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Speed Control Optimization of Permanent Magnet Synchronous Motors (PMSM) Using the Cuckoo Optimization Algorithm (COA)

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ABSTRACT

This paper presents the speed control optimization of a Permanent Magnet Synchronous Motor (PMSM) utilizing the Cuckoo Optimization Algorithm (COA). Due to their high-power density, superior efficiency, and robust structural design, PMSMs are extensively utilized in a wide range of industrial and domestic applications. However, achieving precise and optimal speed control in these motors remains a significant challenge due to their non-linear dynamics. In this research, the parameters of a Proportional-Integral-Derivative (PID) controller are optimized to minimize speed tracking errors and enhance the motor's dynamic response. The Cuckoo Optimization Algorithm (COA) was selected for this optimization task owing to its algorithmic simplicity, fast convergence, and high efficiency in solving complex engineering problems. The problem formulation incorporates an objective function designed based on the Integral Squared Error (ISE) criterion, where the decision variables are defined as the tuning gains of the PID controller. Simulation studies conducted in MATLAB/Simulink R2024a demonstrate that employing the COA for PID parameter tuning yields a substantial improvement in the performance of the PMSM drive system. Specifically, a significant reduction in speed error, suppressed overshoot, and an accelerated system settling time are achieved using the proposed optimization approach. Finally, the proposed method is benchmarked against other metaheuristic optimization techniques, confirming its superior performance and efficacy.

1. INTRODUCTION

Permanent magnet synchronous motors (PMSMs) have emerged as a key technology for high-performance electric drive systems because of their high-power density, high efficiency, compact structure, and excellent dynamic performance. The absence of rotor copper losses and the high magnetic flux density provided by permanent magnets enable PMSMs to achieve superior efficiency and torque-to-weight characteristics compared with many conventional electric-machine technologies. Consequently, PMSMs have been increasingly employed in electric

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vehicles, industrial automation, robotics, aerospace propulsion, renewable-energy conversion systems, and high-performance servo applications [1–4]. The growing demand for energy-efficient and highly responsive electric drives has therefore stimulated extensive research into accurate modeling, advanced control, and optimization of PMSM-based drive systems.

The control of PMSMs, however, is challenging because of the nonlinear and coupled characteristics of their electrical and mechanical dynamics. In the synchronously rotating d-q reference frame, the stator voltage equations are coupled through the rotor electrical speed, while the electromagnetic torque depends on the interaction between the stator currents and rotor permanent-magnet flux. Moreover, variations in stator resistance, d- and q-axis inductances, permanent-magnet flux linkage, rotor inertia, load torque, and operating temperature can significantly affect the dynamic response of the drive [1,2,5]. These characteristics make accurate speed regulation particularly important in applications where rapid acceleration, low steady-state error, low torque ripple, and strong disturbance rejection are required.

Field-oriented control (FOC) has become one of the most widely adopted control strategies for PMSM drives because it transforms the three-phase machine variables into a rotating reference frame and enables independent regulation of the torque- and flux-related current components. The approach provides a relatively simple control structure while offering fast dynamic response and accurate torque control [3,6]. In practical implementations, the inner current loops are generally combined with an outer speed-control loop, for which proportional–integral (PI) controllers remain widely used because of their simple structure, low computational burden, and straightforward implementation. Nevertheless, the effectiveness of a PI-controlled PMSM drive is highly dependent on appropriate selection of its proportional and integral gains. Conventional tuning approaches may provide satisfactory performance around a nominal operating point but may become less effective when the motor is subjected to rapid reference changes, load disturbances, parameter uncertainty, or wide operating-speed variations.

The limitations associated with fixed controller parameters have motivated the development of adaptive, nonlinear, intelligent, and optimization-based control techniques for electric drives. Among these approaches, metaheuristic optimization algorithms have attracted considerable attention because they can solve nonlinear optimization problems without requiring gradient information or an explicit analytical relationship between the decision variables and the performance index. Genetic algorithms, particle swarm optimization (PSO), differential evolution (DE), and other population-based algorithms have consequently been employed for controller parameter optimization and engineering design problems [7–9]. In a PMSM speed-control problem, controller gains can be considered as optimization variables, whereas the objective function can be constructed from time-domain performance measures such as the integral absolute error (IAE), integral squared error (ISE), integral time-weighted absolute error (ITAE), overshoot, settling time, and control effort.

Particle swarm optimization, for example, has demonstrated the capability of efficiently solving continuous optimization problems through population-based search and has become one of the most frequently investigated metaheuristic methods in control engineering [7]. Differential evolution similarly provides an effective global optimization mechanism based on vector differences between population members [8]. Despite the advantages of these methods, their optimization performance can be influenced by parameter settings, population diversity, convergence characteristics, and the balance between global exploration and local exploitation. These considerations have encouraged continuing research into alternative metaheuristic optimization algorithms that may offer competitive performance for nonlinear engineering control problems.

