Fractional Order PID Controller Design for Two Area Load Frequency Control Using Genetic Algorithm

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Abstract: In this paper, a Fractional Order PID controller has been designed for Load frequency control in case of Two area system using Genetic Algorithm, based on minimization of time base integral performance indices. PID controllers have been modified using the notion of a fractional-order integrator and differentiator. It has been shown that two extra degrees of freedom from the use of a fractional-order integrator and differentiator make it possible to further improve the performance of traditional PID controllers. The results has been compared with a GA tuned PID controller. Simulation results show that the Fractional order PID controller is able to outperform the integer order PID controller.

Keywords: Fractional calculus,Fractional order PID controller, Load frequency control, Genetic Algorithm

I. INTRODUCTION

The control of Load frequency is essential to have safe operation of the power system.The quality of power generating system is defined by three factors:constancy of frequency,constancy of voltage and level reliability.The output power of generating unit is controlled such that the transient deviations of the frequency of each area and the interchanged power between areas remain within the specified limits and their steady state error equals zero[1]. Hence there is a need of a controller which can overcome this problem.Many control strategies have been implemented in the literature using several tuning techniques.

Among the various types of Load frequency controllers,the most widely used is the conventional PI controller.The traditional PI and PID controllers are widely used to minimize the steady state error of the system frequency.Traditional tuning methods may not be sufficient to tackle the nonlinear nature and variable operating points of modern power system.

Recent advancements in Fractional calculus has introduced application of Fractional order calculus in control theory.Fractional order PID controller is an advancement of classical integer order PID controller.FOPID controllers are used by many researchers in designing aerospace control systems,for stabilizing fractional order time delay systems.

In this paper,a Fractional order PID controller has been proposed for Single and Two area power system using Genetic Algorithm, minimizing the performance indices.

II. FRACTIONAL CALCULUS AND FRACTIONAL ORDER PID CONTROLLER

A.Fractional Order Calculus

Fractional order calculus is an area which deals with derivatives and integrals from non-integer orders. There are different definitions of Fractional Order differentiations and integrations. Some of the definitions extend directly from integer-order calculus. The well established definitions include the Grünwald-Letnikov definition, the Cauchy integral formula, the Caputo definition and the Riemann-Liouville definition.The definitions are summarized.

Definition 1 (*Cauchy's Fractional Order integration formula*). This definition is a general extension of the integer-order Cauchy formula

$$D^{\gamma} f(t) = \frac{\Gamma(\gamma+1)}{2\Pi j}\int_{c} \frac{f(\tau)}{(\tau - t)^{\gamma+1}} d\tau \qquad (1)$$

where C is the smooth curve encircling the single-valued function f(t)

Definition .2 (*Grünwald–Letnikov definition*). The definition is defined as [2]

$${}_{\alpha}D^{\alpha}{}_{t} f(t) = \lim_{h\to 0}\frac{1}{h^{\alpha}}\sum \frac{t-\alpha}{h}[-1]^{j}\left|\binom{\alpha}{j}\right| f(t-jh) \qquad (2)$$

Where $\omega_j^{\alpha} = [-1]^{j}\left|\binom{\alpha}{j}\right|$ refer to " (2)," represents the coefficients of the polynomial $(1-z)^{\alpha}$

Definition.3(*Riemann–Liouvill definition)*. The Fractional Order integration defined as [3]

$${}_{\alpha}D^{-\alpha}{}_{t} f(t) = \frac{1}{\Gamma(\alpha)}\int (t-\tau)^{\alpha-1} f(\tau)d\tau \qquad (3)$$

Where 0< α <1 and α is the initial time instance refer to "(3),", often assumed to be zero,i.e,a=0.

To implement the fractional order transfer function in simulation,one way is to approximate them with integer order one,the integer order transfer function has to include an infinite number of zeroes and poles.[3]

B.Fractional Order PID controller

Fractional order PID controller is based on integration and differentiation of non-integer order.A fractional order differential equation is used to describe the fractional order

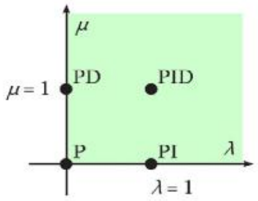

Fig 1.General form of Fractional order PID controller

controller.In PID controllers,three parameters K_p,K_i and K_d should be tuned to design the controller.One of the possibility to improve PID controller is to use fractional-order controllers.The differential equation of fractional order controller is described as [4]

$$u(t) = K_p e(t) + K_i D_t^{-\lambda} e(t) + K_d D_t^{\mu} e(t) \quad (4)$$

Where e(t) is the error between measured process output variable and a desired set point and u(t) is the control output.The general block diagram of Fractional PID is shown in Fig.1.

