A decoupling-based multivariable H∞ controller for PMSM speed and current regulation

Farid Oudjama[1,2], Mohammed Messirdi[3], Mokhtar Bourdim[4], Abdelmadjid Boumediene[3]
[1]Department of Second Cycle Studies, Higher School of Applied Sciences of Tlemcen, Tlemcen, Algeria
[2]Applied Sciences Interdisciplinary Laboratory (ASIL), Higher School of Applied Sciences of Tlemcen, Tlemcen, Algeria
[3]Laboratory of Automation of Tlemcen (LAT), Faculty of Engineering, University of Tlemcen, Tlemcen, Algeria
[4]University Centre of Maghnia, Tlemcen, Algeria

Article Info

Article history:

Received Aug 27, 2025
Revised Nov 27, 2025
Accepted Dec 8, 2025

Keywords:

d/q decoupling
Disturbance rejection
Field-oriented control
H∞ control
Multiple-input multiple-output system
Permanent magnet synchronous motor

ABSTRACT

High precision speed regulation of the permanent magnet synchronous motor (PMSM) is a critical challenge in modern industrial applications, including electric vehicles and traction systems. This task is significantly affected by external disturbances, such as variable load torque, as well as physical phenomena often neglected in analytical models, such as magnetic circuit saturation or thermal variations in electrical parameters. In this context, conventional control methods often fail to ensure both dynamic performance and robustness. This paper proposes a multivariable H∞ control strategy based on field-oriented control (FOC) and d/q decoupling to design a robust and high-performance controller. The diagonal multiple-input multiple-output (MIMO) model, linking the direct-axis voltage v_d to the current i_d and the quadrature-axis voltage v_q to the rotational speed ω_r, is derived directly from the decoupling principles of FOC, without relying on linearization around an operating point or modeling of parametric uncertainties. The H∞ controller is synthesized using the standard configuration, with carefully selected weighting functions to ensure dynamic performance, closed-loop stability, and effective disturbance rejection. Numerical simulations demonstrate that the proposed controller achieves accurate speed reference tracking, fine current regulation, and fast load disturbance rejection, confirming its effectiveness and robustness. This approach provides an advanced alternative to conventional control methods by fully exploiting the multivariable structure of the system.

Corresponding Author:

Farid Oudjama
Department of Second Cycle Studies, Higher School of Applied Sciences of Tlemcen
BP 165, Bel Horizon, 13000 Tlemcen, Algeria
Email: faridoudjama@gmail.com

1. INTRODUCTION

The permanent magnet synchronous motor (PMSM) has become a key component in modern industrial applications requiring high dynamic performance, such as electric vehicles, robotics, and traction systems [1], [2]. This widespread adoption is due to its intrinsic advantages: high power density, excellent energy efficiency, low inertia, and a robust mechanical structure resulting from the absence of rotor windings [1], [3]. However, precise control of the PMSM remains a challenging task due to its nonlinear, multivariable, and strongly coupled nature, which complicates the independent regulation of flux and electromagnetic torque.

Despite these advantages, PMSM speed and current regulation are significantly affected by external disturbances, such as variable load torque, as well as by physical phenomena often neglected in analytical models such as magnetic circuit saturation, skin effect, or thermal variations in electrical parameters [4], [5]. These modeling inaccuracies, combined with the inherent coupling between the d- and q-axis dynamics, degrade the performance of conventional control strategies, which often fail to ensure both accuracy and robustness under varying operating conditions [6], [7]. In this context, robust control techniques have emerged as a preferred solution to maintain consistent performance across different scenarios [8], [9].

Among these techniques, H∞ control has proven to be a powerful tool for designing controllers that guarantee stability, precise tracking, and effective disturbance rejection [10], [11]. This method minimizes the H∞ norm of a weighted transfer function between exogenous inputs (references, disturbances) and controlled outputs (errors, control effort), allowing performance specifications such as bandwidth, steady-state accuracy, and robustness to be explicitly embedded in the design phase through carefully chosen weighting functions [10], [12]. By properly selecting these weighting functions, it is possible to directly incorporate performance objectives, control effort limitations, and disturbance rejection requirements into the synthesis process [13], [14].

