller with faster response and smaller overshoot.

Table 1: Comparative study of Settling time and Peak overshoots for 1% step load variation.

Controllers	Settling time in (Sec)		Peak overshoot (p.u.) X 10^{-4}	
	Δf Area 1	Δf Area 2	Δf Area 1	Δf Area 2
IOPID Control (PSO based)	20	20	-3	-0.5
FOPID Control (PSO based)	9	9	-4	-0.4

Table 2: Comparative study of Settling time and Peak overshoots for 10% step load variation.

Controllers	Settling time in (Sec)		Peak overshoot (p.u.) X 10^{-3}	
	Δf Area 1	Δf Area 2	Δf Area 1	Δf Area 2
IOPID Control (PSO based)	16	16	-3	-0.5
FOPID Control (PSO based)	9	9	-4	-0.4

References

[1]. O.I.Elgerd, Electric Energy Systems Theory: An Introduction. Newyork (McGraw- Hill, 1982).
[2]. Kundur. P, Power system stability and control (McGraw-Hill, Inc., 1994).
[3]. Ibraheem, I.; Kumar, P.; Kothari, D.P., "Recent philosophies of automatic generation control strategies in power systems," Power Systems, IEEE Transactions on , vol.20, no.1, pp.346,357, Feb. 2005
[4]. Talaq, J.; Al-Basri, F., "Adaptive fuzzy gain scheduling for load frequency control," Power Systems, IEEE Transactionson , vol.14, no.1, pp.145,150, Feb 1999
[5]. Y.L. Karnavas and D.P.Papadopoulos,"AGC for autonomous Power System using combined intelligent techniques," Elect. Power Syst.Res. vol.62, no.3,pp. 225-239, Jul.2002
[6]. Sathans and A.Swarup "Intelligent Automatic Generation Control of Two area Interconnected Power System using Hybrid Neuro Fuzzy Controller" World academy of Science, Engineering and Technology 60 2011.
[7]. Gayadhara Panda, Siddhartha Panda and C.Ardil, "Hybrid Neuro Fuzzy Approach for Automatic Generation Control of Two –Area Interconnected Power System" international Journal of Computational Intelligence 5:1 2009.
[8]. Jifeng Wang. Control Performance analysis for Fractional order systems. Bei Jing: Publishing House of Electronics Industry, 2010.
[9]. Jiliu Zhou, Yifei Pu, Ke Liao. The Theory of Fractional calculus and its application in modern signal analysis andprocessing. Bei Jing: Science Press, 2010.

[10]. Jun-Yi Cao and Bing-Gang Cao. Design of Fractional Order Controller Based on Particle Swarm Optimization. IJCAS,vol.4, no.6, pp.775-781, Dec 2006.
[11]. Xiuye Wei, Hongxia Pan. Particle Swarm Optimization and Intelligent Fault Diagnosis. Bei Jing: National Defence Industry Press, 2010.
[12]. Ling Wang, Bo Liu. Particle Swarm Optimization and Scheduling Algorithm. Bei Jing: Tsinghua University Press, 2008.
[13]. Yishu Zhao, Zhijian Hu, Yang Gao, etc. Study of Fractional Order PID Conrollers for STATCOM, Southern Power System Technology, 2009, 3(4): 26-30.
[14]. Shuncai Yao, Hongxia Pan. Fractional order PID Controller for Synchronous Machine Excitation using Particle Swarm Optimizaion. Proceedings of the CSEE, 2010, 30(21): 91-97.
[15]. Muwaffaq Irsheid Alomoush. Load frequency control and automatic generation control using Fractional order controllers. Electr Eng (2010) 91:357-368.

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