

RESEARCH ARTICLE

OPEN ACCESS

AN INNOVATIVE VARIABLE MAGNETIC GEAR SYNCHRONOUS MOTOR TOPOLOGY FOR ELECTRIC VEHICLES

Kamel Salim Belkhir^{*1}, Houcem Achouri² and Kawther Fatmi³^{1, 2, 3}LIS Intelligent System Laboratory, Department of Electrical Engineering, Faculty of Technology, University Setif 1 –Ferhat Abbas, Elmaabouda, 19000, Setif, Algeria.¹<http://orcid.org/0009-0004-7964-9378>²<http://orcid.org/0009-0003-5917-1891>³<http://orcid.org/0009-0008-8685-642X>Email: *belkhirk@yahoo.fr, achourihoussam8@gmail.com, kawtherfatmi1@gmail.com

ARTICLE INFO

Article History

Received: February 22, 2026

Reviewed: March 22, 2026

Accepted: April 01, 2026

Published: May 29, 2026

*Keywords:*Electric vehicle,
Magnetic gear,
Permanent magnet synchronous motor.

ABSTRACT

The Electric vehicle (EV) performance is critically dependent on the balance between speed and torque, which is managed through the ongoing development of motor technologies and control strategies. However, achieving high rotational speeds presents substantial challenges for conventional motor controllers due to issues such as switching losses, oscillations, and increased thermal loads. Furthermore, the integration of multi-speed transmission systems introduces additional complexity and weight, particularly concerning gear ratio selection and torque management. This study presents an innovative electric motor design for EV applications that eliminates the need for mechanical gearing and specialized controllers. The proposed design incorporates a synchronous permanent magnet input rotor that is magnetically coupled to a three-stage winding output rotor. This configuration facilitates high-speed operation, reduces acoustic noise and vibration, minimizes maintenance requirements, enhances reliability, and provides magnetic isolation between the input and output shafts. The novel integration of magnetic gearing with variable-stage windings enables the motor to sustain high efficiency across a wide speed range. Regardless of the motor type—whether Interior Permanent Magnet, Electrically Excited Synchronous, or C-core Hybrid Switched Reluctance—the proposed design achieves exceptional speed performance through simplified control and precise pole-pair determination. These findings indicate a promising direction for high-speed, gearless electric motor systems designed for next-generation EVs.



Copyright ©2026 by authors and Galileo Institute of Technology and Education of the Amazon (ITEGAM). This work is licensed under the Creative Commons Attribution International License (CC BY 4.0).

1. INTRODUCTION

The revolutions per minute (RPM) limit of electric motors in electric vehicles (EVs) can vary significantly based on the type of motor employed and the specific design requirements of the vehicle. EVs primarily utilize motors such as induction motors, brushless DC motors (BLDC), and permanent magnet synchronous motors (PMSM), each possessing distinct operational characteristics. For instance, PMSMs and BLDC motors are widely adopted due to their high efficiency and performance. These motors can operate at elevated RPM limits, typically ranging from 10,000 to 15,000 RPM in commercial EV applications, contingent upon the vehicle's design and manufacturer specifications [1], [2]. Surface-mounted PMSMs are capable of achieving rotational speeds up to 52,000 RPM, offering exceptional power density and compactness for EV traction systems.

However, they face challenges such as substantial rotor stress, eddy current losses, and reliance on costly rare-earth magnets, necessitating reinforced rotors, such as carbon-fiber sleeves, and advanced thermal management strategies [3]. Interior PMSMs (IPMSMs) can operate reliably at speeds up to 40,000 RPM, although commercial models typically restrict them to approximately 20,000 RPM due to increased bearing wear, vibration, and control complexity, despite their enhanced field-weakening capabilities [4]. Switched Reluctance Motors (SRMs) can surpass 100,000 RPM in specialized low-power applications, attributed to their robust rotor structure and magnet-free design [5]. Nevertheless, they generate high torque ripple and acoustic noise, requiring complex control and current shaping to ensure smooth operation, which limits their application in mainstream electric vehicles [6].

Synchronous Reluctance Motors (SynRMs) provide rare-earth-free operation and high efficiency, reaching around 14,000 RPM at 23 kW, but their torque density is generally lower, necessitating precise rotor geometry, which makes them less competitive in high-performance traction applications unless optimized [7]. Induction motors are also a prevalent choice for EVs and can similarly achieve high RPM levels, albeit generally exhibiting a broader RPM range due to their robust design and control flexibility. However, such motors may encounter challenges such as thermal management and efficiency decline at extremely high RPMs [1], [8]. Overall, while PMSMs dominate in high-performance EVs due to their efficiency and control precision, SRMs and SynRMs provide compelling alternatives when cost, simplicity, and rare-earth independence are prioritized, though at the cost of noise, control complexity, or reduced torque output [9-12]. The RPM limit in a particular EV model is largely influenced by the vehicle's design specifications, which encompass elements like the desired maximum speed, acceleration capabilities, and overall efficiency.

Electric motors in these vehicles are crafted to strike a balance among these performance aspects while ensuring reliability and reducing thermal stress during high-speed operations [13-18]. As velocity increases, motor controllers encounter challenges primarily due to elevated switching losses and oscillations. Soft switching technologies can address these issues by reducing the stress associated with high-frequency operations [19]. The implementation of a multi-speed transmission system introduces complexities, such as additional weight and the challenges of selecting appropriate gear ratios and managing torque interruptions during gear shifts [8]. High rotational speeds frequently result in increased heat generation, which can adversely impact the overall efficiency and lifespan of electric motors. Effective thermal management is essential for maintaining the performance of traction motors under high-speed conditions. This necessitates the implementation of innovative cooling solutions and the design of motors capable of handling increased thermal loads without a significant decline in performance [20].

Magnetic gears enable the transmission of power between input and output shafts without direct contact, thereby ensuring quiet operation and protection against overloads, in contrast to traditional mechanical gears [21-24]. High-speed magnetic gear motors are garnering considerable attention within the EV due to their capability to achieve rotational speeds surpassing 20,000 RPM without mechanical contact between the driving and driven components. This non-contact torque transmission mitigates wear, noise, and the necessity for lubrication, thereby enhancing the reliability and efficiency of these systems. Among the most promising designs for high-RPM performance are reluctance magnetic gears, which employ rotors composed entirely of iron to minimize eddy current losses and endure high centrifugal forces [25], and flux-switching magnetic gears, which incorporate multiple magnetic flux paths to sustain high torque density with improved thermal stability [26].