The Cuckoo Optimization Algorithm (COA) is one such population-based metaheuristic technique. COA was introduced by Rajabioun and is inspired by the brood-parasitic behavior of cuckoo birds [10]. The algorithm models candidate solutions as cuckoo habitats and employs mechanisms associated with egg laying, survival of eggs and chicks, and movement toward more favorable habitats. The optimization process therefore combines exploration of the search space with movement toward promising regions. An important characteristic of COA is that it can be applied to continuous nonlinear optimization problems without requiring derivative information. This feature makes it potentially suitable for controller-parameter optimization, where the relationship between controller gains and closed-loop performance is generally nonlinear and may not be conveniently expressed in a differentiable analytical form.

From a control-design perspective, the use of COA provides an opportunity to formulate PMSM speed regulation as a systematic optimization problem rather than relying exclusively on conventional trial-and-error or analytical controller tuning. For example, the proportional and integral gains of a PI speed controller can be represented as the decision variables of COA. During each iteration, candidate controller parameters can be evaluated through the closed-loop PMSM model, and the resulting speed-tracking error can be quantified using a suitable objective function. The optimization process can consequently identify controller gains that provide an appropriate compromise among fast response, small overshoot, low steady-state error, and satisfactory disturbance rejection. Such a strategy is particularly relevant to PMSM applications in which transient performance and tracking accuracy are simultaneously important.

Nevertheless, the use of a metaheuristic algorithm alone does not necessarily guarantee superior control performance. The quality of the resulting controller depends on several factors, including the mathematical model of the PMSM, the selected decision variables, the formulation of the objective function, the optimization bounds, the algorithm parameters, and the operating scenarios used during optimization. Furthermore, a meaningful evaluation should consider not only the nominal speed-tracking response but also transient characteristics and robustness under changes in load torque and operating conditions. Therefore, a rigorous assessment of COA-based controller optimization should include quantitative indicators such as rise time, settling time, maximum overshoot, steady-state error, integral tracking error, and response to load disturbances.

The literature on PMSM control has established sophisticated mathematical models and high-performance control structures, while the broader optimization literature has demonstrated the applicability of metaheuristic algorithms to nonlinear engineering optimization problems [1–10]. However, the effectiveness of an optimization algorithm is problem-dependent, and the suitability of COA for PMSM speed-controller tuning should be established through a clearly defined optimization framework and quantitative comparison rather than assumed from its performance in unrelated optimization problems. In particular, further investigation is warranted into the extent to which COA-based tuning can improve the transient and steady-state characteristics of a PMSM speed-control loop while maintaining acceptable robustness to external disturbances.

Therefore, this study proposes a Cuckoo Optimization Algorithm-based optimization framework for PMSM speed control. A mathematical model of the PMSM is established in the rotating d-q reference frame, and a closed-loop speed-control structure is developed. The COA is then employed to optimize the parameters of the speed controller according to a predefined time-domain objective function. The optimized controller is evaluated using key performance indicators, including speed-tracking accuracy, rise time, settling time, overshoot, steady-state error, and disturbance-rejection capability. The objective is to determine whether COA-based parameter optimization can provide a measurable improvement in PMSM speed-control performance compared with conventionally tuned controller parameters. The proposed framework is intended to provide a systematic and computationally practical approach for optimizing PMSM speed regulation in high-performance electric-drive applications.

1.1. The Cuckoo Optimization Algorithm (COA): A Novel Approach

The Cuckoo Optimization Algorithm (COA) is a powerful, population-based metaheuristic optimization technique inspired by the obligate brood parasitism behavior observed in certain cuckoo species. Introduced by Yang and Deb in 2009, this algorithm has rapidly gained popularity due to its structural simplicity and high search efficiency [11]. In nature, specific cuckoo species lay their eggs in the nests of other host birds, where the parasitic eggs blend with the host's own eggs. Cuckoos strategically choose these nests to maximize the survival and growth probability of their offspring. This biological behavior is mathematically modeled as an iterative search process within the COA.

In the context of the COA, each potential solution within the multi-dimensional search space is represented as a cuckoo egg. These solutions are distributed across the search space and move toward optimal zones through modeled processes of migration and mutation. In each iteration, a fraction of the sub-optimal eggs is replaced by new, candidate solutions, thereby iteratively improving the overall fitness of the population. A defining feature of the COA is the integration of a Lévy flight mechanism to enhance both local exploitation and global exploration. This random-walk mechanism, characterized by a power-law step-length distribution, enables the algorithm to efficiently escape local optima traps and converge toward the true global optimum.

The applications of the COA are highly diverse, demonstrating remarkable success in solving intricate engineering problems such as controller parameter tuning, neural network optimization, and structural design. Its ease of implementation combined with its robust convergence properties makes it a potent tool for continuous optimization tasks. Figure 1 illustrates the detailed flowchart of the Cuckoo Optimization Algorithm.