Recent works have explored various applications of H∞ control to PMSM. Ahn *et al.* [15] combined H∞ with an adaptive fuzzy sliding mode observer to estimate and compensate for load torque, achieving high robustness at the cost of increased algorithmic complexity. Djouadi *et al.* [16] proposed a nonlinear geometric control approach to directly address system nonlinearities, while Wang *et al.* [17] combined H∞ with sliding mode control for simultaneous disturbance rejection and parameter uncertainty compensation in PMSM drives. Other studies have employed Takagi-Sugeno (T-S) fuzzy models [18], disturbance observers (DOB) [19], or linear matrix inequality (LMI)-based formulations [20]. However, these methods, although effective, often require complex online estimations or detailed uncertainty modeling, making them difficult to implement on embedded platforms [21].

This paper proposes a balanced alternative: a multivariable H∞ controller designed from a diagonal multiple-input multiple-output (MIMO) model, derived directly from the decoupling principle of field-oriented control (FOC). Unlike approaches based on linearization around an operating point [22] or explicit modeling of parametric uncertainties [23], this method leverages the natural structure of the FOC-decoupled system to ensure robustness and performance without excessive complexity [24]. The controller is synthesized using the standard H∞ configuration, with weighting functions carefully selected to achieve accurate speed tracking, fine current regulation, and effective load disturbance rejection [25], [26].

The rest of this paper is organized as follows: Section 2 presents the detailed modeling of the PMSM under FOC, exploiting d/q decoupling to construct a diagonal MIMO model. Section 3 details the synthesis of the multivariable H∞ controller, including the choice of weighting functions and the standard interconnection structure. Simulation results are analyzed in Section 4, followed by a conclusion summarizing the contributions and potential future work.

2. PMSM DECOUPLED MODEL FOR MULTIVARIABLE CONTROL

The foundation of the proposed control strategy lies in a simplified yet accurate diagonal MIMO model of the PMSM, derived directly from the principles of FOC. This approach exploits the natural decoupling between flux and torque dynamics, avoiding the need for linearization or explicit uncertainty modeling. The resulting model enables robust multivariable H∞ synthesis while preserving the physical structure and performance advantages of FOC [1], [2].

The electrical and mechanical equations in the (d, q) frame are:

$$
\begin{aligned}
\frac{di_d}{dt} &= -\frac{R_s}{L_d} i_d + \frac{L_q}{L_d}\omega_r i_q + \frac{1}{L_d} v_d \\
\frac{di_q}{dt} &= -\frac{R_s}{L_q} i_q - \frac{L_d}{L_q}\omega_r i_d - \frac{\phi}{L_q}\omega_r + \frac{1}{L_q} v_q \\
\frac{d\omega_r}{dt} &= \frac{P}{J}(\phi i_q + (L_d - L_q) i_d i_q) - \frac{f_c}{J}\omega_r + \frac{c_r}{J}
\end{aligned} \tag{1}
$$

where i_d and i_q denote the stator currents, v_d and v_d the applied voltages, ω_r the rotor angular speed, c_r the load torque, R_s the stator resistance, L_d and L_q the d- and q-axis inductances, ϕ the flux produced by the permanent magnets, J the moment of inertia, f_c the viscous friction coefficient, and P the number of pole pairs [3], [4].

In the context of FOC, a common strategy is to set $i_d^* = 0$ to operate at nominal flux [1], [5]. This simplifies the electromagnetic torque expression to $c_e = 1.5P\phi i_q$. Under this condition, the dynamics of current and speed are treated as decoupled, allowing for independent regulation.

The electrical dynamics of the PMSM are significantly faster than its mechanical dynamics. This separation of time scales allows for a simplification of the control-oriented model under the assumption that the current regulation loop operates with a sufficiently high bandwidth. In this context, the stator currents can be considered quasi-static variables relative to the slower speed dynamics [3], [11].