In advanced EV motor systems, magnetic multiple spur gear (MMSG) configurations are utilized to concentrate torque transmission within a compact space, facilitating both high-speed and high-power-density operation without compromising gear ratio flexibility [27]. Furthermore, the implementation of Halbach arrays in high-speed magnetic gears has been demonstrated to enhance air-gap flux density and reduce torque ripple, resulting in smoother and more efficient operation at extreme speeds [28]. The design and optimization of these high-RPM magnetic gear systems increasingly depend on nonlinear magnetic equivalent circuit (MEC) models, which offer precise and rapid predictions of magnetic behavior and torque characteristics without the computational demands of full finite element analysis (FEA) [29]. Collectively, these advancements support the integration of high-speed magnetic gear motors in next-generation EV drivetrains, where performance, efficiency, and durability are paramount.

This paper presents an innovative electric motor design for EVs, proposing the substitution of conventional motors with this new design rather than relying on advanced algorithms to achieve high-speed rotors. The proposed Variable Magnetic Gear Synchronous Motor (VMGSM) integrates a magnetic gear with a synchronous generator to facilitate high-speed operation without the need for mechanical gears, rendering it particularly suitable for EV applications. These systems employ three rotors in specific configurations to enable contactless torque transfer and speed enhancement. Our objective is to demonstrate that the proposed design is inherently capable of achieving high-speed rotors. It incorporates a multi-speed transmission system that can significantly enhance the vehicle's performance, improving acceleration and gradeability while also increasing energy efficiency.

II. TOPOLOGY OF PROPOSED VMGSM

Building upon the concept of high-performance magnetic gear as examined in [22], [23], our proposed design, illustrated in Figure 1, consists of a permanent magnetic inner rotor, a ferromagnetic rotor, and a variable electromagnetic output rotor equipped with stator winding.

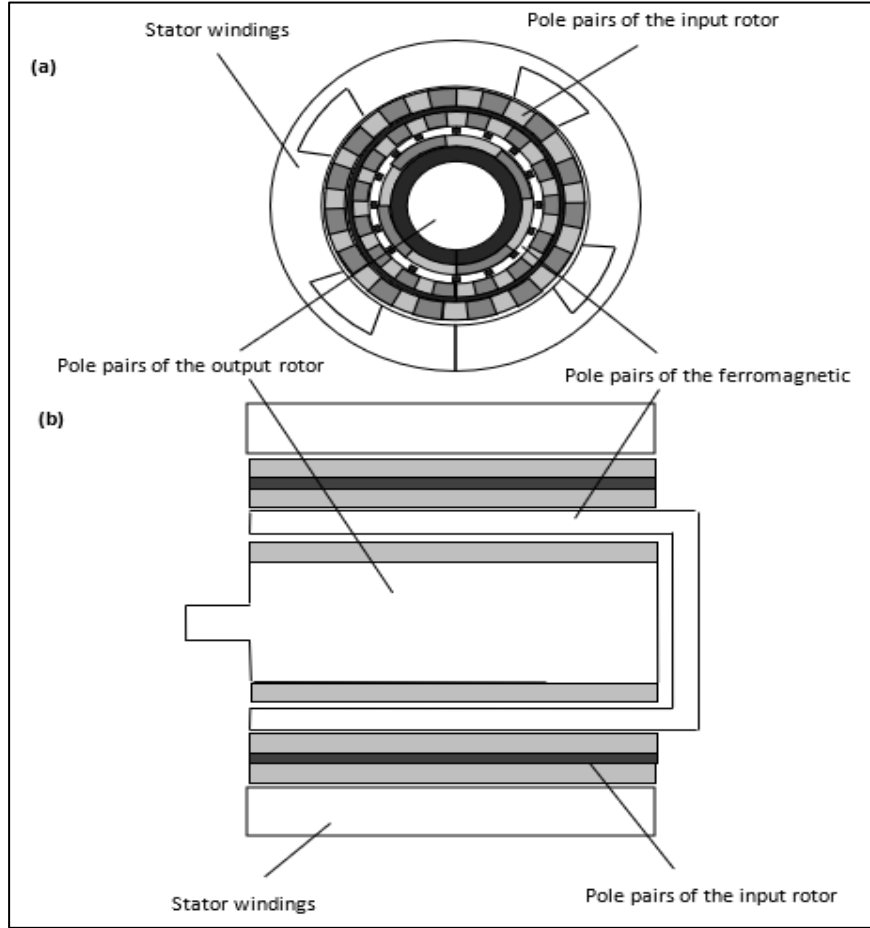


Figure 1: VMGSM (a) Radial cross section. (b) Axial cross section.

Source: Authors, (2026).

This configuration allows for the adjustment of the number of pole pairs in the output rotor. The stator's magnet winding interacts with the input rotor to generate electromagnetic torque, which is subsequently transmitted magnetically from the input rotor to the output rotor via ferromagnetic pole-pieces. This design enables the motor to operate efficiently across a range of speeds, rendering it particularly suitable for EVs. The stator windings interact with the permanent magnetic pole-pairs p_i of the input rotor to produce the electromagnetic torque:

$$T_e = \frac{3}{2} p_i \left(\varphi_{sd}^i i_{sq} - \varphi_{sq}^i i_{sd} \right) \quad (1)$$

The symbol φ represents the flux linkage, i indicates the current, s denotes the stator winding, and d and q refer to the dq reference frame. The three rotors are magnetically coupled according to the equation of motion [22], [23]:

$$\begin{cases} j_i \frac{d^2 \theta_i}{dt^2} = T_e - T_{\max} \frac{p_i}{p_f} \sin(p_i \theta_i - p_f \theta_f - p_o \theta_o) \\ j_f \frac{d^2 \theta_f}{dt^2} = -T_{\max} \sin(p_f \theta_f - p_i \theta_i - p_o \theta_o) \\ j_o \frac{d^2 \theta_o}{dt^2} = T_{\text{load}} - T_{\max} \frac{p_o}{p_f} \sin(p_o \theta_o - p_f \theta_f - p_i \theta_i) \end{cases} \quad (2)$$

In this context, θ_i , θ_o , and θ_f represent the angular positions of the input, output, and ferromagnetic rotors, respectively. The symbol T_{load} is the load torque, $T_{\max}$ signifies the maximum torque that the magnetic gear can produce, and J_i , J_o , and J_f are the inertias associated with the input, output, and ferromagnetic rotors, respectively. The parameters p_i , p_o , and p_f represent the pairs-pole of the input, output, and ferromagnetic rotors. The equation governing these motions is expressed as follows [22], [23]:

$$p_f \cdot \omega_f = p_i \cdot \omega_i + p_o \cdot \omega_o \quad (3)$$

The speeds of the input, output, and ferromagnetic rotors are denoted by ω_i , ω_o , and ω_f , respectively.