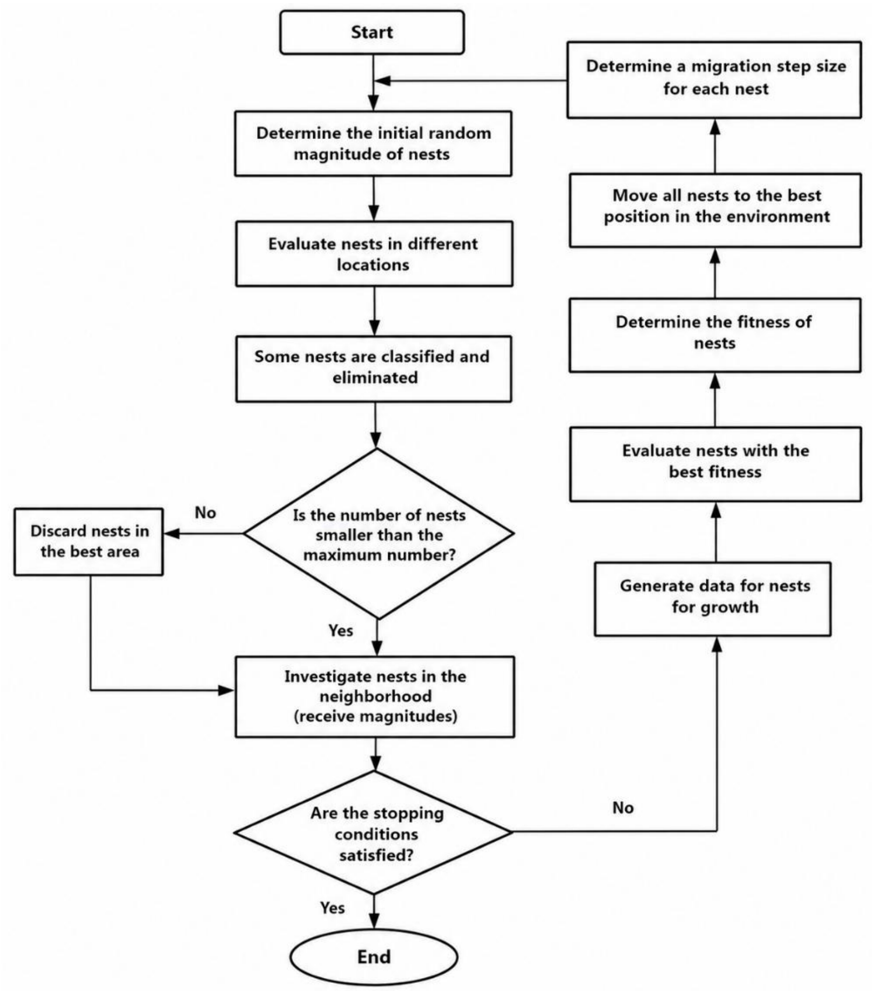

Fig. 1. Flowchart of the Cuckoo Optimization Algorithm (COA).

2. MATHEMATICAL MODELING AND THEORETICAL FRAMEWORK

This section presents the mathematical modeling of the Permanent Magnet Synchronous Motor (PMSM). The objective of this modeling is to provide a comprehensive and precise representation of the motor's dynamic behavior, encompassing both its electrical and mechanical subsystems. These analytical models serve as the foundation for designing and implementing optimal controllers that guarantee superior drive performance. In the following subsections, the governing differential equations of the motor, the dq0 transformation and its application in machine analysis, and the optimization of speed control using metaheuristic algorithms are discussed in detail. These analyses establish the necessary framework for developing advanced control topologies and enhancing the overall efficiency of PMSM drives.

2.1. Mathematical Modeling of the Permanent Magnet Synchronous Motor (PMSM)

Developing an accurate mathematical model of the PMSM is a fundamental step in analyzing and designing high-performance control systems. Precise modeling enables a deep understanding of the machine's transient and steady-state dynamics. The PMSM is a brushless synchronous AC motor characterized by sinusoidally distributed stator windings. The excitation flux in this machine is generated by permanent magnets mounted on or embedded within the rotor structure. To simplify the mathematical modeling and analysis, the following standard idealized assumptions are verified:

- The magnetic permeability of the iron core is assumed to be infinite.
- The magnetic circuit operates outside the saturation region, maintaining a linear relationship.
- The magneto-motive force (MMF) and the magnetic flux linkage are assumed to be sinusoidally distributed along the air gap.
- The effects of spatial and temporal high-order harmonics, as well as core losses (eddy currents and hysteresis), are neglected.

These assumptions streamline the resulting differential equations and facilitate the design, tuning, and optimization of the closed-loop control system.

In a PMSM, the winding inductances vary continuously as a function of the rotor position. Consequently, transforming the machine equations into a two-phase (d-q) equivalent circuit model is the most effective approach for analyzing such multiphase machines. This model is widely accepted due to its decoupling properties and physical intuition. Historically developed for synchronous reluctance machines, the d-q modeling technique eliminates the time-varying coefficients found in the complex three-phase representations, which are inherently difficult to analyze directly. This reference frame theory is now standard practice for analyzing various AC machines, including permanent magnet synchronous motors, induction motors, and synchronous reluctance drives.