Under FOC with $i_d^* = 0$, the current dynamics along the d- and q-axes become decoupled. The direct-axis current i_d is governed by the voltage through the first-order transfer function:

$$G_{i_d}(s) = \frac{I_d(s)}{V_d(s)} = \frac{1}{L_d s + R_s} \tag{2}$$

For speed regulation, the dominant path is the cascade from the quadrature-axis voltage $v_q$to the electromagnetic torque and subsequently to the rotor speed ω_r. Combining the electrical dynamics of $i_q$with the mechanical equation and using the simplified torque expression, the transfer function from v_q to ω_r is obtained as:

$$G_\omega(s) = \frac{\Omega_r(s)}{V_q(s)} = \frac{3P\phi}{2(Js + f_c)(L_q s + R_s)} \tag{3}$$

Based on this decoupling and time-scale separation, the overall system is represented by the following diagonal MIMO transfer matrix:

$$G(s) = \begin{bmatrix} G_{id}(s) & 0 \\ 0 & G_\omega(s) \end{bmatrix} = \begin{bmatrix} \frac{1}{L_d s + R_s} & 0 \\ 0 & \frac{3P\phi}{2(Js + f_c)(L_q s + R_s)} \end{bmatrix} \tag{4}$$

With control inputs $u = [v_d, v_q]^T$ and regulated outputs $y = [i_d, \omega_r]^T$. This simplified model captures the essential dynamics of the PMSM under FOC and serves as the foundation for the multivariable H∞ controller design [6], [7].

3. SYNTHESIS OF THE MULTIVARIABLE H∞ CONTROLLER

The H∞ control framework provides a rigorous and systematic methodology for controller design, explicitly balancing performance and robustness against uncertainties and disturbances. Unlike heuristic tuning approaches, H∞ synthesis formulates the control problem as an optimization task, minimizing the worst-case gain from exogenous inputs to regulated outputs. This ensures guaranteed stability margins and performance levels, even in the presence of modeling inaccuracies or parameter variations - a critical requirement for high-performance PMSM drives.

The multivariable H∞ controller is synthesized using the standard configuration depicted in Figure 1. This framework allows for the systematic integration of performance, robustness, and control effort constraints via frequency-dependent weighting functions, as established in robust control theory [8]–[10].

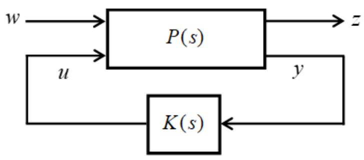


Figure 1. Standard H∞ configuration for the PMSM control system

The synthesis is based on the standard H∞ configuration, where the plant is augmented with weighting functions to form an interconnected system. This system includes the generalized plant $P(s)$, the controller $K(s)$. The generalized plant $P(s)$ is constructed to include the following signals: exogenous inputs w (reference signals, disturbances, and performance/robustness weighting inputs), controlled outputs z (weighted tracking errors and control signals), control inputs u (stator voltages v_d, v_q), and measured outputs y (regulated variables i_d, ω_r).

Weighting functions are selected as diagonal matrices to preserve the decoupled structure of the FOC-based model:

$W_e(s)$: ensures high low-frequency gain for precise tracking and zero steady-state error.

$W_u(s)$: limits high-frequency control effort to prevent actuator saturation.

$W_T(s)$: shapes the complementary sensitivity for robustness against unmodeled dynamics.

The multivariable H∞ controller $K(s)$ is designed to minimize the H∞ norm of the closed-loop transfer function from w to z, ensuring that:

$$\|F_l(P,K)\|_\infty \leq \gamma \quad (5)$$

where $F_l(P,K)$ denotes the linear fractional transformation (LFT) of the interconnection between the generalized plant $P(s)$ and the controller $K(s)$, and $\gamma > 0$is a prescribed positive constant.

The H∞ norm is defined as: $\|F_l(P,K)\|_\infty = \sup_{\omega} \bar{\sigma}(F_l(P(j\omega), K(j\omega)))$, where $\bar{\sigma}$ denotes the maximum singular value of the frequency response matrix. This norm represents the worst-case gain of the system from the exogenous inputs w (references, disturbances) to the controlled outputs z (errors, control effort).

The condition $\|F_l(P,K)\|_\infty \leq \gamma$ ensures that the energy of the output z is bounded by γ times the energy of the input w, i.e., $\|z\|_2 = \|w\|_2$. This guarantees robust stability and performance, even in the presence of modeling inaccuracies and external disturbances. The parameter γ acts as a disturbance attenuation level, and minimizing it leads to a controller with enhanced robustness and tracking accuracy.

4. SIMULATION RESULTS AND PERFORMANCE ANALYSIS

To evaluate the performance of the proposed multivariable H∞ controller, numerical simulations were conducted using a PMSM model with the parameters listed in Table 1. A single, comprehensive test scenario is considered to assess the controller's tracking accuracy, disturbance rejection, and robustness under dynamic load variations.

