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Improved tuning of fractional-order PID controller for an AVR system using geometric mean optimizer

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***Abstract*—This paper presents an effective tuning strategy for the Fractional Order Proportional-Integral-Derivative (FOPID) controller that improves the dynamic performance of an automatic voltage regulator (AVR) in power systems. The proposed controller fine-tunes essential design parameters, including proportional, integral, and derivative gains, as well as the integral and derivative orders, using the recently reported Geometric Mean Optimizer (GMO) algorithm. We demonstrate that an integral absolute error (IAE) cost function improves the regulation performance by using time domain analysis. We also conduct robustness studies on the proposed system. Comparative analyses with existing works demonstrate that the proposed FOPID controller achieves competitive performance with the reported techniques.**

***Index Terms*—automatic voltage regulator, fractional-order pid controller, geometric mean optimizer, transient and frequency-domain analysis, integral absolute error**

I. Introduction

The reliable operation of power systems is vital for maintaining the uninterrupted supply of electricity to industries, businesses, and households. Central to this reliability is maintaining stable voltage levels across the network, which is essential for the efficient and safe functioning of the system. Voltage stability is vital for the proper operation of electrical equipment and the overall efficiency of the power system. AVR plays a key role in achieving this stability by keeping generator voltage output within specified limits, despite load fluctuations or external disturbances [1].

Without an AVR, generators cannot automatically adjust to voltage variations, leading to instability that could result in overvoltage or undervoltage conditions, potentially damaging sensitive equipment. Furthermore, AVR is crucial for enhancing power system efficiency by maintaining consistent voltage levels, reducing energy losses, and optimizing grid performance. Additionally, AVR improves power quality by mitigating voltage fluctuations, which helps to prevent issues like flickering lights, malfunctioning electronics, and increased maintenance costs [2].

An additional controller is required with an AVR system to enhance dynamic response and stability, ensuring faster settling times and reduced overshoot under varying load conditions. Literature shows that PID controllers are popular due to their simplicity, effectiveness, and versatility [3]. The gains of PID controllers for AVR systems have been optimized using newly developed algorithms like the constrained Nelder-Mead algorithm-based ant colony optimization [4], stochastic fractal search algorithm [5], enhanced fitness-adaptive differential evolution [6], tree seed algorithm [7], and nonlinear sine cosine algorithm [8].

PID controllers may lack the flexibility required to handle the dynamic and nonlinear behaviors of modern AVR systems effectively. In contrast, FOPID controllers offer an extended degree of freedom through fractional calculus, allowing finer adjustments in control response under varying load and operational conditions [9]. Commonly employed metaheuristic algorithms to tune FOPID controller for AVR systems include the cuckoo search [10], chaotic black widow [11], salp swarm optimization [12], sigmoid-based [13], memorizable smoothed functional [14], enhanced slime mould [15], chaotic yellow saddle goatfish (CYSG) [16], Jaya optimization [17], gradient-based optimization [18], improved slime mould algorithm [19], and improved artificial bee colony (IABC) [20].

This article introduces, for the first time, the application of GMO [21], a new metaheuristic optimizer inspired from mathematics, in the context of AVR. The motivation for tuning a FOPID controller by GMO stems from the need for enhanced control precision and robustness in power systems. The objectives include achieving faster settling time (t_s), smaller maximum overshoot (M_p), better stability, and improved robustness against plant parameter variations. Additionally, the paper provides a comparative time-domain and frequency-domain analysis with other optimization techniques, such as [16] and [20], validating the effectiveness of the proposed approach.

This paper is structured as follows: Section II covers the mathematical modeling of the AVR system. FOPID controller structure, GMO algorithm, and the proposed objective function (OF) have been described in Section III. Section IV presents simulation results. Finally, Section V summarizes the findings and suggests potential future work.

II. Linearized AVR System

The linearized model of an AVR system is a simplified mathematical representation used for analysis and design and is shown in Fig. 1 [16], [20]. Here, V_r is the amplified error