Robust FOPID Controller Load performance Control Using PSO

M .Saranya[1], A.Rajendran M.E., (Ph.D)[2]

[1]*PG Student, M.E(EST), Amrita College of Engineering and Technology, Nagercoil, Tamilnadu, India*
[2]*Assistant Professor, Department of ECE, Amrita College of Engineering and Technology, Tamilnadu, India*

ABSTRACT

Fractional order Proportional – integral – derivative (FOPID) controller is designed for load frequency control (LFC) of power system. The performance of FOPID controller is compared with proportional – integral – derivative (PID) and proportional – integral (PI) controllers. The comparison is made based on various time domain performance indices such as Integral of absolute error (IAE), Integral of square error (ISE), Integral of time absolute error (ITAE), Integral of time square error (ITSE) and integral of square time square error. When load frequency control of power system is to design for open communication network, delay occur in area control error (ACE) signal. Delay issues in damping frequency oscillation w.r.t. change in load variation are also discussed. Particle Swarm Optimization (PSO) technique is being used to tune the parameters of the controllers. It is shown that FOPID controller has better dynamic performance than other controllers.

Keywords- **LFC;** *FOPID; PSO; deviation in frequency; error criterions.*

I. INTRODUCTION

A frequency oscillation when load is suddenly changed is an important issue in power system [1]. Convention PI [2-5]and PID controller [6-14] have been used to damp out such oscillation in the literature in single area and multi area. Many artificial intelligence (AI) based controllers have also been investigated by the various researchers like decentralized controllers such as sliding mode control[15-18], artificial neural network (ANN) controller [19], fuzzy logic (FL) controller [20-22], and neuro-fuzzy controller [23]. Many optimization techniques have also been applied to tune the parameters of the various controllers such as Differential Evolution (DE) [6, 24], Genetic Algorithm [7], and craziness based particle swarm optimization [12]. However, all of these controllers are integer controllers, but many of the physical systems are realized by fractional order differential equations. So, designing the fractional order controllers for these kinds of systems ensure better performance than integer controllers [25, 26]. Therefore, the main focus of the paper is designing the FOPID controller for load frequency control.

In this paper, five tuning parameters (K_p , K_i , K_d , λ , μ) have been tuned to design FOPID controller. PSO is used for optimization [27, 28] and various objective functions (IAE, ISE, ITAE, ITSE and ISTSE) have been employed for the purpose. To show the effectiveness of FOPID controller the results are compared with PID and PI controller. The effect of delay when power system works in open communication network has also been discussed. The various delay issues discussed in this paper are gain crossover frequency, phase margin, gain margin and robustness. Presentation of this paper is as follows: Section II explains the problem formulation of load frequency control. Section III describes fractional order system and controllers. Section IV describes PSO technique. Section V is devoted to tuning of various controllers for LFC and their comparison. The effect of delay is also discussed in this section. Section VI concludes the paper.

II. LOAD FREQUENCY CONTROL PROBLEM

In a power system, the frequency should remain nearly constant for satisfactory operation. Relatively close control of frequency ensures constancy of speed of induction and synchronous motor which is required for satisfactory performance of generating units. Frequency deviation cause high magnetizing currents in induction motors and transformers. Also, change in frequencyreflects change in active power demand. As there are many generators supplying power into the system, some means must be provided to allocate change in demand to the generators. A speed governor on each generating unit provides the speed control function [1]. The control of generation and frequency is referred as load frequency control (LFC). LFC model is shown in Fig. 1 in detail.

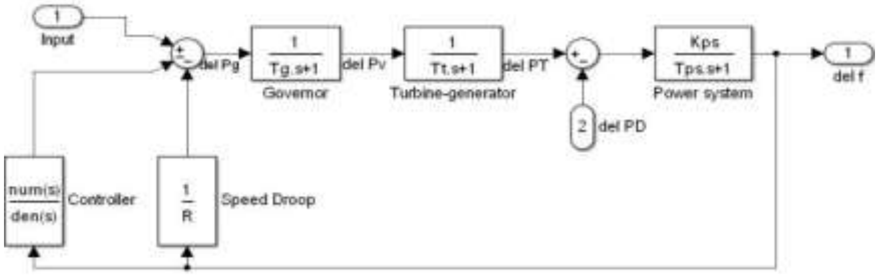

Fig. 1 Load Frequency Control Model Symbols

Table 1 Symbols used in LFC model

f	Frequency deviation
P_D	Change in load demand
P_g	Electromechanical air gap power
P_v	Governor valve position
P_T	Mechanical power output of turbine-generator
$T_q = 0.4$	Governor time constant (in sec)
$T_t = 0.5$	Turbine time constant (in sec)
$K_{PS} = 100$	Power system gain
$T_{PS} = 20$	Power system time constant (in sec)
$R = 3$	Governor speed droop

III. FRACTIONAL ORDER SYSTEMS

Many real-world physical systems need fractional calculus as they are modeled by fractional-order differential equations, i.e., equations involving non-integer order integrals and derivatives.

A. Fractional Calculus

Fractional calculus may be explained as the extension of the concept of a derivative operator from integer order '*n*' to arbitrary order '*z*' where *z* may be a real value or a complex value or may be a complex valued function:

$$z = z(x,t)$$

For initial conditions to be zero, the Laplace Transform of D is given by $L[{}_0 D_x^z] = s^z F(s)$ i.e., for zero initial conditions, the system whose dynamic behavior described by differential equations having fractional derivatives results in transfer functions with fractional orders of *s*. To simulate fractional order of *s* in MATLAB, this is to be approximated by usual integer order transfer function having an infinite number of poles and zeroes. It is also possible to logically approximate it with a finite number of poles and zeros.