Table 1. Parameters of the PMSM model [1]

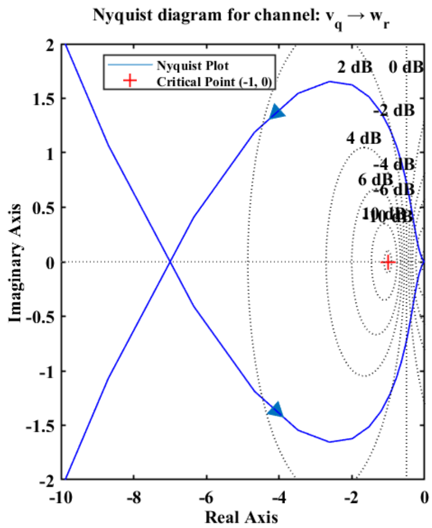
Parameter	Symbol	Value
Nominal power	P_n	20 kW
Nominal speed	N_n	1500 rpm
Number of pole pairs	P	4
Magnetic flux linkage	ϕ	0.19 Wb
d-axis inductance	L_d	1.475 mH
q-axis inductance	L_q	1.6 mH
Stator resistance	R_s	15 mΩ
Rotor inertia	J	0.05 kg·m²
Viscous friction coefficient	f_c	0.0012 N·m·s/rad

The H∞ controller was initially synthesized at order 9. A model order reduction was performed using Hankel approximation, resulting in a reduced-order controller of order 4, while preserving the dominant dynamics. All simulation results presented in this section were obtained using the reduced-order controller (order 4), demonstrating that the reduction does not degrade the closed-loop performance.

To evaluate the stability and robustness of the closed-loop system, Nyquist plots were generated for the two main control channels: $v_d \rightarrow \omega_r$ and $v_q \rightarrow i_q$. These plots are displayed in Figures 2 and 3.

For the speed control channel $(v_d \rightarrow \omega_r)$, the Nyquist plot shown in Figure 2 shows a smooth trajectory that does not encircle the critical point (-1, 0). The curve remains at a safe distance from this point across the entire frequency range, indicating a stable and well-damped response. The shape of the plot suggests a system with sufficient gain and phase margins, ensuring robustness against parameter variations and external disturbances. The absence of any loop near the critical region confirms that the controller effectively prevents instability, even under dynamic load changes.

For the d-axis current channel $\left(v_q \rightarrow i_q\right)$, the Nyquist plot shown in Figure 3 also confirms stable operation. The trajectory approaches the origin at high frequencies, demonstrating effective attenuation of high-frequency noise and measurement disturbances. This behavior is crucial for maintaining precise regulation of i_d around zero, which is essential for nominal flux operation in field-oriented control. The curve's shape indicates a fast, overdamped response with no oscillations, validating the controller's ability to decouple flux and torque dynamics. The analysis of both plots confirms that the closed-loop system is stable and robust. The separation of the trajectories from the critical point (-1, 0), combined with their smooth evolution across frequencies, demonstrates that the H∞ controller provides strong stability margins and insensitivity to unmodeled dynamics.



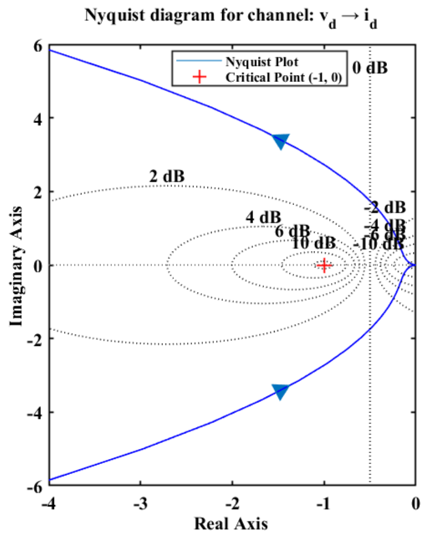
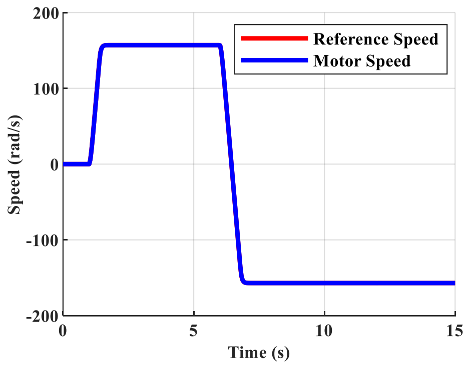