It is evident that the rotor's speed is intrinsically connected to the number of pole pairs. The output rotor speed [22], [23]:

$$\omega_o = \frac{p_f}{p_o} \omega_f - \frac{p_i}{p_o} \omega_i \quad (4)$$

The output rotor is equipped with a winding that features variable pole pairs, enabling the adjustment of the number of pole pairs p_o . According to (4), it is evident that the speed of the output rotor ω_o is inversely related to the number of pole pairs, p_o . The torque is transferred magnetically from the input rotor T_i to the output rotor T_o , as described by the equation [22], [23]:

$$T_i = \frac{p_i}{p_o} T_o \quad (5)$$

The torque needed for the output rotor is not influenced by the rotor speeds; instead, it relies on the input torque applied and the gear ratio.

III. DYNAMIC INTERACTIONS AMONG THREE ROTOR

To elucidate the relationship between the input and output rotor speeds, we have selected two distinct gear ratios. The proposed VMGSM is directly powered by the stator winding. As depicted in Figure 2, the VMGSM is characterized by $p_i = 18$, $p_o = 8$, and $n_p = 26$. With these parameters, the input rotor achieves a speed of 200 rpm, while the output rotor operates at approximately 155 rpm.

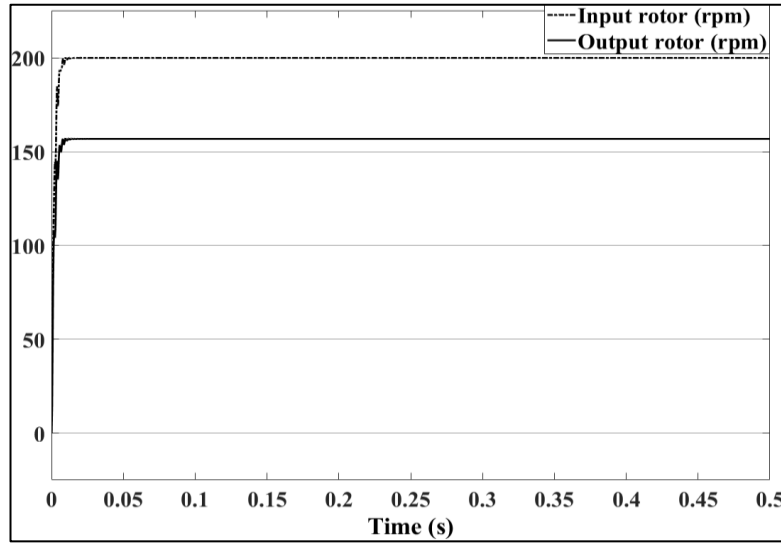


Figure 1: Rotors speed ($p_i = 18$, $p_o = 8$, and $n_p = 26$).
Source: Authors, (2026).

With the parameters p_i , p_o , and n_p set at 3, 16, and 24, respectively, the input rotor speed is documented at 1200 rpm. Consequently, this leads to an amplification of the output rotor speed to an estimated 12200 rpm.

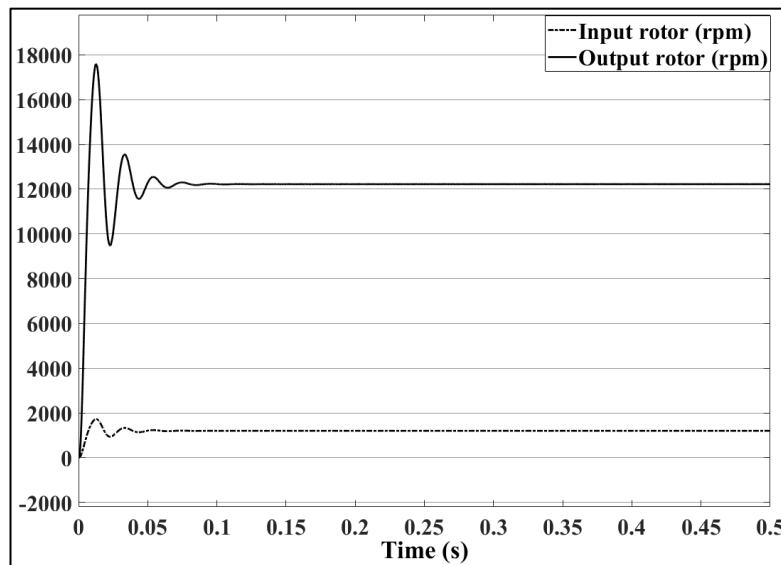


Figure 2: Rotors speed ($p_i = 3$, $p_o = 16$, and $n_p = 24$).
Source: Authors, (2026).

The rotational speed of the output rotor is not influenced by the torques of the rotors; instead, it is determined by the input speed and the gear ratio. The configuration of pole-pairs on both the input and output rotors, along with the number of ferromagnetic pole-pieces, significantly affects the resulting output speed.

Figure 4 illustrates a basic control system design that utilizes feedback mechanisms to regulate the speed and current of a 1.1 kW MGSM to their specified levels, without the reliance on completed algorithms. This closed-loop system continuously monitors the motor's actual speed and current through sensors, compares these measurements to the target values, and adjusts the motor's voltage to correct any deviations, thereby ensuring precise and stable operation.

