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Design of Tuning Methods for Fractional order $PI^{\lambda}D^{\mu}$ Controller using PSO Algorithm

M.Suresh Kumar[1], Smt.K.Vindhya Smitha[2]
[1]PG student, [C.S],EEE Department, Gudlavalleru Engineering College (JNTUK), Gudlavalleru, AP, India
[2]Associate professor, EEE Department, Gudlavalleru Engineering College, Gudlavalleru, AP, India

Abstract: - PID controllers are widely used in many industrial applications due to their simplicity and robustness. In conventional PID controllers such as Ziegler's-Nicholas tuning method it has been found that the controller designed using conventional PID may not be able to satisfy required performance criterion. To overcome this difficulty, in this paper a new fractional order PID controller is proposed using PSO technique. The proposed PSO-FOPID strategy determines the controller parameters by optimizing performance index such as ISE. The performance of the closed loop system with FOPID controller is much better than conventional order PID controller for the same system by using the MATLAB/Simulink.
Keywords: - Fractional calculus, fractional order controller, fractional order toolbox for MATLAB, PSO algorithm.

I. INTRODUCTION

The main requirements for a closed loop control system including the controller are to sustain the stability and robustness through the rejection of the disturbance and exclusion of noise. The most popular controllers is the PID controllers which has parameters to be tuned to get well condition for the system both in time domain and frequency domain. The PID controller that are significantly used in the industries and manufactures and in other domestic equipment which has three parameters to be tuned. Tuning of PID controller is most important issue in industrial and plant controllers due to its ability to tune the few parameters like proportional, integral and derivative physically or self-tune mechanically. According to the Japan electric measuring instrument manufacture association in 1989, PID controller is used in more than 90% of the control loop. As an example for the application of PID controller in industry, slow industrial plant can be pointed; low percentage overshoot and small settling time can be obtained by using this controller. In feedback control systems the controller function has ability to remove steady state offsets through derivative action. The derivative action in the control loop will improve the damping and therefore accelerating the transient response. Many theoretical and industrial studies have been done in PID controller setting rules like Ziegler and Nichols in 1942 proposed a method to set the PID controller parameter Hägglund and Åström in 1955 and in 1999 modifying in the technique have been introduced by them. By generalizing the derivative and integer orders, from the integer field to non-integer numbers, the fractional order PID control is obtained The performance of the PID controller can be improved by making the use of fractional order derivatives and integrals. This flexibility helps the design more robust system. The advantages of the PID controller is the better control of dynamical systems and less sensitive to changes of parameters of a control system Before using the fractional order controller in design an introduction to the fractional calculus is required. The first time, calculus generation to fractional, was proposed Leibniz and Hospital for the first time after words, the systematic studies in this field by many researchers such as Liouville1832, Holmgren 1864 and Riemann 1953 were performed. Due to widespread usage Of PID controller in industries and product manufactures so researchers always motivated to look for a better and suitable design method or alternative controller. For example, the fractional order algorithm for the control of dynamic systems has been introduced by utilization of CRONE for over the PID controller, which has been demonstrated by Oustaloup. Podlubny has proposed a generalization of the PID controller as PID controller which is known as fractional order PID controller He also demonstrated that the PID controller has better response than classical PID controller. Frequency domain approaches of PID controller are studied. Fractional order controllers and their implementations in significance of tuning of the controllers cannot be under estimated. Thus, various tuning techniques for obtaining the parameters of the controllers were introduced during last few decades. Tuning techniques of PID controllers are current research subject. Most of the researchers oriented to the classical optimization and intelligent techniques some tuning rules for robustness to process uncertainty for PID controller However in order to get best results, there are still requirements for new techniques to get the parameters of PID controllers. In this paper the Particle Swarm Optimization (PSO) algorithm has been used to tune the parameter of $PI^{\lambda}D^{\mu}$ controller in order to get an optimum time domain specifications in which integral of time square error (ISE) has been reduced and the results compared with conventional PID.