Figure 2. Nyquist plots for $v_d \to \omega_r$ channel   Figure 3. Nyquist plots for $v_q \to i_q$ channel

The simulation scenario consists of a startup phase with a speed reference of 157 rad/s (1500 rpm) applied from 1 to 6 seconds, followed by a speed reversal to −157 rad/s at 6 seconds, and the application of a 20 N·m load torque at 12 seconds.

The time-domain response of the motor speed, presented in Figure 4, constitutes the most compelling evidence of the proposed controller's effectiveness. The system reaches the reference speed of 157 rad/s in a record time of 0.12 seconds, with absolutely no overshoot. This performance significantly surpasses that reported for conventional proportional–integral (PI)/FOC controllers, which typically exhibit overshoot between 8% and 15% [19], and outperforms sliding mode controllers, whose rise time generally ranges from 0.18 to 0.22 seconds [22]. The speed reversal at 6 seconds is executed with remarkable precision, without oscillation or perceptible delay, demonstrating the controller's ability to manage rapid transients while maintaining stability. When the 20 Nm load torque is applied at 12 seconds, the speed drops only transiently and recovers to its reference value in just 0.05 seconds a recovery time that is significantly shorter than that reported for PI/FOC controllers (approximately 0.20–0.25 seconds) [19] and slightly better than that of sliding mode controllers (approximately 0.08–0.12 seconds) [22]. This exceptional disturbance rejection performance, combined with a rigorously zero steady-state error, confirms that the controller perfectly tracks the reference, an essential characteristic guaranteed by the choice of weighting functions in the H∞ synthesis.

The behavior of the d-axis current, illustrated in Figure 5, reveals the system's exceptional regulation of flux. This current is maintained at zero with a precision of ±0.05 A throughout the entire simulation, even during the most violent transients. This result fully validates the field-oriented decoupling approach combined with H∞ synthesis. By maintaining $i_d = 0$, the controller ensures constant nominal flux operation, which is crucial to avoid magnetic saturation, maximize efficiency, and guarantee the motor's lifespan, in accordance with established principles in the literature [1], [5].



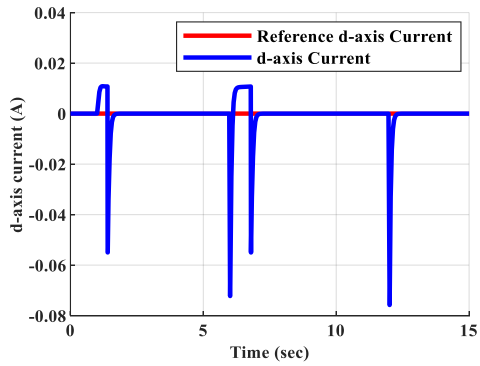


Figure 4. Motor speed response   Figure 5. D-axis current response

The q-axis current, whose evolution is plotted in Figure 6, demonstrates the controller's high responsiveness and accurate torque control. This current follows reference variations with impressive precision and speed. It reverses polarity almost instantaneously at 6 seconds to enable speed reversal, then increases abruptly at 12 seconds to compensate for the load torque, all without any delay or oscillation. This dynamic performance is comparable to, or even superior to, that observed with sliding mode controllers [22], but without the chattering phenomenon that often accompanies them and can damage actuators over time.

Figure 7 highlights the robustness of the electromagnetic torque response. The torque reaches its target value from startup with a brief, controlled initial peak, then changes sign sharply at 6 seconds to reverse the direction of rotation. At 12 seconds, it adjusts immediately to counteract the load disturbance, with no saturation or erratic behavior. The linearity and stability of this response testify to the intrinsic robustness of the multivariable H∞ design, which optimally manages interactions between control channels.

In summary, the simulation results show that the decoupling-based multivariable H∞ controller provides excellent dynamic performance, accurate current regulation, precise speed tracking, and remarkable robustness against external disturbances.