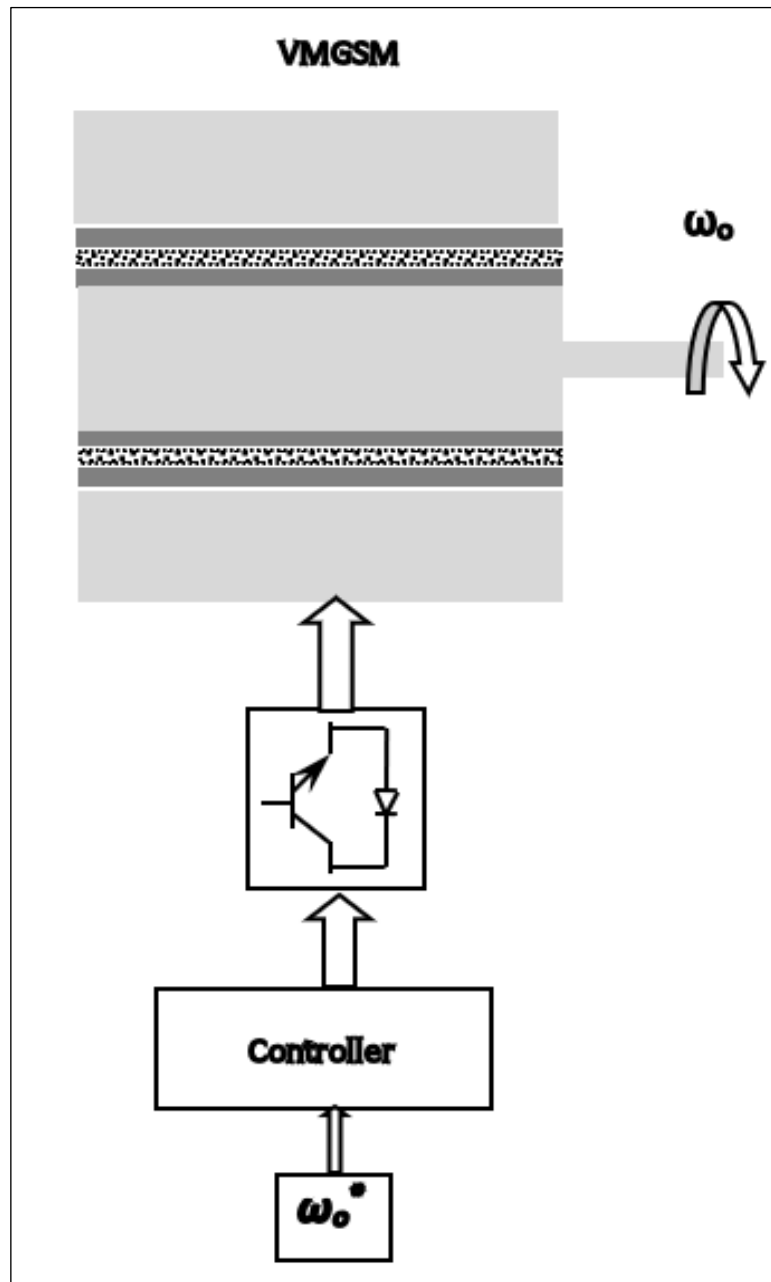


Figure 3: Control of proposed VMGSM.

Source: Authors, (2026).

Table 1 delineates the rated values of the VMGSM, which are regulated by a PWM inverter. The output from this inverter is transmitted through controlled voltage source before being applied to the stator windings of the VMGSM. Initially, the load torque on the machine's output shaft is set at 0 Nm, and then it increases to more than twice its nominal value of 7 Nm at $t = 0.05s$. A straightforward control strategy is employed, comprising two control loops: the inner loop regulates the stator currents of the motor, while the outer loop manages the motor's speed.

Table1: The rated values of the VMGSM.

Power	1.1 (kw)
voltage	220 (v)
p_i	4
p_o	10
n_s	14

Source: Authors, (2026).

As shown in Figure 5, setting the reference speed of the VMGSM's input rotor to 1900 rpm results in an output speed of 10,000 rpm, without the need for mechanical gears. This exemplifies the capability of this configuration to achieve high rotational speeds.

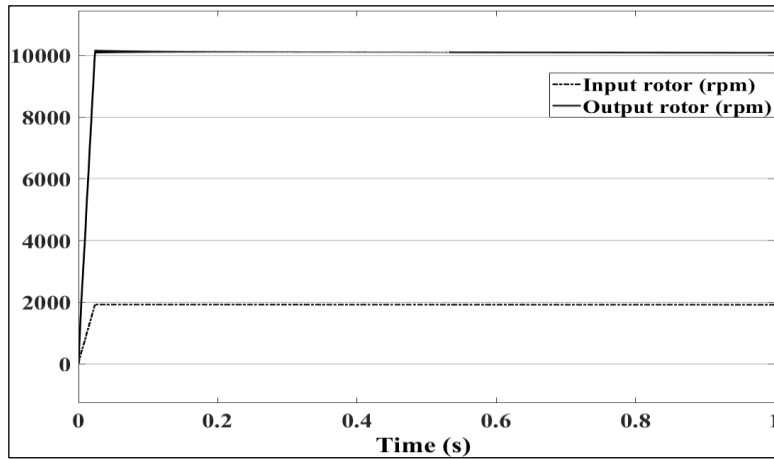


Figure 5: Input and output rotor speed.

Source: Authors, (2026).

Furthermore, Figure 6 the torque transmitted from the load via the output shaft surpasses the motor's rated value by 7 N.m, while the input rotor receives only 2.8 Nm. In this context, the VMGSM is subjected to a load that is 250% of its rated capacity.

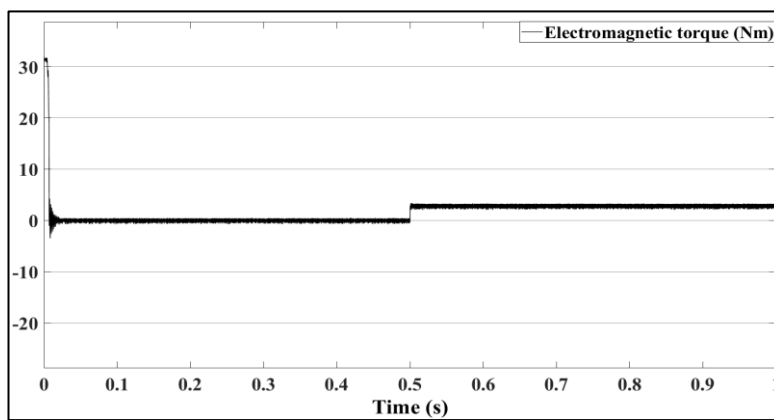


Figure 6: Electromagnetic torque.