II. TUNING OF INTEGER ORDER PID CONTROLLER

A proportional–integral–derivative controller (PID controller) is a generic control loop feedback mechanism (controller) commonly used in industrial control systems– a PID is the most frequently used feedback controller. A PID controller calculates an "error" value as the difference between a measured plant variable and a preferred set point. The controller attempts to reduce the error by tuning the plant control inputs. The proportional, integral, and derivative terms are adding to calculate the output of the PID controller. Defining u(t) as the controller output, the PID algorithm final form is:

$$u(t) = K_p e(t) + K_i \int_0^t e(\tau)d\tau + K_d \frac{d}{dt} e(t) \qquad (1)$$

The PID controller transfer function in Laplace transform form is

$$c(s) = K_p + \frac{K_i}{s} + K_d s \qquad (2)$$

The PID controller transfer function is given as

$$G(S) = \frac{1}{s(s+1)(s+2)} \qquad (3)$$

Then according to tuning method ZEIGLER-NICHOLAS

$K_p = 0.6K_{cu}$
$T_i = 0.5P_{cu}$
$T_d = 0.2P_{cu}$

$$G(s) = K_p\left(1 + \frac{1}{T_i s} + T_d s\right) \qquad (4)$$

PID (IOPID) controller integer order is given as.

$$G(s) = 3.6 + \frac{1.63}{s} + 1.98s \qquad (5)$$

III. FRACTIONAL CALCULUS

Fractional calculus is a mathematical subject with more than 300-year history, but the application in physics and engineering has been newly attracted lots of attention. During past three centuries, this subject was through mathematicians, and single in last few years, this was pulled to some (applied) fields of engineering, science and economics. In engineering mainly in plant control, fractional calculus is suitable for hot topic in both modeling and control area.

A frequently used definition of the fractional differ integral is the Riemann-Liouville definition

$$aD_t^{\propto} f(t) = \frac{1}{\Gamma(m-\propto)}\left(\frac{d^m}{dt^m}\right)\int_{\propto}^{t} \frac{f(\tau)}{(t-\tau)^{1-(m-\propto)}} d\tau \qquad (6)$$

form $-1 < \propto < m$ where $\Gamma(\cdot)$ is the well-known Euler's gamma function. An alternative definition, based on the concept of fractional differentiation, is the Grunwald-Letnikov definition given as

$$aD_t^{\propto} f(t) = \lim_{h\to 0} \frac{1}{\Gamma(\propto)h^{\propto}} \sum_{k=0}^{(t-\propto)/h} \frac{\Gamma(\propto+k)}{\Gamma(k+1)} f(t-kh) \qquad (7)$$

One can examine that by introducing the notion of fractional order operator $aD_t^{\alpha}f(t)$, the differentiator and integrator can be combined.

Another helpful tool is the Laplace transform, a fractional order differential equation, provided both the signals u(t) and y(t) at t = 0, can be expressed in a transfer function form is given by

$$G(s) = \frac{a_1 s^{\alpha_1} + a_2 s^{\alpha_2} + \cdots + a_{m_a} s^{\alpha_{m_a}}}{b_1 s^{\beta_1} + b_2 s^{\beta_2} + \cdots + b_{m_B} s^{\beta_{m_B}}} \quad (8)$$

$$\text{Where } (a_m, b_m) \in R^2, (\alpha_m, \beta_m) \in R_+^2, \forall\, (m \in N)$$

Fractional derivatives provide an outstanding instrument for the description of memory and hereditary properties of various materials and processes. This is the main benefit of fractional derivatives in comparison with classical integer order models, in which such effects are in fact ignored. The importance of fractional order control is that it is a generalization of classical integral order control theory, which could lead to more adequate modeling and more robust control performance. The benefits of fractional derivatives become obvious in modeling mechanical and electrical properties of real materials, as well as in the description of rheological properties of rocks, and in several other fields

IV. FRACTIONAL ORDER PID (FOPID) CONTROLLER

The integral-differential equation defining the control action of a fractional order PID controller is given as

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

Where e(t) is the tracking system error signal, u(t) is the control signal, Applying Laplace transform to this equation with null basic conditions, the transfer function for fractional order PID controller can be expressed as

$$c(s) = K_p + \frac{K_i}{s^{\lambda}} + K_d s^{\mu} (\lambda, \mu > 0)$$

In a graphical way, the control possibilities using a fractional-order PID controller are shown in Fig 2.

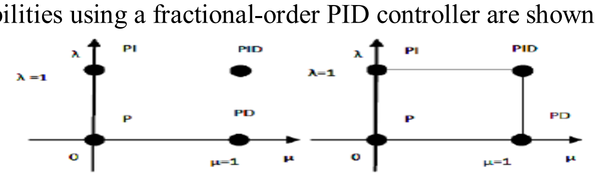

Fig 2.: Fractional-order PID vs classical PID

Expansion of the four control points of the classical PID to the range of control points of the quarter-plane defined by selecting the values of λ and μ

A. Tuning method for the fractional order PID controller

The tuning parameters of fractional order PID controllers are Kc, T_i, T_d,lambda and mu. Ziegler-Nichols tuning rule is useful for tuning the parameters Kc, $T_i$and T_d. Having obtained the parameters Kc, $T_i$and $T_d$in the first step, the optimum settings of the fractional integration of order lambda and the fractional differentiation of order mu of the PID controller are determined by using optimization method.