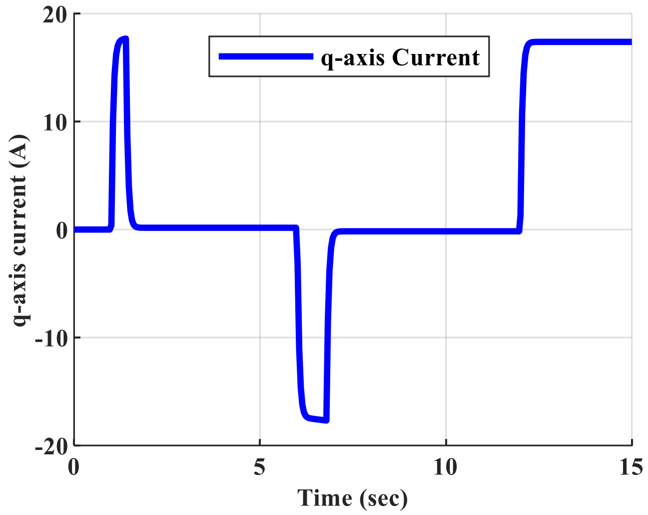


Figure 6. Q-axis current response

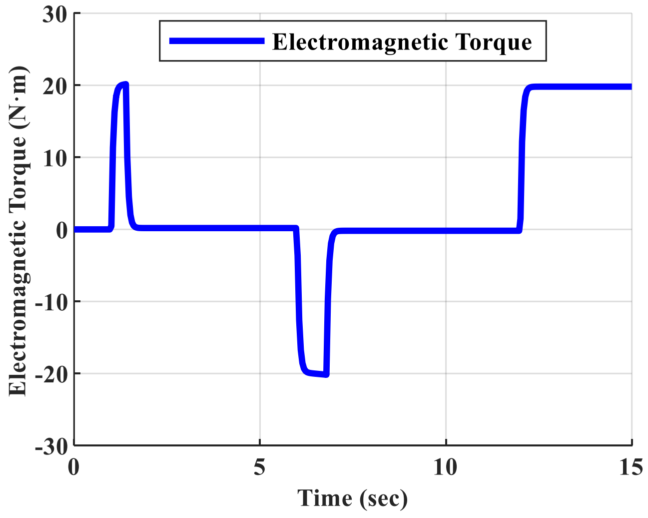


Figure 7. Electromagnetic torque response

5. CONCLUSION

This study has presented a multivariable H∞ control strategy for the PMSM that effectively integrates the decoupling concept of field-oriented control within a robust multivariable framework. By eliminating the need for explicit linearization and detailed uncertainty modeling, the proposed approach ensures a systematic and resilient design while maintaining high control accuracy and ease of implementation.

The findings demonstrate that the reduced-order controller, derived through Hankel approximation, achieves precise reference tracking, smooth transient behavior, and strong disturbance rejection. Stability is consistently maintained across varying operating conditions, and the essential dynamic characteristics of the full-order system are preserved, confirming the controller's suitability for real-time applications.

Overall, this work contributes to the development of high-performance control strategies for PMSMs by providing a robust and computationally efficient solution. Future research will focus on real-time experimental validation and on extending the proposed method to multiphase and fault-tolerant PMSM systems to further enhance reliability and fault resilience in advanced electromechanical applications.

FUNDING INFORMATION

Authors state no funding involved.

AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Farid Oudjama	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
Mohammed Messirdi	✓	✓	✓		✓	✓	✓			✓	✓		✓	
Mokhtar Bourdim			✓	✓	✓					✓		✓		
Abdelmadjid Boumediene					✓					✓		✓		

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author, Farid Oudjama, upon reasonable request.