Comparing a conventional wound-rotor synchronous motor (WRSM) with a PMSM reveals that the stator of a PMSM features three-phase, star-connected, sinusoidally distributed windings identical to those of a standard WRSM. However, on the rotor side, instead of an active electrical field winding energized by an external DC source, the constant rotor magnetic flux linkage (λ_r) generated by the permanent magnets must be integrated into the d-q model of the PMSM. Incorporating this constant flux source allows for precise tracking of the machine's dynamic performance, enabling the synthesis of highly effective vector control strategies (such as Field-Oriented Control). Figure 2 illustrates the cross-sectional view of a three-phase, two-pole PMSM mapped onto the synchronous rotating d-q reference frame.

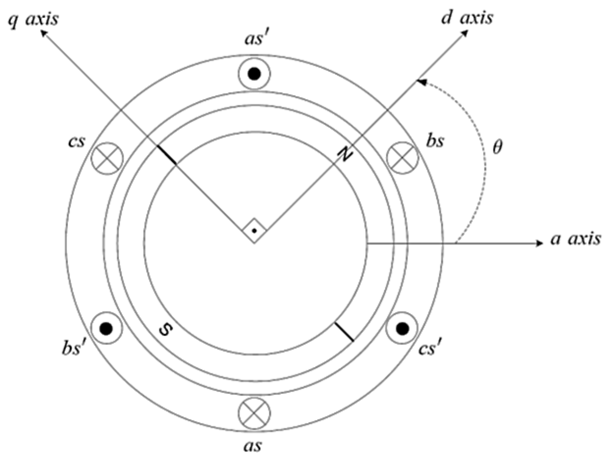

Fig. 2. Cross-sectional view of a three-phase, two-pole PMSM in the synchronous rotating **d-q** reference frame.

2.2. Stator Voltage Equations in the dq Reference Frame

The space vector representation of the stator voltage equation in the stationary reference frame is formulated as follows [12]:

$$V_s = r_s i_s + d\lambda_s/dt \tag{1}$$

Where r_s ،V_s ،i_s and λ_s denote the stator winding resistance, the complex space vector of the three-phase stator voltages, the stator currents, and the stator flux linkages, respectively. These parameters are defined within the stationary reference frame fixed to the stator, and their mathematical formulations are expressed as follows:

$$V_s = \frac{2}{3}[V_{sa}(t) + aV_{sb}(t) + a^2V_{sc}(t)] \tag{2}$$

$$i_s = \frac{2}{3}[i_{sa}(t) + ai_{sb}(t) + a^2 i_{\infty}(t)] \tag{3}$$

$$\lambda_s = \frac{2}{3}[\lambda_{sa}(t) + a\lambda_{sb}(t) + a^2\lambda_{sc}(t)] \tag{4}$$

Where V_{sa} ،V_{sb} and V_{sc} represent the instantaneous stator phase voltages, and i_{sa} ،i_{sb} and i_{sc} denote the instantaneous stator phase currents.

The terms a and a^2 are the space operators associated with the spatial displacement of the stator windings.

$$a^2 = e^{j4\pi/3}, a = e^{j2\pi/3} \tag{5}$$

Generally, the stator voltage equations expressed in the synchronous rotating dq reference frame are defined as follows:

$$V_d = R_s I_d + L_d \frac{dI_d}{dt} - \omega L_q I_q + E_d \tag{6}$$

$$V_q = R_s I_q + L_q \frac{dI_q}{dt} + \omega L_d I_d + E_q \tag{7}$$

where V_d and V_q represent the stator voltages, I_d and I_q denote the stator currents, R_s is the stator resistance, L_d and L_q are the inductances along the d , q and ω is the rotor angular velocity, and E_d and E_q represent the induced voltages along the d- and q-axes.

The induced voltages E_d and E_q are generated by the permanent magnet of the rotor and are defined as follows:

$$E_d = -\omega\lambda_q \tag{8}$$

$$E_q = \omega\lambda_d \tag{9}$$

In these equations, λ_d and λ_q represent the stator magnetic flux linkages along the d and q axes, respectively, which are established by the permanent magnets embedded in the rotor structure.

2.3. Current Equations in the dq Reference Frame

The three-phase instantaneous stator currents (I_a ،I_b and I_c) are transformed into the synchronous rotating dq reference frame components using Park's transformation matrix as follows [13]:

$$\begin{bmatrix} I_d \\ I_q \\ I_0 \end{bmatrix} = \frac{2}{3}\begin{bmatrix} \cos(\theta) & \cos(\theta - \frac{2\pi}{3}) & \cos(\theta + \frac{2\pi}{3}) \\ -\sin(\theta) & -\sin(\theta - \frac{2\pi}{3}) & -\sin(\theta + \frac{2\pi}{3}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} \tag{10}$$

In Equation (10), I_d represents the direct-axis (d-axis) current, I_q denotes the quadrature-axis (q-axis) current, I_0 is the zero-sequence current, and θ signifies the electrical rotor angle.