$$C_f(s) = 3.6 + \frac{1.63}{s^{1.39}} + 3.75 s^{0.79} \quad (10)$$

V. PARTICLE SWARM OPTIMIZATION

The PSO techniques have been employed effectively to solve difficult optimization problems. PSO first introduced by Kennedy and

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Eberhart is one of the modern heuristic procedures; it has been forced by the behavior of organisms, such as fish schooling and bird flocking. Commonly, PSO is characterized as a easy concept, simple to implement, and computationally capable.

PSO is a robust stochastic optimization method based on the movement and intelligence of swarms.PSO applies the idea of social interaction to problem solving. It uses a number of particles that constitute a swarm moving around in the search space looking for the best solution .Each particle is taken as a point in a N-dimensional. Each particle keeps path of its coordinates in the explanation space which are related with the best result (fitness) that has achieved so far by that particle. This value is called personal best, pbest.Another best value that is tracked by the PSO is the best value obtained so far by any particle in the locality of that particle. This value is called gbest. The fundamental concept of PSO lies in accelerating each particle toward its pbest and the gbest positions, with a random weighted acceleration at each time step as shown in Fig14.

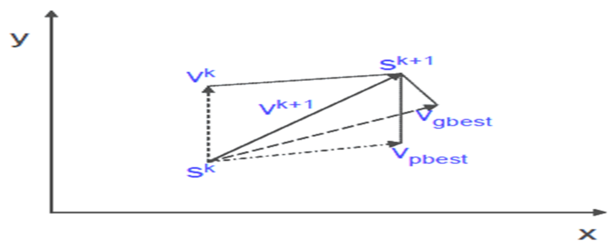

Fig 3: idea of modification of a searching point by PSO

The alteration of the particle's position can be mathematically changed. According the following equation:

$$V_i^{k+1} = wV_i^k + c_1\, rand_1 (\ldots) \times (pbest_i - s_i^k) + c_2\, rand_2 (\ldots) \times (gbest - s_i^k) \qquad \ldots..(11)$$

A. Performance Indices for the PSO Algorithm

The main function considered is based on the error working criterion. The working of a controller is best calculation in terms of error criterion. A number of such criteria are accessible and in the proposed work, controller's performance index is evaluated in terms of Integral of square error, it gives

$$ISE = \int |e^2(t)|\, dt \qquad (12)$$

B. Arrangement PSO for FOPID Controller parameters

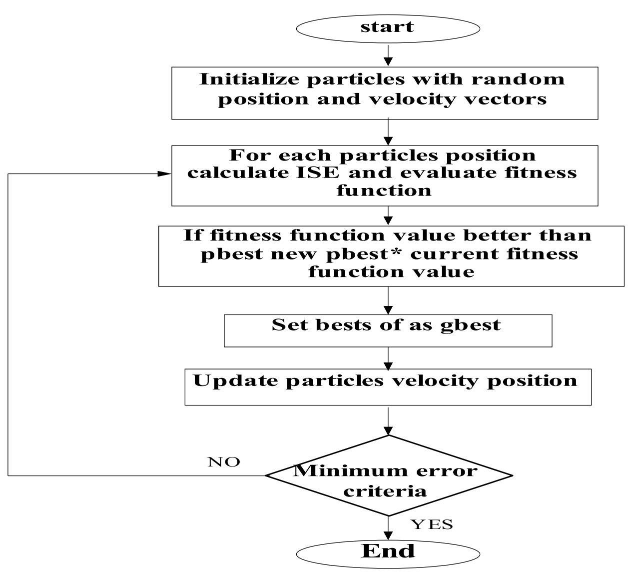

Fig 4:Flow chart for FOPID

C. Parameters of PSO algorithms

TABLE1: Parameters of PSO algorithms

Population size	50
No. of iterations	50
W_{max}	0.9
c_1	1.2
c_2	0.12

VI. DESIGN OF $PI^{\lambda}D^{\mu}$ CONTROLLER WITH OPTIMAL PSO ALGORITHM

The closed loop system with negative unity feedback control system simulation with MATLAB shown in fig. where the fractional order PID (FOPID) controller $G_c(s)$ developed by using fractional control toolbox the integral of time square error (ISE) as objective function and the process *G*(*s*) were developed by MATLAB toolbox.

$$Gc(s) = K_p + \frac{K_i}{s^{\lambda}} + K_d s^{\mu}$$

$$\mathrm{G(s)} = \frac{1}{\mathrm{s(s+1)(s+2)}}$$

A. Implementation of PSO-PID&PSO-FOPID Algorithm

The optimal values of the conventional PID controller parameters K_p, K_i &K_d, is found using PSO-PID. After getting optimized value of K_p,K_i,K_d replacement in FOPID block and find lambda, mu values using PSO-FOPID and attuned so as to reduce the objective function ISE.