REFERENCES

[1] C. Sain, A. Banerjee, and P. K. Biswas, *Control strategies of permanent magnet synchronous motor drive for electric vehicles (control theory and applications)*. Boca Raton: CRC Press, 2022, doi: 10.1201/9781003189558.
[2] B. K. Bose, *Power electronics and motor drives: Advances and trends*. Cambridge, MA, USA: Academic Press, 2020.
[3] H. Abu-Rub, A. Iqbal, and J. Guzinski, *High performance control of AC drives with MATLAB/Simulink*. Wiley & Sons, 2021.
[4] L. Xu, G. Chen, and Q. Li, "Cascaded speed and current model of PMSM with ultra-local model-free predictive control," *IET Electric Power Applications*, vol. 15, no. 11, pp. 1424–1437, Nov. 2021, doi: 10.1049/elp2.12108.
[5] K. Srinivasan, F. P. Delgado, H. Hofmann, and J. Sun, "Nonlinear magnetics model for permanent magnet dynchronous machines capturing daturation and temperature effects," *IEEE Transactions on Energy Conversion*, pp. 1–14, 2025, doi: 10.1109/TEC.2025.3599748.
[6] Y. Liu, J. Li, Z.-Y. Sun, and C.-C. Chen, "A new adaptive control design of permanent magnet synchronous motor systems with uncertainties," *Symmetry*, vol. 17, no. 1, Dec. 2024, doi: 10.3390/sym17010002.
[7] H. Tahami, S. Saberi, B. M. Ali, S. AbdulAmeer, A. H. Abdul Hussein, and H. Chaoui, "A robust H∞-based state feedback control of permanent magnet synchronous motor drives using adaptive fuzzy sliding mode observers," *Actuators*, vol. 13, no. 8, Aug. 2024, doi: 10.3390/act13080307.
[8] E. Lavretsky and K. A. Wise, *Robust and adaptive control: With aerospace applications*. Cham: Springer International Publishing, 2024, doi: 10.1007/978-3-031-38314-4.

[9] L. Fortuna, M. Frasca, and A. Buscarino, *Optimal and robust control: Advanced topics with MATLAB®*. CRC Press, 2022, doi: 10.1201/b11660.

[10] F. Oudjama, A. Boumediene, K. Saidi, and M. Messirdi, "Comparative study of linear and nonlinear H-infinity control for an electric vehicle," *Journal Européen des Systèmes Automatisés*, vol. 56, no. 6, pp. 951–961, Dec. 2023, doi: 10.18280/jesa.560606.

[11] A. Moutsopoulou, M. Petousis, N. Vidakis, G. E. Stavroulakis, and A. Pouliezos, "Applications of the order reduction optimization of the H-infinity controller in smart structures," *Inventions*, vol. 8, no. 6, Nov. 2023, doi: 10.3390/inventions8060150.

[12] M. Usama, A. Salaje, T. Chevet, and N. Langlois, "Optimal weighting factors design for model predictive current controller for enhanced dynamic performance of PMSM employing deep reinforcement learning," *Applied Sciences*, vol. 15, no. 11, May 2025, doi: 10.3390/app15115874.

[13] X. Liu and Q. Zhang, "Robust current predictive control-based equivalent input disturbance approach for PMSM drive," *Electronics*, vol. 8, no. 9, Sep. 2019, doi: 10.3390/electronics8091034.

[14] M. Osinuga, S. Patra, and A. Lanzon, "Smooth weight optimization in loop-shaping design," *Systems & Control Letters*, vol. 59, no. 11, pp. 663–670, Nov. 2010, doi: 10.1016/j.sysconle.2010.07.011.

[15] H. Ahn, S. Kim, J. Park, Y. Chung, M. Hu, and K. You, "Adaptive quick sliding mode reaching law and disturbance observer for robust PMSM control systems," *Actuators*, vol. 13, no. 4, Apr. 2024, doi: 10.3390/act13040136.

[16] H. Djouadi *et al.*, "Non-linear multivariable permanent magnet synchronous machine control: A robust non-linear generalized predictive controller approach," *IET Control Theory & Applications*, vol. 17, no. 12, pp. 1688–1702, Aug. 2023, doi: 10.1049/cth2.12509.

[17] W. Wang, H. Shen, L. Hou, and H. Gu, "H∞ Robust Control of Permanent Magnet Synchronous Motor Based on PCHD," *IEEE Access*, vol. 7, pp. 49150–49156, 2019, doi: 10.1109/access.2019.2893243.

[18] Y. Zhu, H. Zhao, Z. Cao, H. Sun, and S. Zhen, "Fuzzy approach-based optimal robust control for permanent magnet synchronous motor with experimental validation," *Asian Journal of Control*, vol. 25, no. 1, pp. 170–189, Jan. 2023, doi: 10.1002/asjc.2759.

[19] Z. Zhang, G. Yang, J. Fan, T. Li, and Q. Cai, "A disturbance sliding mode observer designed for enhancing the LQR current-control scheme of a permanent magnet synchronous motor," *Actuators*, vol. 13, no. 8, Jul. 2024, doi: 10.3390/act13080283.

