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A metaheuristic approach for optimal tuning of PIDD^α controller for AVR performance improvement

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Abstract—This paper presents an effective controller design technique for the automatic voltage regulator system where an additional fractional-order derivative term is incorporated along with the standard PID controller structure, resulting in the PIDD^α structure. The proposed controller is tuned using a recently reported metaheuristic optimizer, namely the Manta Ray Foraging Optimization Algorithm (MRFOA). Average performance for the proposed approach is studied by considering various performance metrics. Comparison with those of the recently reported controllers of different types demonstrates significant improvement in rise time (0.0682 s) and settling time (0.1044 s) along with competitive peak overshoot characteristics (0.75%) for the proposed MRFOA-PIDD^α controller.

Index Terms—automatic voltage regulator, fractional-order control, PID controller, metaheuristics, manta ray foraging optimization

I. INTRODUCTION

Achieving voltage stability in power systems is of critical importance. Transmission line characteristics, efficiency of controller, and profile of synchronous generators may influence voltage stability. The generated voltage should remain within a specific range in order to maintain performance and safety. The automatic voltage regulator (AVR) controller plays a critical role in attaining the desired transient and steady-state performance so that stable and reliable operation for the generators even under external disturbances and load fluctuations can be attained [1], [2].

The proportional-integral-derivative (PID) controller is the most popular industrial controller. The PID controller is known for its ease of implementation and the tuning techniques are well-established. The tuning parameters of the PID controller, namely the proportional (k_p), integral (k_i), and derivative (k_d) gains, are determined using various techniques such that the regulation performance of the AVR system meets the objectives [3]. Recent developments in the field have shown

that increasing the degrees-of-freedom in the classical PID controller can lead to significant improvement in the transient performance of the AVR [4].

Metaheuristic algorithms have gained significant prominence in achieving improved parameter tuning of various controllers and systems [5]–[7]. These algorithms avoid the calculation of gradients, whereas some degree of stochasticity is blended with deterministic procedures to locate the optimal solution in the search space [8]. Though the global-optima location cannot be guaranteed, metaheuristics are preferable due to their ability to solve diverse categories of problems. Recent articles have justified the use of metaheuristics for optimal tuning of sophisticated controllers [9].

Optimal tuning of PID parameters for the AVR has been achieved using an equilibrium optimizer [10], a hybrid algorithm of manta ray foraging and simulated annealing where the exploration and exploitation are effectively carried out respectively by the former and later algorithms [11], cuckoo search optimization [12], an enhanced differential evolution technique [13], etc. Fuzzy-PID [14] and sigmoid-based PID controllers [15] for AVR have also demonstrated improved dynamic performances.

Fractional-order PID (FOPID) controller, being an advancement over the classical PID, have been employed effectively for various control systems, demonstrating significant improvements over the classical PID [16], [17]. Since FOPID controllers employ fractional derivative and integrals, the number of controller tuning parameter increases to five; thus, the complexity increases. However, the FOPID controller can help to attain performances that may not be feasible to achieve using PID controllers (e.g., fractal robustness, disturbance rejection, etc.) [9]. FOPID controllers for automatic voltage regulation have been designed using the gradient-based optimizer [18], Jaya optimizer [19], improved artificial bee colony