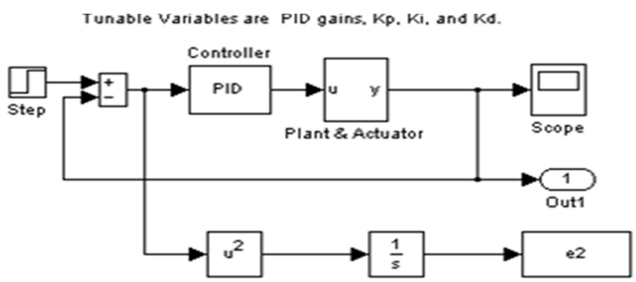

Fig5:simulink diagram for PSO-PID

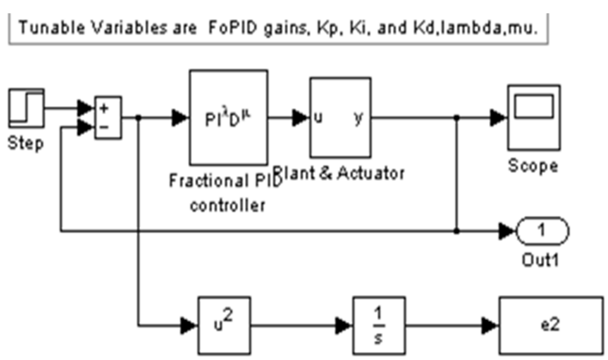

Fig 6:simulink diagram for PSO-FOPID

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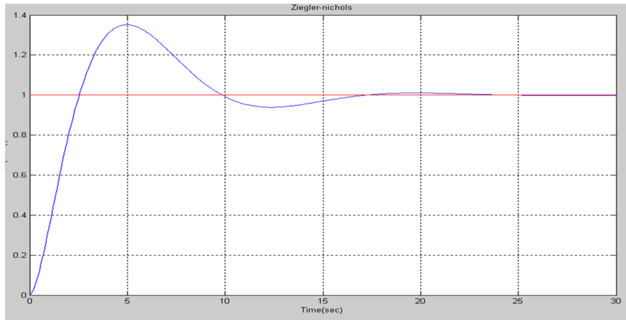

Fig 7:Step response of PID control systems tuned by Z-N method

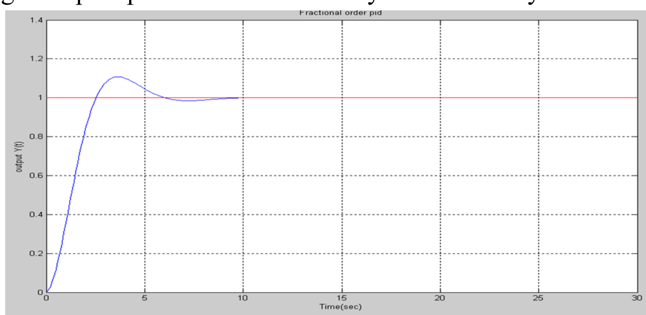

Fig 8: Step response of fractional order PID controller

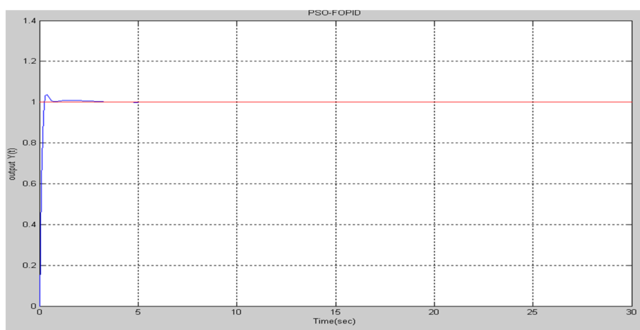

Fig 9: Step response of FOPID controller tuned by PSO

TABLE 2 .Parameters of PID&FOPID controller

Tuning method and controller	**Parameters**				
	k_p	**k_i**	**k_d**	**lambda**	**mu**
Z-N PID	3.6	1.63	1.98	1	1
FOPID	3.6	1.63	1.98	1.39	0.79
PSO-FOPID	98.19	0	70.95	0	1.4497

