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Practical Application of Fractional-Order PID Controller based on Evolutionary Optimization Approach for a Magnetic Levitation System

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ABSTRACT

This article proposes a state-of-the-art design procedure of integer-order PID (IOPID) and fractional-order PID (FOPID) controller applied to a well-established and diversified engineering application of the Magnetic Levitation System (Maglev). Controller design and implementation for the Maglev system are quite complicated and difficult since the system dynamics exhibits non-linearity with a wide variation of operating points. Also, the system is highly unstable which rules out the possibility to accomplish conventional tuning techniques. Thus in this work, the controller tuning methodology is framed as a complex optimization problem by incorporating a new transient specification-based objective function. For designing and tuning of proposed controller parameters, modern meta-heuristic and evolutionary optimization algorithms are deployed; those are Bird Swarm Algorithm, Elephant Herding Optimization, Equilibrium optimizer and Grey Wolf Optimization. The software and hardware results demonstrate that FOPID controllers yield better time-domain and frequency-domain performance specifications and exhibit excellent reference tracking capability than IOPID controllers. The performance robustness of the proposed controllers is greatly enhanced subjected to a vast range of parametric uncertainties along with a significant minimization of the control effort.

KEYWORDS

Equilibrium optimizer; Evolutionary optimization algorithms; FOPID; Intelligent control system design; MAGLEV system; Real-time control; Robustness analysis

1. INTRODUCTION

Fractional-order calculus (FOC) is a powerful mathematical tool that can accurately describe the dynamical behavior of various real-world systems with a great deal of efficiency [1]. It has successfully put a great impact on various fields of modern-day engineering and technology like bio-engineering [2], signal processing [3], communication systems, robotics [4], mechatronics [5], etc. Control systems engineering has also been benefitted from the application of FOC because FOC can capture the exact internal dynamics of real-time physical processes. Several shreds of evidence of implementation of FOC in modern control theory can be found in the recent works of literature which show that fractional-order (FO) controllers have enhanced the overall closed-loop performance of various complicated linear, non-linear and unstable systems and have been proved to be superior to classical integer-order (IO) controllers. This work focuses on a state-of-the-art design procedure of integer-order PID (IOPID) and fractional-order PID (FOPID) controller for Magnetic Levitation System (Maglev) which is inherently unstable and strongly nonlinear in nature.

1.1 Literature Review

A fractional-order PID (FOPID) controller is implemented in the digital environment and supporting software and hardware results establish the proficiency of the said controller [6]. In Ref. [7], the authors propose FO controllers based on the flower pollination algorithm for grid-connected electric vehicles under load frequency control. A fractional-order feedback-type controller [8] is designed and implemented for a class of non-linear chaotic systems. Development of internal model control (IMC) for fractional-order time-delay system is carried out in Ref. [9]. Authors have investigated the design problem through a frequency domain approach that will satisfy a set of desired gain margin and phase margin specifications and also produce the targeted solutions for gain and phase crossover frequency. A fractional-order PI/PD controller is devised in Ref. [10]; for controlling the two-loop liquid level control system. Some authors have utilized the time-domain tuning method to design an FO-PI controller to achieve nominal time response [11]. A cascaded fractional-order integral-derivative controller with filter is adopted in Ref. [12] to

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