Source: Authors, (2026).

IV. PRINCIPLE OF OPERATION

To elucidate the correlation between the input and output rotor speeds of the VMGSM, the proposed VMGSM operates directly from a standard power source without the use of a controller Figure 7.

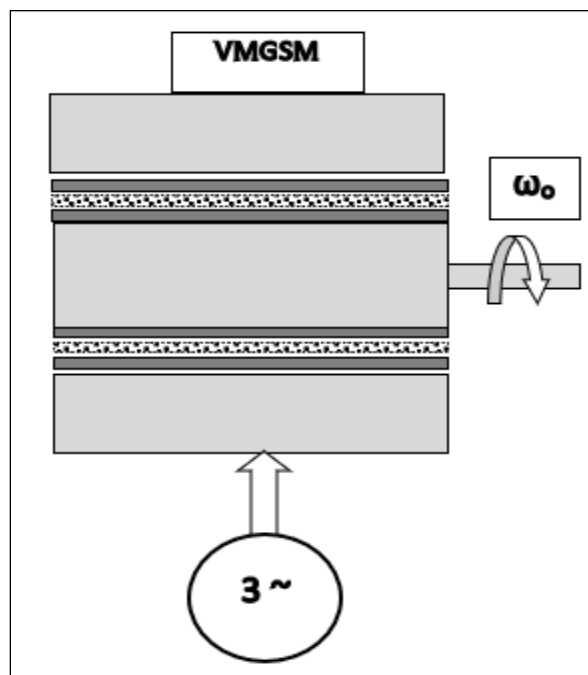


Figure 7: VMGSM with three-phase power supply.

Source: Authors, (2026).

We have chosen three distinct gear ratios, labeled as p_o , with values of 8, 12, and 16, corresponding to time intervals of 0 seconds, 1 second, and 2 seconds, respectively. As shown in Figure 8, the synchronous speed of the VMGSM (input rotor speed) is 900 rpm. Initially, this results in the output rotor reaching a speed of 3193 rpm for $p_o = 8$. At 1 second, the speed increases to 4214 rpm for $p_o = 12$, and finally, at 2 seconds, the system achieves a speed of 11311 rpm for $p_o = 16$. Without the integration of a controller, the output rotor of the VMGSM is capable of reaching a velocity that is 12.6 times the synchronous speed.

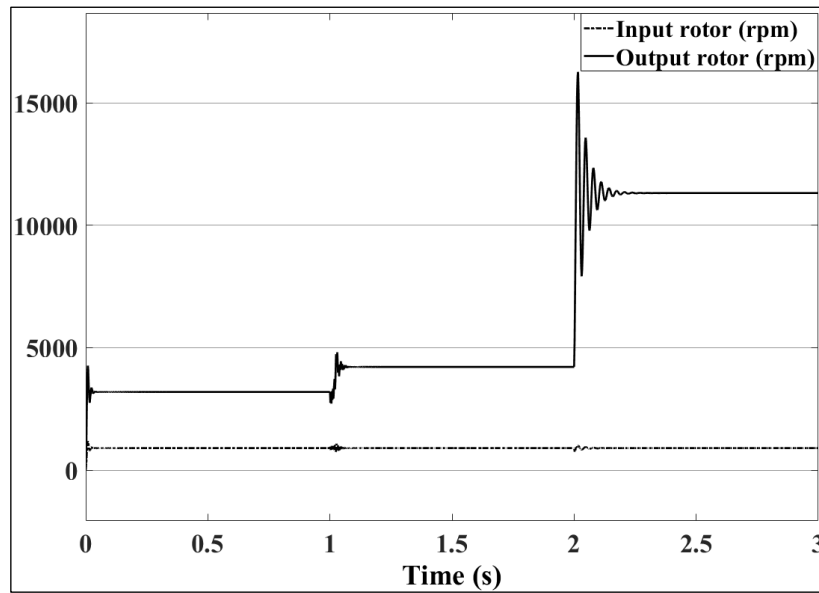


Figure 8: Input and output rotors speed with $P_i = 4$, $P_f = 14$, $P_o = 8, 12$ and 16 .
Source: Authors, (2026).

We explore another scenario involving three distinct gear ratios: 4, 10, and 14, which align with time intervals of 0 seconds, 1 second, and 2 seconds, respectively. As shown in Figure 9, the synchronous speed of the VMGSM, acting as the input rotor speed, is established at 1800 rpm. Initially, this setup enables the output rotor to achieve a speed of 3193 rpm when the gear ratio of p_o is 4. After 1 second, the speed escalates to 7976 rpm for a gear ratio of $p_o = 10$. Ultimately, at 2 seconds, the system reaches a speed of 30330 rpm for $p_o = 14$. The pronounced oscillation peak observed is attributed to the abrupt shift to a significantly higher speed, which is relevant solely in the context of speed gain.

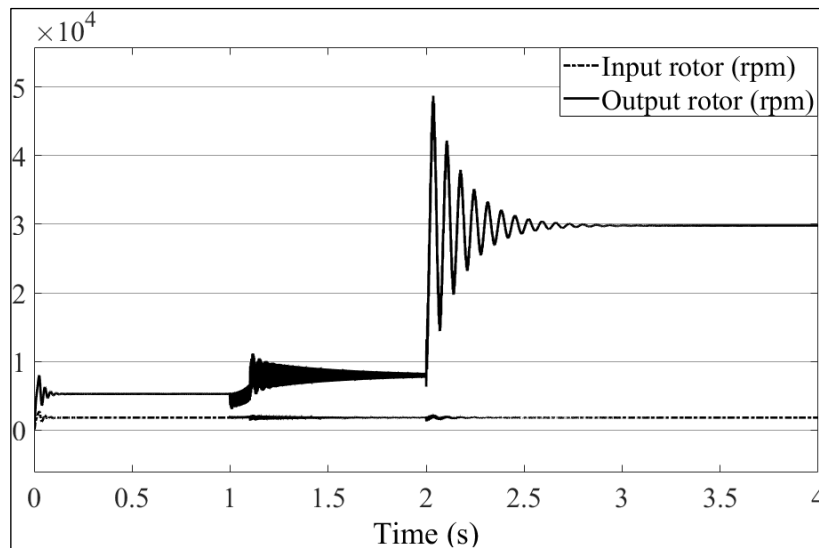


Figure 9: Input and output rotors speed with $P_i = 2$, $P_f = 12$, $P_o = 4, 10$ and 14 .
Source: Authors, (2026).