By applying the transformation matrix from Equation (10), the d-axis and q-axis currents (I_d and I_q) are explicitly expressed as follows:

$$I_d = \frac{2}{3}\left[I_a \cos(\theta) + I_b \cos(\theta - \frac{2\pi}{3}) + I_c \cos(\theta + \frac{2\pi}{3})\right] \quad (11)$$

$$I_q = \frac{2}{3}\left[-I_a \sin(\theta) - I_b \sin(\theta - \frac{2\pi}{3}) - I_c \sin(\theta + \frac{2\pi}{3})\right] \quad (12)$$

These equations indicate that the direct-axis currents and the quadrature-axis currents are linear combinations of the three-phase currents, each multiplied by the respective angles θ, $\theta + \frac{2\pi}{3}$, and $\theta - \frac{2\pi}{3}$.

The zero-sequence (I_0) current component is calculated as follows:

$$I_0 = \frac{1}{3}(I_a + I_b + I_c) \quad (13)$$

This current is normally zero in balanced systems; however, under unbalanced conditions it may take on a non-zero value.

2.4. Speed Control Optimization Using COA

The Cuckoo Optimization Algorithm (COA) is a metaheuristic algorithm inspired by the obligate brood parasitism and unique egg-laying behavior of certain cuckoo species. In the context of Permanent Magnet Synchronous Motor (PMSM) speed control, the primary objective of optimization is to minimize the speed tracking error and enhance the dynamic transient response of the drive system. To achieve this objective, the tuning parameters of the PID controller—namely the proportional gain (Kp), integral gain (Ki), and derivative gain (Kd)—are globally optimized. The objective function is formulated to minimize the cumulative speed error over the simulation time horizon. One of the most widely adopted performance indices in control systems engineering is the Integral of Squared Error (ISE), which is mathematically defined as follows:

$$J = \int_0^T e(t)^2 dt \quad (14)$$

where $e(t)$denotes the speed error at time $t$and Trepresents the simulation time interval.

The optimization problem consists of determining the optimal values of the PID controller parameters K_p, K_i, and $K_d$such that the objective function J is minimized.

2.5. Cuckoo Optimization Algorithm (COA) Strategy

To achieve optimal performance, the parameters K_p, K_i, and $K_d$must be optimized. The Cuckoo Optimization Algorithm (COA) is employed for this purpose. The optimization process consists of the following steps [11]:

- **Generation of the initial population**: A number of nests (solutions) are randomly generated. Each nest represents a set of parameters K_p, K_i, and K_d.
- **Evaluation of the objective function**: The value of the objective function is calculated for each nest. This value indicates the quality of each solution.
- **Generation of new eggs**: Based on the current locations of the nests, new eggs are produced. These eggs replace the previous ones and represent new solutions.
- **Selection of the best nests**: A number of the best nests are selected according to the objective function value for the next generation. This process ensures that higher-quality solutions are retained for further improvement.

- **Iteration of the steps until the termination criterion is met**: The above steps are repeated until the termination criterion is satisfied. The termination criterion may be a predefined number of iterations, negligible changes in the objective function, or the attainment of a specified value of the objective function.
- **Implementation of the optimal controller**: Once the termination criterion is reached, the best set of PID controller parameters (K_p, K_i, and K_d) is selected as the optimization result. These parameters are used to implement the PID controller for the PMSM. The optimally designed controller can improve the overall motor performance by reducing the speed error and enhancing the dynamic response.

After optimizing the PID parameters using COA, the optimized PID controller is implemented on the PMSM. This controller improves the overall motor performance with the aim of reducing the speed error and enhancing the dynamic response time. Simulation results demonstrate that the application of this control strategy can lead to a significant improvement in the stability and efficiency of the PMSM.

Figure 3 illustrates the block diagram of the PMSM control system employing a PID controller optimized by the COA algorithm. In this system, the reference signal is continuously compared with the actual value, and the calculated error is fed to the PID controller. The PID controller then generates the control signal, which, after the transformation process, is applied to the motor to achieve the desired output. The COA algorithm continuously optimizes the PID parameters to ensure optimal system performance against dynamic variations and varying loads. This system represents a combination of classical control techniques and advanced optimization methods.

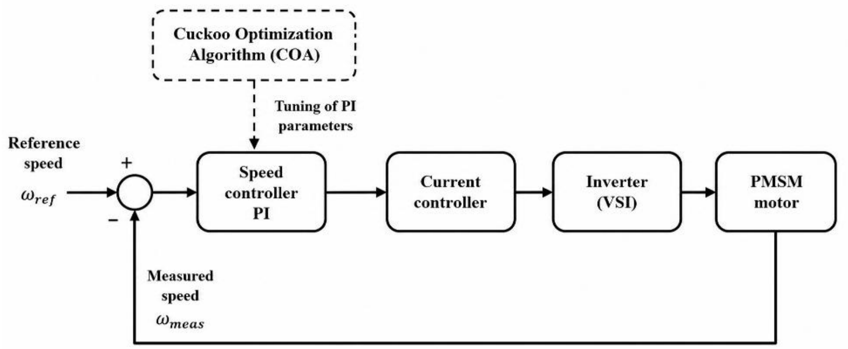

Fig. 3. Block diagram of the PMSM motor model with the PID controller optimized using the COA algorithm

3. SIMULATION AND RESULTS

The system simulation was carried out in MATLAB/Simulink version 2024, as shown in Figure 4, in order to evaluate the performance of the PID controller optimized by the Cuckoo Optimization Algorithm (COA). Table 1 presents the parameters considered for the PMSM under realistic operating conditions. In the simulation scenario, the permanent-magnet synchronous motor (PMSM) starts at an initial speed of 500 rpm. At $t = 0.1$s, a sudden increase in load torque from 5 N·m to 20 N·m is applied. This simulation condition is designed to assess the system response and the effectiveness of the optimized PID controller in the face of abrupt torque variations.

