PERFORMANCE EVALUATION OF FIELD-ORIENTED CONTROL BASED FEM-PARAMETERIZED PMSM TRACTION DRIVE USING HIGH-FIDELITY RESOLVER FEEDBACK

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ABSTRACT

Permanent Magnet Synchronous Motors (PMSMs) are widely used in electric vehicle traction systems due to their high efficiency, superior power density, and excellent dynamic performance. This paper presents the modeling and performance evaluation of a Field-Oriented Control (FOC) based Finite Element Method (FEM)-parameterized PMSM traction drive integrated with high-fidelity resolver feedback. The proposed system consists of a high-voltage battery source, voltage source inverter, FEM-based PMSM model, resolver-based position sensing unit, and cascaded speed-current control loops. The FEM-parameterized PMSM model accurately captures nonlinear magnetic characteristics, saturation effects, and flux linkage variations, resulting in improved modeling accuracy compared with conventional analytical PMSM models. The complete traction drive system is developed in MATLAB/Simulink and evaluated under transient and steady-state operating conditions. Simulation results demonstrate excellent speed tracking capability, effective current regulation, stable battery performance, and accurate torque control. The PMSM achieves the reference speed of 1100 rpm within 0.24 s without overshoot and with negligible steady-state error. The results validate the effectiveness of the proposed control strategy for high-performance electric vehicle traction applications.

Keywords: PMSM, Field-Oriented Control (FOC), FEM-Parameterized PMSM, Resolver Feedback, Electric Vehicle, Traction Drive, MATLAB/Simulink.

1. INTRODUCTION

The increasing adoption of electric vehicles has created a growing demand for high-performance traction drive systems capable of providing high efficiency, rapid dynamic response, and reliable operation. Permanent Magnet Synchronous Motors (PMSMs) have emerged as one of the most suitable candidates for electric vehicle propulsion because of their high torque density, high efficiency, compact size, and superior speed control characteristics.[1]

The performance of a PMSM drive strongly depends on accurate motor modeling and advanced control strategies. Conventional PMSM models generally employ constant machine parameters and fail to accurately represent nonlinear magnetic phenomena such as saturation and cross-coupling effects. [2] In contrast, FEM-parameterized PMSM models utilize magnetic characteristics derived from finite element analysis, enabling accurate representation of nonlinear machine behavior and improving simulation fidelity.

Field-Oriented Control (FOC) is one of the most widely adopted control techniques for PMSM drives. By transforming three-phase stator quantities into a synchronously rotating dq reference frame, FOC enables independent control of flux and torque, thereby achieving high dynamic performance similar to that of a separately excited DC motor. Accurate rotor position information is essential for successful implementation of FOC. [4] Therefore, a high-fidelity resolver feedback system is employed in this work to provide precise rotor position and speed estimation.

This paper presents the development and performance evaluation of a Field-Oriented Control based FEM-parameterized PMSM traction drive with resolver feedback. The proposed system is analyzed under dynamic operating conditions to evaluate speed regulation, battery behavior, loss characteristics, and electrical performance.

2. RESEARCH METHODOLOGY

The proposed PMSM traction drive consists of a high-voltage battery source, three-phase voltage source inverter, FEM-parameterized PMSM, resolver-based feedback unit, and Field-Oriented Control system. The complete MATLAB/Simulink model of the proposed traction drive is shown in Fig. 1.