As illustrated in Figure 8 and Figure 9, the rotational speed of the output rotor remains unaffected by the torques exerted by the rotors. Instead, it is determined by the input speed and the gear ratio. The configuration of pole-pairs on both the input and output rotors, in conjunction with the number of ferromagnetic pole-pieces, is instrumental in determining the final output speed. An important study investigates the connected C-core hybrid Switched Reluctance Motor (SRM), which incorporates inter-phase permanent magnets and an innovative magnetic configuration to enhance torque density and support high rotational speeds. Although the specific peak torque is not specified, the design achieves a significantly higher torque relative to magnet volume and is optimized for rotational speeds ranging from 10,000 to 15,000 RPM, rendering it highly suitable for compact, high-speed electric vehicle applications [30]. This level of speed performance was attained through the implementation of specific control strategies. Within the VMGSM framework, a rotational speed of 30,000 RPM was achieved by employing straightforward control techniques and a distinctive rotor design.

V. RESULTS AND DISCUSSIONS

Table 2 shows the proposed control topology of 1.1 kw VMGSM in a simple closed-loop speed and current control. Table 2 outlines the rated values of the VMGSM, which are controlled by a PWM inverter. The inverter's output is transmitted through a controlled voltage source before being applied to the stator windings of the VMGSM. Initially, the load torque on the machine's output shaft is set at 0 Nm, then it increases to more than twice its nominal value of 7 Nm at $t = 0.2$ s. A straightforward control strategy is employed, consisting of two control loops: the inner loop regulates the motor's stator currents, while the outer loop manages the motor's speed. The reference speed of the VMGSM's synchronous speed is fixed at 1900 rpm, the gear ratio is increased from $p_o = 4$ to 10 and finally to 14 at 0 s, 0.5 s, and 1 s, respectively.

Table 2: Rated values of vmgsm.

Power	1.1 kw
Voltage	220 v
p_i	2
p_o	4, 10, 14.
P_f	12

Source: Authors, (2026).

As depicted in Figure 10, setting the reference speed of the VMGSM's input rotor to 1900 rpm results in output rotor speeds of 5544 rpm, 8450 rpm, and 32200 rpm, all achieved without the utilization of mechanical gears. This illustrates the VMGSM configuration's capability to attain high rotational speeds.

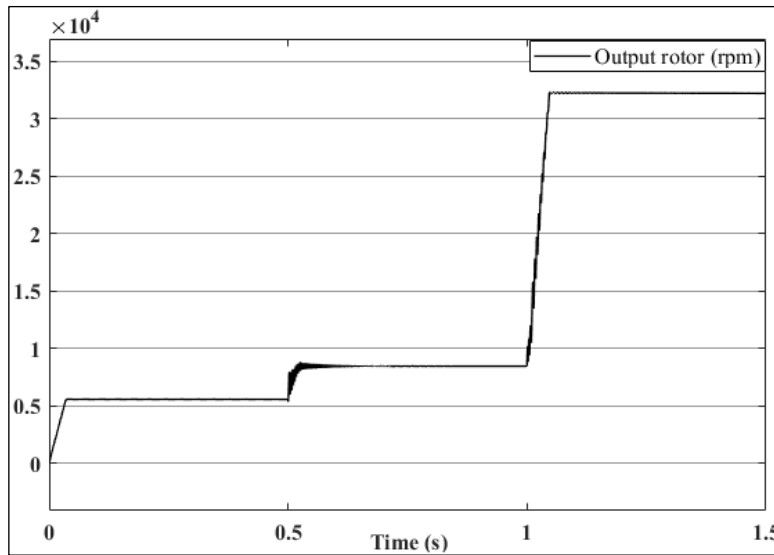


Figure 10: Output rotor speed.

Source: Authors, (2026).

As illustrated in Figure 11, the torque transmitted from the load via the output shaft exceeds the motor's rated capacity by 7 N.m. In contrast, the input rotor receives 3.5 Nm for $p_o = 4$, 1.4 Nm for $p_o = 10$, and 1 Nm for $p_o = 14$. In this context, the VMGSM is subjected to a load that is 250% of its rated capacity, yet the recorded electromagnetic torque is merely 1 Nm. The pronounced oscillation peak is attributed to the abrupt transition to a significantly higher speed, which occurs due to the absence of torque control in the controller.

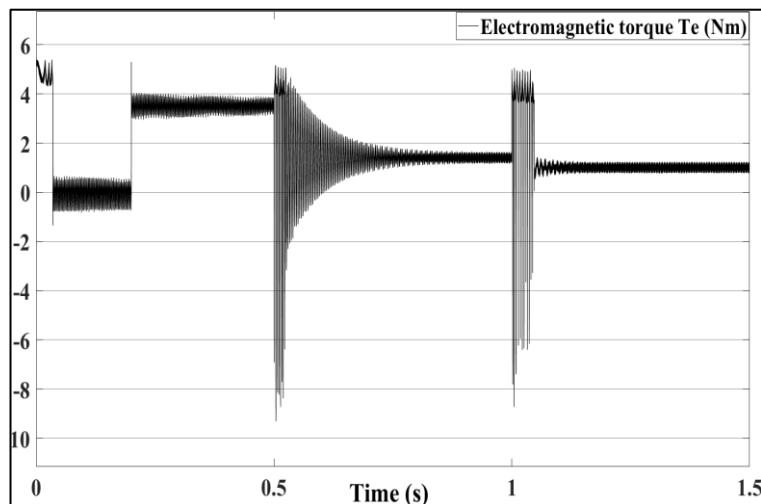


Figure 11: Electromagnetic torque.