Table 1. Parameters of the permanent-magnet synchronous motor (PMSM)

Parameter	Value	Parameter	Value
Inertia coefficient (J)	kg·m^2$8 \times 10^{-4}$	Stator resistance (R)	2.875 Ω
Damping coefficient (B)	N·m·s2.1×10^{-3}	Inductance (L)	H8.5×10^{-3}
Permanent-magnet flux (λ_s)	0.175 Wb	Number of poles (P)	2

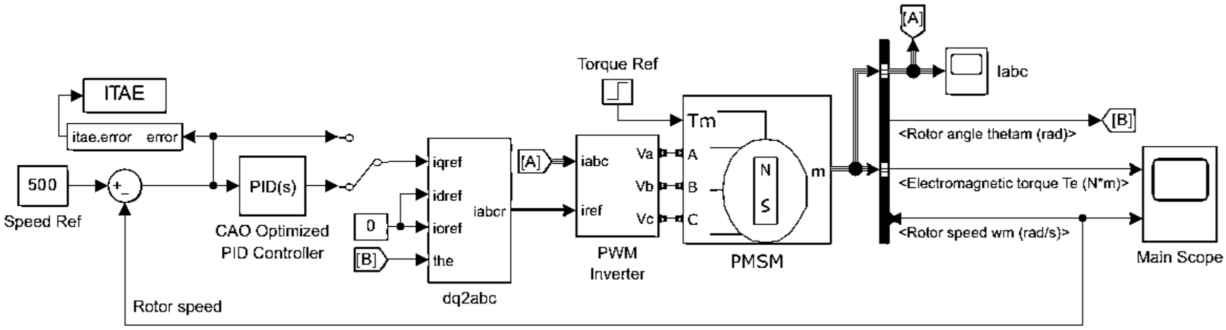

Fig. 4. Model of the PID control system optimized by the COA algorithm for speed control of the PMSM

The coefficients of the PID controller have been tuned using the COA algorithm in order to optimize system performance. The objective of this optimization is to maintain the system speed under critical conditions, enhance stability, and reduce the system response time to sudden torque variations. The simulation results illustrate the system response to rapid torque changes and provide an analysis of stability, response speed, and the system's ability to maintain the reference speed.

Figures 5 and 6 present the simulation results under the aforementioned scenario. The upper plots correspond to the electromagnetic torque response, while the lower plots show the rotor speed. These results demonstrate that the PID controller optimized by COA is capable of effectively maintaining the motor speed even in the presence of abrupt torque variations. This highlights the high capability of COA in precisely tuning the PID controller coefficients and improving the overall system performance. By comparing the obtained data with the results of conventional controllers, the effectiveness and superiority of the COA algorithm in tuning the PID controller gains under realistic dynamic conditions become clearly evident.

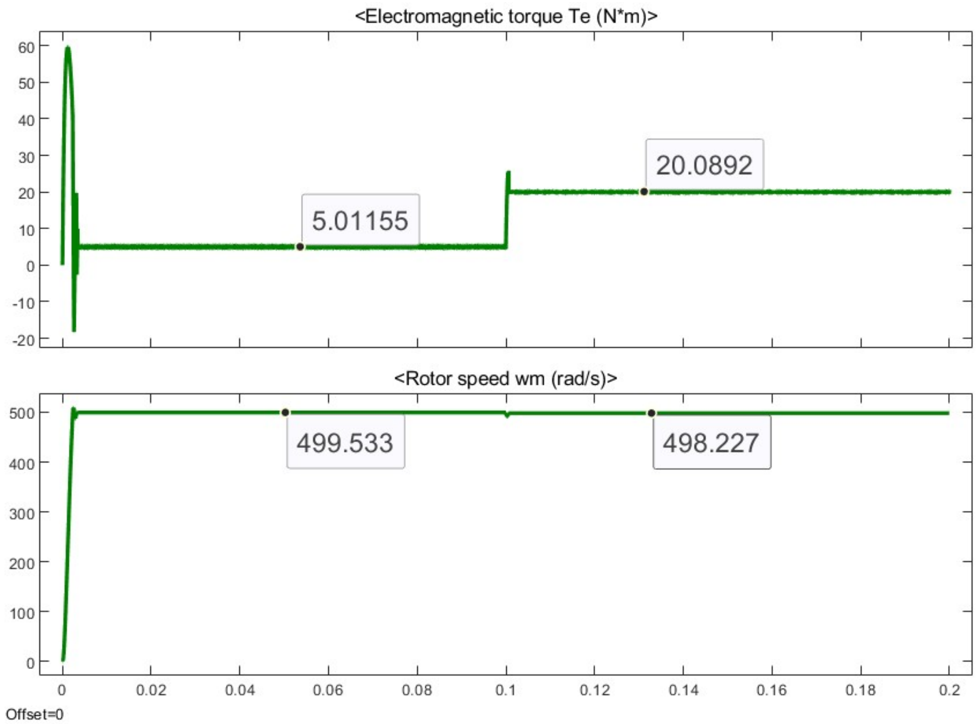

Fig. 5. Closed-loop simulation profiles utilizing the proposed COA-optimized PID controller.