The continous transfer function of Fractional order PID controller is given by

$$G(s) = \frac{U(s)}{E(s)} = K_p + \frac{K_i}{s^{\lambda}} + K_d s^{\mu} \quad (5)$$

Thus compared to PID controller,a Fractional PID controller needs to tune five parameters K_p,K_i ,K_d, λ and μ .

III. GENETIC ALGORITHM

Genetic Algorithm is a global search technique based on the operations of natural genetics and a Darwinian survival of the fittest with a randomly structured information exchange. Genetic Algorithm search techniques are rooted in mechanisms of natural selection, a biological process in which stronger individuals are likely to be winners in a competing environment. GA related search has received increasing interest owing to its advantages over conventional PID optimization techniques. It uses directed algorithms based on the mechanics of biological evolution such as inheritance, natural selection and recombination or crossover.

In recent years, there has been extensive research on heuristic search techniques like GA, Simulated Annealing, Particle Swarm Optimization and Ant Colony Optimization, etc., for optimization of the PID gains.Given an optimization problem, GA encodes the parameters concerned into a finite bit binary string called a chromosome. A chromosome population is subsequently formed, each representing a possible solution to the optimization problem. Each chromosome is then evaluated according to its fitness function.

A. Genetic Algorithm Operators

Three basic operators of GA are

- Reproduction
- Crossover
- Mutation.

The reproduction task randomly selects a new generation of chromosomes. The crossover involves exchanging parts of two chromosomes. With the crossover operation, more chromosomes are generated and genetic search space is extended and completely filled. Mutation is the random alteration of the bits in the string. For the binary representation, mutation task simply flips the state of a bit from 1 to 0 or, vice versa. The mutation operation is usually associated with helping to re-inject any information that may be vital to the performance of a search process.GA, capable of searching for a population of chromosomes rather than a single chromosome, can arrive at the global optimal point rapidly and simultaneously avoid locking at local optima. In addition, GA deals with coding of parameters and not just the parameter itself, thereby freeing itself from the limitations of conventional PID technique.The parameters of Genetic algorithm opted to tune the fractional PID controller is given in Table.I

B. *Tuning Fractional Order PID Controller Using Genetic Algorithm*

The Flowchart for tuning a Fractional order PID controller is shown in Fig.2.Steps to tune gain values for the Fractional order PID controller

- Randomly choose the genetic pool of parameters K
- Compute the fitness of all population.
- Choose the best subset of the population of the parameters
- Generate new strings using the subset chosen in step 3 as parents and the “single point crossover” and “uniform mutation” as operators.
- Verify the fitness of the new population members

- Repeat steps until the fixed amount of fitness is attained.

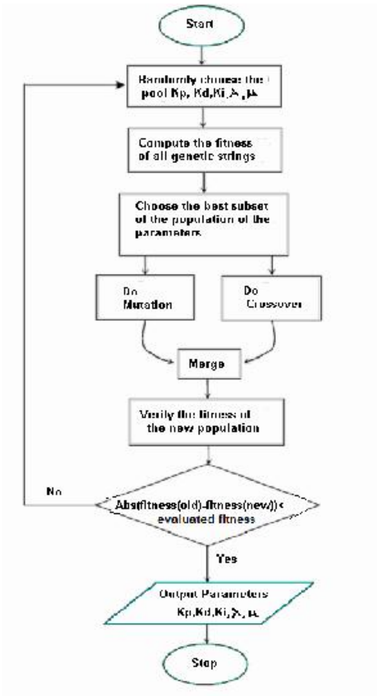

Fig.2 Flowchart to tune Fractional Order PID controller using Genetic Algorithm

C. Fitness Function

The Plant model for single area and Two area Load frequency control is shown in Fig.3The fitness function to be minimized is IAE and ISE performance criterion.The integral absolute error(IAE) and Integral square error (ISE) is defined as

$$IAE = \int_0^t |ACE| dt$$

$$ISE = \int_0^t (ACE)^2 dt$$

Where ACE is the Area Control Error for the Plant model considered.