Source: Authors, (2026).

Conversely, Interior Permanent Magnet (IPM) and Electrically Excited Synchronous Motors (EESMs) illustrate that the IPM achieves a maximum torque of 192 Nm at a constant torque speed of 6,559 RPM, whereas the EESM attains a higher peak torque of 232 Nm but operates at a lower constant-torque speed of 5,152 RPM [31]. This highlights the trade-off between torque and speed: although the torque required for the output rotor in VMGSM is independent of rotor speeds, it is dependent on the input torque applied and the gear ratio. In our case, the VMGSM is subjected to a load that is 250% of its rated capacity, yet the observed electromagnetic torque is merely 1 Nm.

VI. CONCLUSIONS

The present study investigates the performance characteristics of a variable magnetic gear synchronous motor across three distinct gear ratios, during which the output rotor speed progressively increases. The input rotor speed is consistently maintained at 1,800 rpm, serving as the baseline, while the output rotor achieves a maximum speed of 30,330 rpm. The output rotor speed is determined solely by the input rotor speed and the gear ratio, remaining unaffected by the electromagnetic torques produced by the rotors. These factors collectively establish the magnetic gear ratio and, consequently, the output speed. This decoupling of speed from torque underscores the variable magnetic gear synchronous motor's unique operational principle compared to conventional motors. The motor is subjected to a load exceeding 250% of its rated capacity, with the load torque transmitted through the output shaft surpassing the motor's nominal torque by 7 Nm.

Despite this substantial load, the electromagnetic torque generated by the variable magnetic gear synchronous motor remains high, recorded at only 1 Nm. In contrast, traditional motor types such as Interior Permanent Magnet (IPM) and Electrically Excited Synchronous Motors (EESMs) exhibit significantly lower speeds. The variable magnetic gear synchronous motor excels in achieving very high output speeds (up to 30,000 rpm) with simple control mechanisms and a specialized rotor design. The this substantial's design leverages a distinctive magnetic gear mechanism and straightforward control to enable high-speed operation, making it a promising candidate for applications where high rotational speeds are critical. This proposed motor eliminates the need for mechanical gears by incorporating a synchronous permanent magnet input rotor that is magnetically coupled to a three-stage windings output rotor.

This advanced design offers several advantages, including reduced weight and size, minimal maintenance requirements, operation without lubrication, an integrated cooling system, overload protection, and physical separation between the input and output shafts. It has been observed that the configuration of pole-pairs on the input and output rotors, along with the number of ferromagnetic pole-pieces, significantly influences the maximum torque transmission and output speed. The motor is capable of achieving high speeds, with the output rotor's rotational speed being determined by the input speed and gear ratio rather than the rotor torques. The arrangement of pole-pairs on both the input and output rotors, in conjunction with the ferromagnetic pole-pieces, is crucial in defining the output speed and torque load.

VII. AUTHOR'S CONTRIBUTION

Conceptualization: Kamel Salim Belkhir, Houcem Achouri and Kawther Fatmi.

Methodology: Houcem Achouri and Kawther Fatmi.

Investigation: Kamel Salim Belkhir.

Discussion of results: Kamel Salim Belkhir, Houcem Achouri and Kawther Fatmi.

Writing – Original Draft: Kawther Fatmi.

Writing – Review and Editing: Houcem Achouri and Kawther Fatmi.

Resources: Kamel Salim Belkhir.

Supervision: Kamel Salim Belkhir.

Approval of the final text: Kamel Salim Belkhir, Houcem Achouri and Kawther Fatmi.

VIII. REFERENCES

- [1] S. Krishnamoorthy and P. P. K. Panikkar, "A comprehensive review of different electric motors for electric vehicle applications," *Int. J. Power Electron. Drive Syst.*, vol. 15, no. 1, pp. 74–90, Mar. 2024. DOI: 10.11591/ijpeds.v15.i1.pp74-90.
- [2] Z. Cao, A. Mahmoudi, S. Kahourzade, and W. L. Soong, "An overview of electric motors for electric vehicles," in *Proc. IEEE Australasian Universities Power Engineering Conf. (AUPEC)*, Sep. 2021. DOI: 10.1109/AUPEC52110.2021.9597739.
- [3] W. Ueda, H. Yamamoto, M. Azegami, and H. Yamashita, "Design and evaluation of a high-speed surface permanent magnet synchronous motor for electric vehicle applications," *World Electr. Veh. J.*, vol. 13, no. 4, art. 57, 2022. DOI: 10.3390/wevj13040057.
- [4] T. El Hajji, M. Lakhdar, A. Kheloui, and M. Belhadi, "Optimal design of high-speed electric machines for electric vehicles: A case study of a 100-kW V-shaped interior PMSM," *Machines*, vol. 11, no. 1, art. 57, Jan. 2023. DOI: 10.3390/machines11010057.
- [5] S. Kováč, P. Rafajdus, and M. Puškár, "Design and optimization of a high-speed switched reluctance motor," *Energies*, vol. 14, no. 20, art. 6733, Oct. 2021. DOI: 10.3390/en14206733.
- [6] M. Zandi Nasab, E. Afjei, G. Davarpanah, and A. Ghaheeri, "An innovative hybrid-excited switched reluctance motor for enhanced performance: Design, analysis, and experimental study," *IEEE Trans. Transp. Electrific.*, early access, Jan. 2025. DOI: 10.1109/TTE.2025.3563666.
- [7] M. Beza and R. Bojoi, "Design and optimization of a 23-kW synchronous reluctance motor for electric vehicles," *Energies*, vol. 16, no. 10, art. 4221, 2023. DOI: 10.3390/en16104221.
- [8] T. A. Huynh and M.-F. Hsieh, "Performance analysis of permanent magnet motors for electric vehicle traction considering driving cycles," *Energies*, vol. 11, no. 6, art. 1385, May 2018. DOI: 10.3390/en11061385.
- [9] M. Beza and R. Bojoi, "Design and optimization of a 23-kW synchronous reluctance motor for electric vehicles," *Energies*, vol. 16, no. 10, art. 4221, 2023. DOI: 10.3390/en16104221.