B. Designed ControllersPI controller has only two terms to control and is the simplest one.
Tuning parameters for PI controller are: $p = [K_p , K_i]$
PID control with its three term functionality offers the simplest solution to many real world control problems. A PID controller with four tuning parameters is usually selected:

The differential equation of a fractional order PI D controller can be described as:

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

its transfer function can be given as:

$) = K_p + K_i s^{-\lambda} + K_d s^{\mu}$

FOPID controller involves selection of five parameters: three parameters $[K_p , K_i , K_d]$ (same as PID) and two fractional parameters λ , μ . More flexibility is added in accomplishing control objective by this expansion.

So, there are five parameters to tune now: $p = [K_p , K_i , K_d ,\lambda, \mu]$

IV. PARTICLE SWARM OPTIMIZATION

The evolutionary optimization technique based on the movement and intelligence of swarm that move around in a search space looking for the best solution. Each particle is treated as a point in N-dimensional space which adjusts its flight according to its own flying experience as well as the flying experience of the other particles. Each particle tries to improve its position using its current position, its current velocity, the distance between its current position and its best position '*pbest*' and the distance between its current position and global best position '*gbest*'[28].

Proposed algorithm is summarized as follows:

(i) Randomly initialize the particles of the population including searching points and velocities for each parameter of the controller.
(ii) For each initial particle 'i' of the population, calculate the values of the fitness function in (10) to (14). Compare each particle's calculated value with its personal best K_i. The best calculated value among the K_i is denoted as K_g.
(iii) Modify the member velocity of each particle 'i' by adjusting value of inertia weights.
(iv) Modify the member position of each particle 'i' w.r.t. its best position and global best position.
(v) If the number of iterations reaches the maximum, then go to step (vii), otherwise go to step (ii).
(vii) The latest Kg is the optimal controller parameter.

V. SIMULATION AND DISCUSSION

The parameters of FOPID, PID and PI controllers have been designed using PSO techniques with the objective functions given by equations (10-14). The simulation has been done using MatLabR2007a. The parameters of the LFC model are given in Table 1.Initialization parameters used for PSO are: population size = 25, maximum number of iterations = 2500, minimum and maximum velocities are 0 and 2, cognitive and social acceleration coefficient 'C_1' = 2.1, 'C_2' = 1.3, minimum and maximum inertia weight = 0.6 and 0.9.Various comparative figures are given in Fig. 2-6 and their comparative values are given in Tables 2-6. Figures and tables show that settling time, overshoot, undershoot and phase margin are less and gain margin, gain and phase crossover frequencies are more in case of FOPID controller than PID controller except ITAE where settling time is less in case of PID. Settling time and overshoot are very much high in case of PI controller. Therefore, FOPID controller is best out of these three controllers. Deviation in frequency with IAEas objective function.

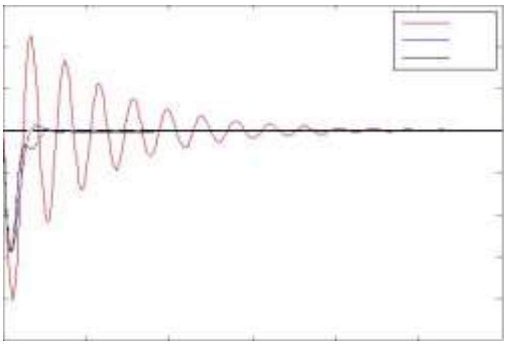

Fig.2 Comparison of PI, PID and FOPID based on IAE

Table2 Comparative values of parameters using IAE

Parameters		**D**	**PID**
Settling Time (sec)	38.4	4.97	4.88
Overshoot	0.0449	0.00213	---
Undershoot	-0.0807	-0.0577	-0.0576
Gain Margin	0.0385	0.2188	0.2575
Phase Margin	75.8010	76.0044	70.0350
Gain Crossover Freuency	1.4859	1.2204	1.5287
Phase Crossover Freuency	0.1981	0.2016	0.2138
K_p	0.08	0.08	0.0799
K_i	0.19	0.2011	0.3000
K_d	---	0.1825	0.1732
τ_d	---	0.005	---
λ	---	---	0.9545
μ	---	---	0.7010
F(Fitness function)	4.8010	1.0576	1.2681

Fig. 7 and table 7 discuss the effect of communication delay in LFC. As the delay increases, the performance of the system degrades. Settling time and overshoot increases. Gain margin and crossover frequency also decreases. As a result of all issues, significant dead time is a significant source of instability for closed loop response.

VI.CONCLUSION

In this paper, a comparison of PI, PID and FOPID controllers for LFC has been investigated. The comparison involves time domain performance criterion. In order to examine the effect of cost function, different error criterions (IAE, ISE, ITAE, ITSE and ISTSE) are examined. The performance of PI, PID and FOPID is compared using PSO and it is observer that in each case, FOPID controller has better performance characteristics than PID and PI controllers. The effect of time delay is also studied and it is observed that as time delay increases ultimate gain and crossover frequencies decreases.

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