Table.I Genetic Algorithm Parameters Opted For The Tuning of Fractional PID Controller

PARAMETER	VALUE
Number of variables	5
Total number of generation	20
Population size	100
Cross over	Scattered

IV. SIMULATION AND RESULTS

The Simulink model of Load frequency control for Two area system is shown in Fig.3.The parameters considered for the system considered is given in the Appendix

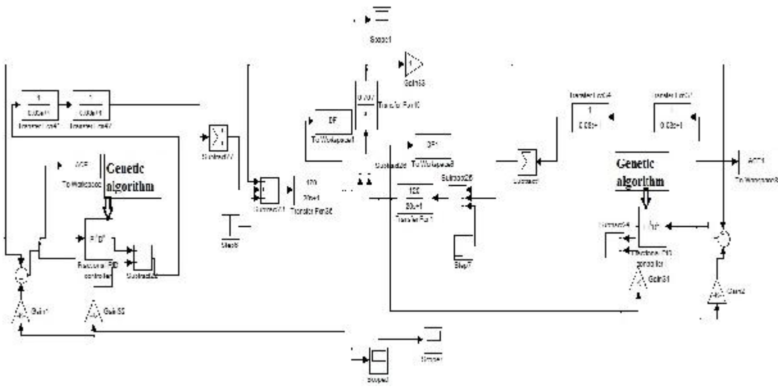

Fig.3 Simulink model for Two area load frequency control in using Genetic algorithm tuned Fractional order PID controller

The simulation results for the model considered is analysed without a controller,with a PID controller and with Fractional PID controller.

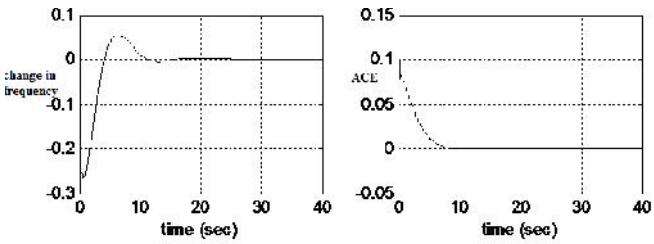

Fig 4 .Simulation results for frequency response and Area control Error(Area-1) forTwo area LFC without controller

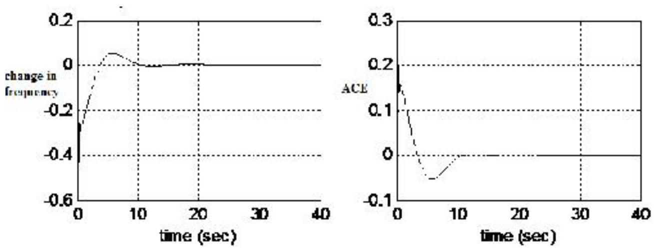

Fig 5 .Simulation results for frequency response and Area control Error(Area-2) forTwo area LFC without controller

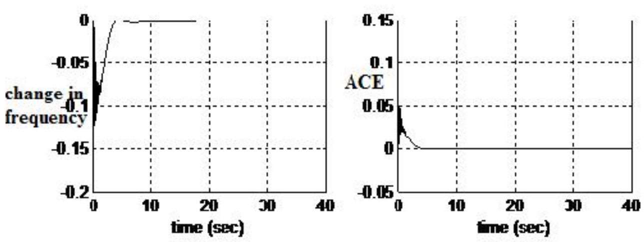

Fig 6 .Simulation results for frequency response and Area control Error(Area-1) forTwo area LFC with Fractional order PID controller

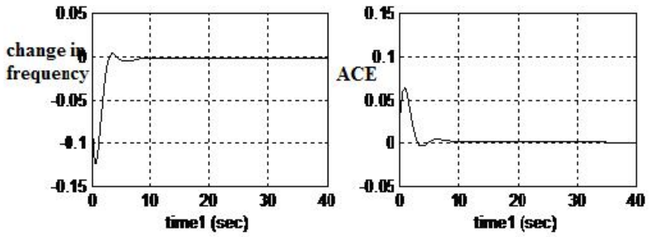

Fig 7 .Simulation results for frequency response and Area control Error(Area-2) forTwo area LFC with Fractional order PID controller

Based on minimization of Performance indices the results obtained are shown

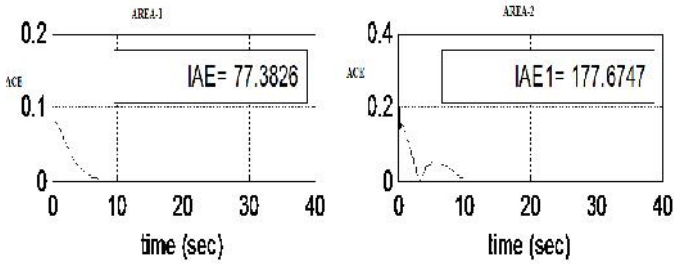

Fig 9 Simulation results for Area control error(Area-1&2) based on mimimization of IAE in Two area load frequency control without controller