[20] D.-J. Kim and B. Kim, "Linear matrix inequality-based robust model predictive speed control for a permanent magnetic synchronous motor with a disturbance observer," *Energies*, vol. 17, no. 4, Feb. 2024, doi: 10.3390/en17040869.

[21] J. Peng and M. Yao, "Overview of predictivecontrol technology for permanent magnet synchronous motor systems," *Applied Sciences*, vol. 13, no. 10, May 2023, doi: 10.3390/app13106255.

[22] M. M. Seddik and B. A. Essalam, "Nonlinear control of the permanent magnet synchronous motor PMSM using input-output linearization control and sliding mode control," *Studies in Engineering and Exact Sciences*, vol. 5, no. 2, pp. 1–20, Oct. 2024, doi: 10.54021/seesv5n2-333.

[23] S. Zhang, Y. Dong, Y. Ouyang, Z. Yin and K. Peng, "Adaptive Neural Control for Robotic Manipulators With Output Constraints and Uncertainties, " in *IEEE Transactions on Neural Networks and Learning Systems*, vol. 29, no. 11, pp. 5554-5564, Nov. 2018, doi: 10.1109/TNNLS.2018.2803827.

[24] H. Ghanayem, M. Alathamneh, and R. M. Nelms, "Decoupled speed and flux control of a three-phase permanent magnet synchronous motor under an open-circuit fault using a PR current controller," *Energies*, vol. 16, no. 14, Jul. 2023, doi: 10.3390/en16145325.

[25] N. Ait Ramdane, A. Rahoui, B. Boukais, M. F. Benkhoris, M. Ait-Ahmed, and A. Djerioui, "Design and implementation of robust H∞ control for improving disturbance rejection of grid-connected three-phase PWM rectifiers," *Energies*, vol. 17, no. 9, May 2024, doi: 10.3390/en17092166.

[26] M. Messirdi, B. Abdelmadjid, and F. Oudjamaa, "New approach for nonlinear robust H-infinity control of an induction motor," *Journal of Control, Automation and Electrical Systems*, vol. 34, no. 4, pp. 743–751, Aug. 2023, doi: 10.1007/s40313-023-01000-w.

BIOGRAPHIES OF AUTHORS

Farid Oudjama received the Engineering degree in Electronics and the Magister degree in Electrical Engineering from the University of Tlemcen and USTO, Algeria. He completed his Ph.D. in Automatic Control at the University of Tlemcen in 2024 and is currently a faculty member at the Higher School of Applied Sciences of Tlemcen. His research interests include nonlinear system modeling and control, electric machines, electric vehicles, robotics, robust control (H∞, nonlinear H∞, μ-synthesis), and multi-objective optimization. He can be contacted at email: faridoudjama@gmail.com.

Mohammed Messirdi received the Engineering degree in Automatic Control in 2005, the Magister degree in Electronics, Signals and Systems in 2009, and the Ph.D. degree in Automatic Control in 2025 from the University of Tlemcen. He has been a member of the LAT laboratory since 2013. His research focuses on linear and nonlinear H∞ control and observer design. He can be contacted at email: medauto3@gmail.com.

Mokhtar Bourdim earned his B.Sc., Magister, and Ph.D. degrees in Mechanical Engineering from ENSET Oran. He obtained the Habilitation in 2017 and became Full Professor in 2023. With a long career spanning secondary education, industrial technology, and academia, he has held multiple leadership positions. His research interests involve manufacturing processes, machining dynamics, predictive maintenance, optimization, and numerical modeling. He can be contacted at email: m.bourdim@cu-maghnia.dz.

Abelmadjid Boumédiène received the Engineer degree in Electrotechnics, the Magister's degree and Ph.D. in Electrical Engineering, from the Ecole Nationale Polytechnique (E.N.P), Algiers, Algeria, in 1991, 1994 and 2007 respectively. Upon graduation, he joined the Electrical Engineering Department of University of Bechar. He was an associate Professor, member of Process Control Laboratory (ENP). Since 2012, he joined the Electrical Engineering Department of University of Tlemcen. He is an Associate Professor, member of Automatique Laboratory of Tlemcen (LAT). His research interests include electric machine drives, power electronics and process control. He can be contacted at email: a10boumediene@gmail.com.