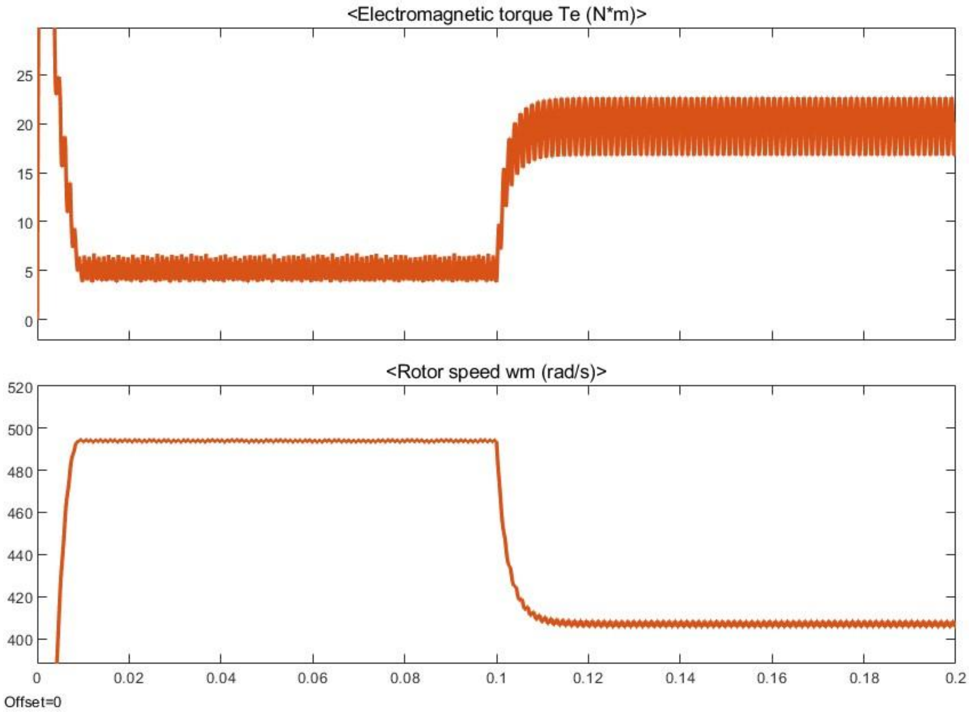

Fig. 6. Open-loop/Unoptimized simulation profiles without the deployment of the optimized PID controller.

3.1. Electromagnetic Torque Response

Without the optimized PID controller: The upper plot in Figure 6 shows severe oscillations and instability in the electromagnetic torque following the sudden increase in load torque from 5 N·m to 20 N·m. These oscillations indicate the system's inability to respond adequately to abrupt load changes.

With the optimized PID controller: The upper plot in Figure 5 demonstrates a rapid and stable system response to the sudden torque variation. The torque quickly reaches its new value (20 N·m) with minimal oscillations.

3.2. Rotor Speed Response

Without the optimized PID controller: The lower plot in Figure 6 shows a sudden drop in rotor speed from 500 rpm to approximately 400 rpm after the torque increase. This variation indicates the system's inability to maintain a constant speed under variable load conditions.

With the optimized PID controller: The lower plot in Figure 5 illustrates that the rotor speed is maintained at a nearly constant value (approximately 500 rpm) with minimal deviation following the abrupt torque increase. This response highlights the high effectiveness of the optimized PID controller in regulating speed under variable load conditions.

3.3. Motor Current Response

Figure 7 presents the three-phase currents of the permanent-magnet synchronous motor (PMSM) throughout the simulation period. This plot is used to analyze the dynamic behavior of the motor currents in the presence of sudden torque variations.