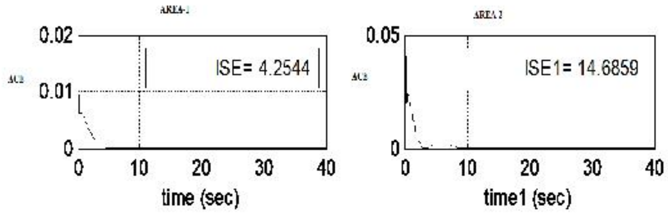

Fig 10 Simulation results for Area control error(Area-1&2) based on mimimization of ISE in Two area load frequency control without controller

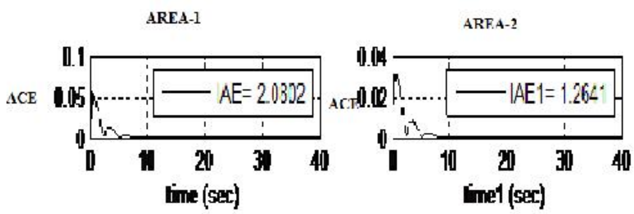

Fig 11 Simulation results for Area control error(Area-1&2) based on mimimization of IAE in Two area load frequency control withGA tuned Fractional order PID controller

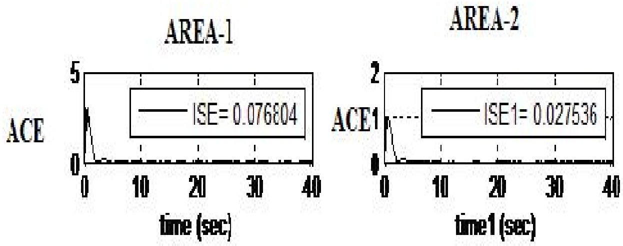

Fig 12 Simulation results for Area control error(Area-1&2) based on mimimization of ISE in Two area load frequency control with GA tuned Fractional order PID controller

Based on the simulation results,the overall performance of the system without and with PID AND Fractional order PID controller is been tabulated and shown in Table.II.

Table.II Comparision based on results of two area Load frequency control

	AREA-1				AREA-2			
Controller	Settling time (sec)		Area control error		Settling time (sec)		Area control error	
	ΔF	ACE	IAE	ISE	ΔF	ACE	IAE	ISE
Without controller	15	9	77	4.2	11	10	177.6	14.68
PID	7	4	16.28	0.416	9	9	50.3	1.754
FOPID	7	4	2.08	0.076	9	8	1.264	0.027

Based on the comparision,a slight change is observed in frequency error,and area control error in the response obtained comparing PID and Fractional order PID controller,but the response is increased using Fractional PID compared to PID controller based on minimization of performance indices,IAE and ISE.

V.CONCLUSIONS

In this paper,a Fractional order PID controller for Two area load frequency control whose parameters are tuned using Genetic algorithm is presented.Simulation results show that using Fractional PID controller,the overall response of the system is improved by decreasing the transient oscillation and responses to the disturbance is observed to be smoother and less oscillatory.It shows better and smoother response compared to a PID controller.It has been observed that a Fractional PID can overcome an integer order PID controller.This application can be extended for the case of multi area load frequency control.

APPENDIX

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The simulink model is shown in Fig.3.In this paper,Two similar areas are considered.The parameters considered for the system is as given below.

AREA- 1

Power system gain constant, K_{ps} =120

Power system time constatnt, τ_{ps} =20sec

Speed regulation,R=2.4

Normal frequency,f=50Hz

Governor time constant, τ_{sg} =0.03sec

Turbine time constant, τ_t =0.08sec

Bias parameter B_1 =0.416

$2\pi T_{12}$ =0.707

Step load change in AREA-1=0.5

AREA -2

Power system gain constant, K_{ps} =120

Power system time constatnt, τ_{ps} =20sec

Speed regulation,R=2.4

Normal frequency,f=50Hz

Governor time constant, τ_{sg} =0.03sec

Turbine time constant, τ_t =0.08sec

Bias parameter B_2=0.416

$2\pi T_{12}$ =0.707

Step load change in AREA-2=0.4

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