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TABLE 3: Step response specification of PID , FOPID & PSO-FOPID controller

TUNING METHOD	Maximum over shoot $\%M_P$	Peak time T_P	Rise time T_R	Settling time T_S
Z-N PID	38.54	1.34	5.36	25.52
FO-PID	15.92	0.96	3.24	9.89
PSOFOPID	8.25	0.55	0.084	3.58

VII. CONCLUSION

The proposed PSO-FOPID strategy determines the controller parameters by optimizing performance index such as ISE. In this paper the PSO algorithm has been utilized to get the optimal parameters of FOPID controller while reducing the ISE. The system with FOPID controller exhibits excellent time domain response as compared with the integer order PID controller by using the MATLAB/Simulink.

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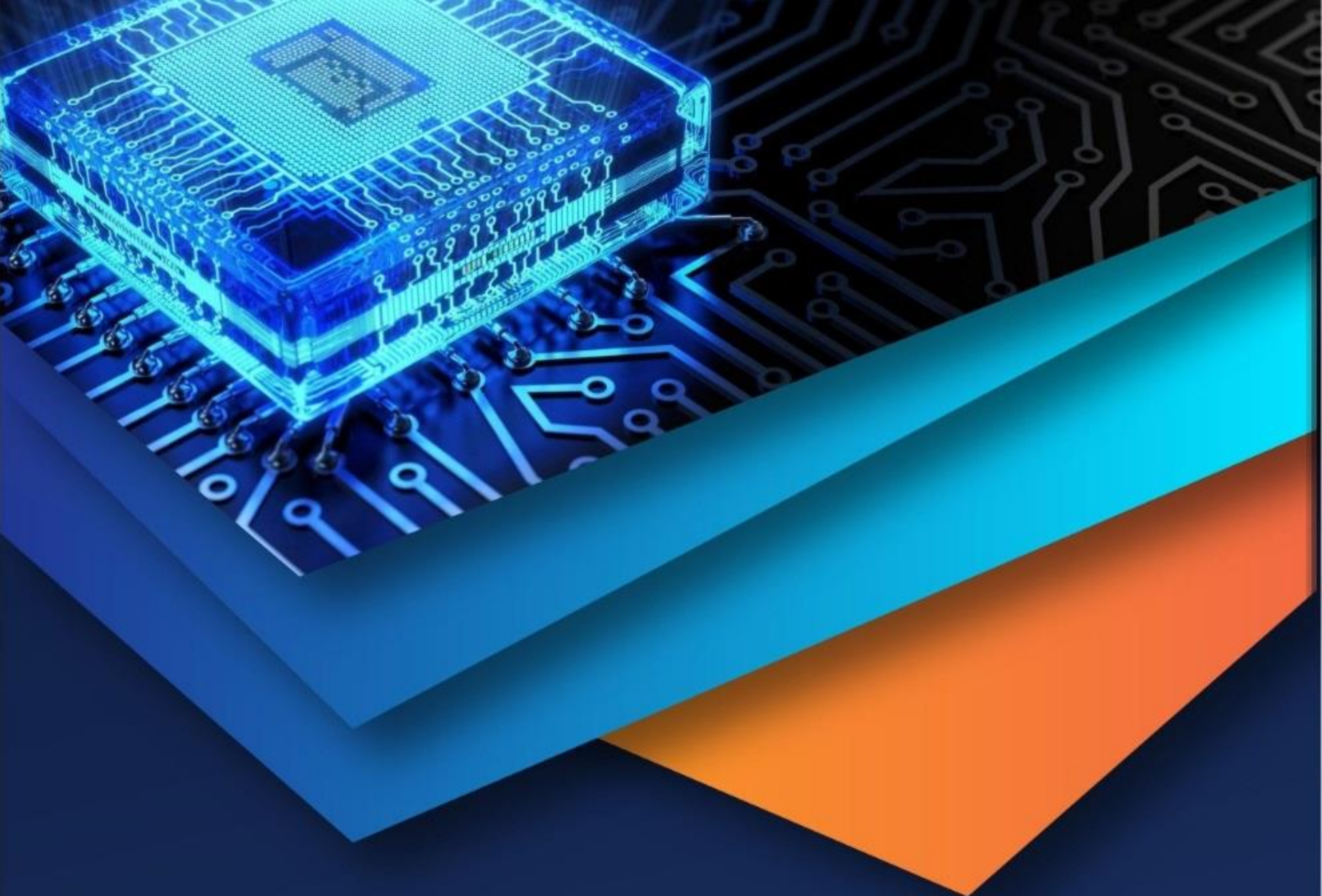

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