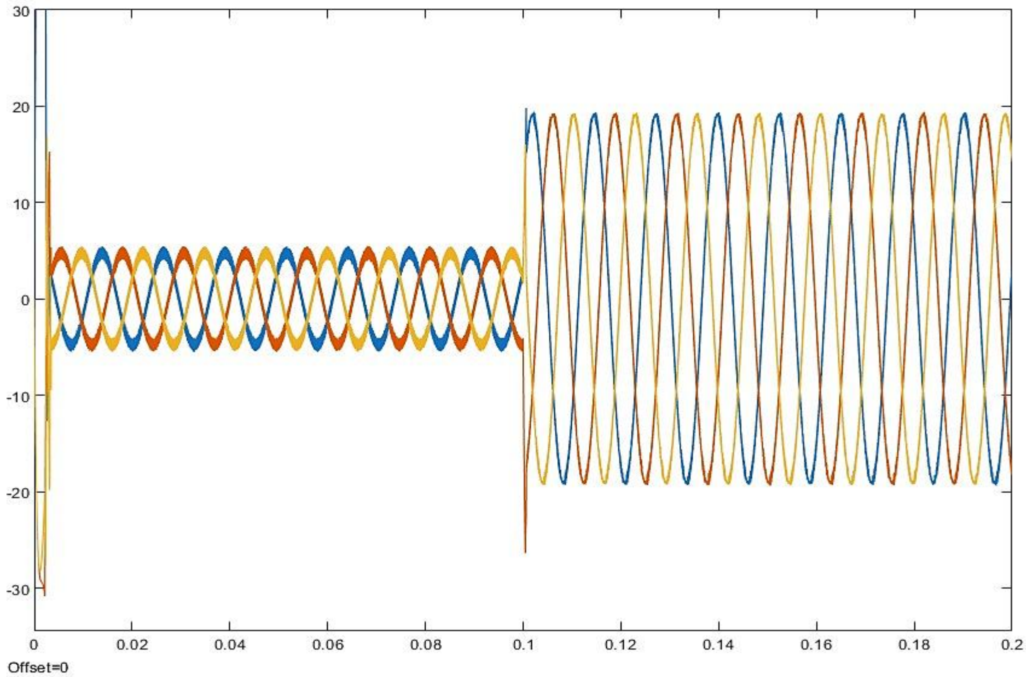

Fig. 7. Three-phase stator current waveforms of the PMSM utilizing the proposed COA-optimized PID controller.

Before $t = 0.1$s, the currents exhibit oscillatory behavior with a specific amplitude and frequency. This indicates the normal operation of the motor under the initial constant torque of 5 N·m.

At $t = 0.1$s, a sudden increase in torque from 5 N·m to 20 N·m is applied. This abrupt change in torque causes significant variations in the motor currents, which are clearly observable in the plot.

After $t = 0.1$s, the amplitude of the current oscillations increases considerably, reflecting the motor's response to the sudden load increase. This rise in current oscillation amplitude results from the motor's effort to maintain a constant speed despite the increased load torque.

The current oscillations following the torque increase indicate the effort of the optimized PID controller to stabilize the system and reduce the speed error. The PID controller adjusts the motor currents in an attempt to maintain a constant rotor speed. The oscillatory behavior of the currents reflects the performance of the control system under dynamic variations. These oscillations gradually diminish, demonstrating the effective performance of the optimized PID controller in returning the system to a stable state. The noticeable improvement in current oscillations after $t = 0.1$s highlights the capability of the optimized PID controller to manage sudden torque changes and maintain stable system performance.

4. CONCLUSION

In this study, the optimization of the speed control of a permanent-magnet synchronous motor (PMSM) using the Cuckoo Optimization Algorithm (COA) was investigated. The primary objective of this optimization was to improve the performance of the motor control system by reducing the speed error and enhancing the dynamic response time. Using COA, the parameters of the PID controller were optimized and subsequently simulated and evaluated in the MATLAB/Simulink R2024a environment. The results demonstrated that the application of COA for tuning the PID controller parameters led to a significant improvement in the overall system performance. The optimized PID controller was able to maintain the motor speed constant in the presence of sudden torque variations and minimize current oscillations.

The plots obtained from the simulations clearly illustrate the dynamic behavior of the system. The electromagnetic torque and rotor speed plots indicate a rapid and stable system response to these variations. A comparison of the simulation results with and without the optimized PID controller clearly demonstrates the superiority of the optimized controller in dealing with abrupt changes. The optimized PID controller was able to respond to load variations with greater accuracy and speed and return the system to a stable state.

The use of the COA algorithm for optimizing the PID parameters highlights the high capability of this algorithm in searching the parameter space and finding the best values to improve system performance. By employing Lévy flights and an effective search process, COA was able to perform precise optimization. This algorithm enhanced the overall efficiency of the PMSM by reducing the speed error and improving the system response time. The results obtained from the simulations confirm the effectiveness of the COA algorithm.

Ultimately, the present study demonstrated that optimizing the PID controller using the COA algorithm can achieve a significant improvement in the performance of PMSM control systems. By reducing dynamic errors and improving transient responses, this method can be widely applied in industrial and practical applications. Given the positive results of this research, it is recommended that future studies also employ metaheuristic optimization algorithms such as COA for optimizing other control and dynamic parameters of complex systems. This approach can contribute to the continuous improvement of industrial system performance and increased productivity.

Declaration

We acknowledge that we used ChatGPT to enhance the academic writing of our manuscript while ensuring the originality and integrity of our work.

Transparency Statement

The data supporting this study are available upon reasonable request to the corresponding author, subject to ethical and confidentiality considerations.

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Declaration of Interest

The authors declare that they have no competing interests.

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