- [10] S. Kováč, P. Rafajdus, and M. Puškár, “Design and optimization of a high-speed switched reluctance motor,” *Energies*, vol. 14, no. 20, art. 6733, 2021. DOI: 10.3390/en14206733.
- [11] A. M. El-Refaie, “Motors/generators for traction/propulsion applications: A review,” *IEEE Trans. Veh. Technol.*, vol. 64, no. 3, pp. 954–980, Mar. 2015. DOI: 10.1109/TVT.2014.2327053.
- [12] G. Pellegrino, A. Vagati, B. Boazzo, and P. Guglielmi, “Comparison of induction and permanent-magnet motors for electric vehicle applications,” *IEEE Trans. Ind. Appl.*, vol. 48, no. 6, pp. 2322–2332, Nov.–Dec. 2012. DOI: 10.1109/TIA.2012.2214213.
- [13] F. R. Mazzola, M. G. Simões, and R. A. Dougal, “Thermal and mechanical constraints in high-speed electric machines for electric vehicles,” *IEEE Trans. Transp. Electrific.*, vol. 10, no. 1, pp. 110–120, Mar. 2024. DOI: 10.1109/TTE.2024.3345123.
- [14] S. Li, H. Yang, and Z. Chen, “Optimal design of electric vehicle traction motors considering performance, efficiency, and thermal constraints,” *IEEE Trans. Ind. Electron.*, vol. 71, no. 2, pp. 1345–1355, Feb. 2024. DOI: 10.1109/TIE.2023.3301122.
- [15] J. S. Kim and C. H. Kim, “High-speed traction motor design for electric vehicles with emphasis on rotor dynamics and thermal reliability,” *IEEE Trans. Ind. Appl.*, vol. 60, no. 3, pp. 2351–2362, May–Jun. 2024. DOI: 10.1109/TIA.2024.3334567.
- [16] S. Divya and D. K. Kumar, “Comparative study of energy management strategies for hybrid electric vehicle with hybrid energy storage system,” *ITEGAM-JETIA*, vol. 12, no. 57, pp. 340–347, Jan./Feb. 2026, doi: 10.5935/jetia.v12i57.2975.
- [17] Kumar, G. S. Negi, and A. Sati, “Enhancing the cooling system design of high-power density permanent magnet motor for EV,” *ITEGAM-JETIA*, vol. 11, no. 54, pp. 205–214, Jul./Aug. 2025, doi: 10.5935/jetia.v11i54.1764.
- [18] B. P. K. Reddy and V. U. Reddy, “Design and analysis of novel topology for PV-fed EV charging system,” *ITEGAM-JETIA*, vol. 10, no. 47, pp. 109–114, May/June 2024, doi: 10.5935/jetia.v10i47.1108.
- [19] H. Lu, Y. Li, Q. Wang, and J. Chai, “Review of three-phase soft-switching inverters and challenges for motor drives,” *CES Trans. Electr. Mach. Syst.*, vol. 8, no. 2, pp. 177–190, Jun. 2024. DOI: 10.30941/CESTEMS.2024.00030.
- [20] M. Gobbi, A. Sattar, R. Palazzetti, and G. Mastinu, “Traction motors for electric vehicles: Maximization of mechanical efficiency—A review,” *Appl. Energy*, vol. 357, art. 122496, Dec. 2023. DOI: 10.1016/j.apenergy.2023.122496.
- [21] G. Ruiz-Ponce, C. Hernandez, M. A. Arjona, and R. Escarela-Perez, “A review of magnetic gear technologies used in mechanical power transmission,” *Energies*, vol. 16, no. 4, art. 1721, Feb. 2023. DOI: 10.3390/en16041721.
- [22] K. Atallah, S. D. Calverley, and D. Howe, “Design, analysis, and realization of high-performance magnetic gears,” *IEE Proc. Electr. Power Appl.*, vol. 151, no. 2, pp. 135–143, Mar. 2004.
- [23] K. Atallah and D. Howe, “A novel high-performance magnetic gear,” *IEEE Trans. Magn.*, vol. 37, no. 4, pp. 2844–2846, Jul. 2001.
- [24] K. Atallah, S. D. Calverley, and D. Howe, “A brushless permanent-magnet motor with integrated torque limiter,” *IEEE Trans. Magn.*, vol. 43, no. 6, pp. 2844–2846, Jun. 2007.
- [25] K. Aiso, K. Akatsu, and Y. Aoyama, “A novel reluctance magnetic gear for high-speed motors,” *IEEE Trans. Ind. Appl.*, vol. 55, no. 3, pp. 2690–2699, May–Jun. 2019.
- [26] K. Aiso, K. Akatsu, and Y. Aoyama, “A novel magnetic gear for high-speed motor systems,” in *Proc. IEEE Int. Electr. Mach. Drives Conf. (IEMDC)*, 2017. DOI: 10.1109/IEMDC.2017.8002311.
- [27] K. Aiso, K. Akatsu, and Y. Aoyama, “EV motor system with magnetic gear satisfying high power density and high torque density,” *Electr. Eng. Jpn.*, vol. 218, no. 1, 2025. DOI: 10.1002/eej.23483.
- [28] S. Y. Kim, H. S. Choi, and K. Lee, “Performance analysis of magnetic gears with Halbach arrays for high power and high speed,” *J. Adv. Eng.*, vol. 14, no. 2, pp. 145–154, 2020. DOI: 10.3233/JAE-209410.
- [29] D. Kazemikia and M. Gardner, “A parameterized nonlinear magnetic equivalent circuit for design and fast analysis of radial flux magnetic gears,” *arXiv preprint arXiv:2406.08375*, Jun. 2024.
- [30] S. Kocan, P. Rafajdus, R. Bastovansky, R. Lenhard, and M. Stano, “Design and optimization of a high-speed switched reluctance motor,” *Energies*, vol. 14, no. 20, art. 6733, Oct. 2021. DOI: 10.3390/en14206733.
- [31] F. Yang, N. Li, G. Du, M. Huang, and Z. Kang, “Electromagnetic optimization of a high-speed interior permanent magnet motor considering rotor stress,” *Appl. Sci.*, vol. 14, no. 14, art. 6033, Jul. 2024. DOI: 10.3390/app14146033.