2023 10th International Conference on Signal Processing and Integrated Networks (SPIN) | 978-1-6654-9099-3/23/$31.00 ©2023 IEEE | DOI: 10.1109/SPIN57001.2023.10116786

Dynamic Performance Enhancement of Fractional-Order PID Controller using a High-Level Ensemble Swarm Intelligence Method

Mou Das Mahapatra
Dept. of Electrical Engineering
Dr. B. C. Roy Engineering College
Durgapur, India
mou.dasmahapatra@bcrec.ac.in

Shibendu Mahata
Dept. of Electrical Engineering
Dr. B. C. Roy Engineering College
Durgapur, India
shibendu.mahata@bcrec.ac.in

Ritu Rani De (Maity)
Dept. of Electrical Engineering
Dr. B. C. Roy Engineering College
Durgapur, India
riturani.de@bcrec.ac.in

Rajani Kanta Mudi
Dept. of Instrumentation and Electronics Engineering
Jadavpur University
Kolkata, India
rkmudi@yahoo.com

Chanchal Dey
Dept. of Applied Physics
University of Calcutta
Kolkata, India
cdaphy@caluniv.ac.in

***Abstract*—This paper deals with the optimal design of fractional-order proportional-integral-derivative (FOPID) controller using a high-level ensemble method. An ensemble particle swarm optimization (EPSO) algorithm is employed to determine the five design parameters of the FOPID controller based on a time-domain approach. Several design examples, including time-delay system, DC motor plant transfer function, etc., are considered to demonstrate the suitability of the proposed strategy. Results reveal that the closed loop control system employing the EPSO-based controller can achieve an optimal and improved dynamic performance as compared to the reported literature.**

***Index Terms*—ensemble particle swarm optimization, fractional calculus, fractional order PID controller, optimization**

I. Introduction

In the end of the seventeenth century, Gottfried Leibnitz introduced a bright thought about fractional calculus (FC) [1]. Presently, FC has been widely used in describing the features of real-life systems in science and engineering. Due to better theoretical understanding, since the past two decades, FC has been extensively used in well-known classical fields of science and engineering such as electro-chemistry, signal processing, thermal engineering, power system, visco-elasticity, fluid mechanics, optics, electromagnetics, etc. [2]. FC has also been applied in less well known fields which include filter design, capacitor theory, fractional multipoles, electrode-electrolyte interface models, bio-impedance modeling, modeling of neurons, etc. [3], [4], [5].

Modern design tools encourage researchers to use FC in solving control engineering problems [6]. As a result, numerous comprehensive studies have been proposed to establish connections between control problem with fractional-order (FO) integral and derivative [7], [8]. Among the several definitions of FO derivative prevalent in the literature, the definition as per Caputo is given in (1) [1].

$$D_{t_0}^{\alpha} f(t) = \frac{1}{\Gamma(m-\alpha)} \int_{t_0}^{t} (t-\tau)^{m-\alpha-1} f^{(m)}(\tau) d\tau \tag{1}$$

where $f(t)$ is a causal function; m is an integer; and $\alpha \in (m-1, m]$. If the initial conditions are set to zero, the Laplace transform of (1) is given by $s^{\alpha}F(s)$.

One of the seminal works that dealt with the applicability of fractional-order proportional-integral-derivative (FOPID) controller is cited in [9]. The continuous-time transfer function of an FOPID controller is given by (2).

$$G_C(s) = k_p + \frac{k_i}{s^{\lambda}} + k_d s^{\mu} \tag{2}$$

where the controller gains for proportional, integral, and derivative actions are denoted by k_p, k_i, and k_d, respectively, and $\lambda, \mu \in [0, 2]$.

In contrast to the classical PID controller where the values of λ and μ are strictly equal to one, an FOPID controller can take non-integer values for these two new design parameters. Hence, instead of only three tuning parameters available in classical PID controller, a $PI^{\lambda}D^{\mu}$ controller possesses five 'tuning knobs'. This lends additional flexibility to the FOPID controller in meeting stringent control specifications. Tuning and implementation techniques of the FO controllers is a dynamic area of research [10], [11]. The block diagram of a unity feedback system involving the FOPID controller and plant transfer function $G_P(s)$ is shown in Fig. 1. The closed loop transfer function of this system is given by (3).

$$\frac{Y(s)}{U(s)} = \frac{G_C(s)G_P(s)}{1 + G_C(s)G_P(s)} \tag{3}$$