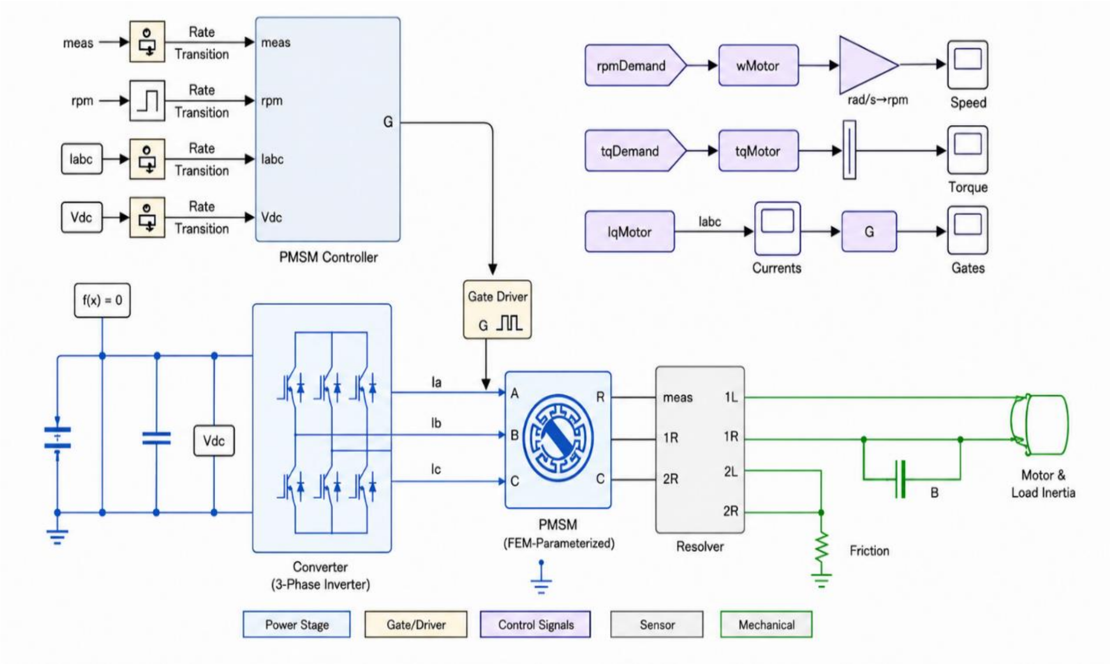

Fig. 1 Block Diagram of FOC-Based FEM-Parameterized PMSM Traction Drive with Resolver Feedback

The PMSM model utilizes FEM-derived lookup tables to represent nonlinear flux linkage characteristics and magnetic saturation effects. This modeling approach provides higher accuracy than conventional PMSM models and allows realistic representation of machine behavior under dynamic operating conditions.

The control system employs a cascaded Field-Oriented Control architecture consisting of an outer speed control loop and inner current control loops. The reference speed is compared with the measured rotor speed obtained from the resolver. The resulting speed error is processed by a PI controller to generate the reference q-axis current. The d-axis current reference is maintained at zero to achieve maximum torque per ampere operation.

The measured three-phase stator currents are transformed into the dq reference frame using Clarke and Park transformations. Independent PI controllers regulate the d-axis and q-axis currents. The generated voltage references are transformed back into three-phase quantities and applied to a Space Vector PWM inverter for switching signal generation. Resolver feedback continuously provides rotor position and speed information required for accurate field orientation. The simulation is performed for a duration of 1 s under dynamic operating conditions. A step speed reference of 1100 rpm is applied at t = 0.02 s to evaluate the transient and steady-state performance of the proposed PMSM traction drive.

3. RESULTS AND DISCUSSION

3.1 Speed Response Analysis

The proposed PMSM traction drive was simulated for a duration of 1 second. A speed reference of 1100 rpm was applied at t = 0.02 s to evaluate both transient and steady-state performance.

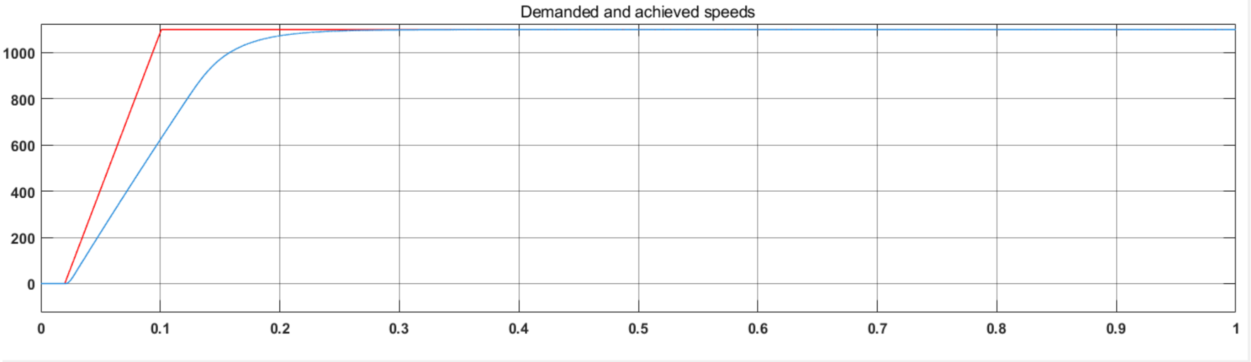

Fig. 2 Reference and Actual Speed Response of PMSM Drive

Figure 2 illustrates the speed response of the PMSM drive under Field-Oriented Control. The motor accelerates smoothly from standstill and reaches the reference speed of 1100 rpm within approximately 0.24 s. No overshoot is observed, and the steady-state error is practically zero, indicating excellent controller performance and precise speed regulation.

Table 1 Dynamic Performance Parameters

Parameter	Value
Reference Speed	1100 rpm
Step Time	0.02 s

Parameter	Value
Time to 90% Speed	0.16 s
Settling Time	0.24 s
Overshoot	0 %
Steady-State Error	0

3.2 Battery Performance Analysis

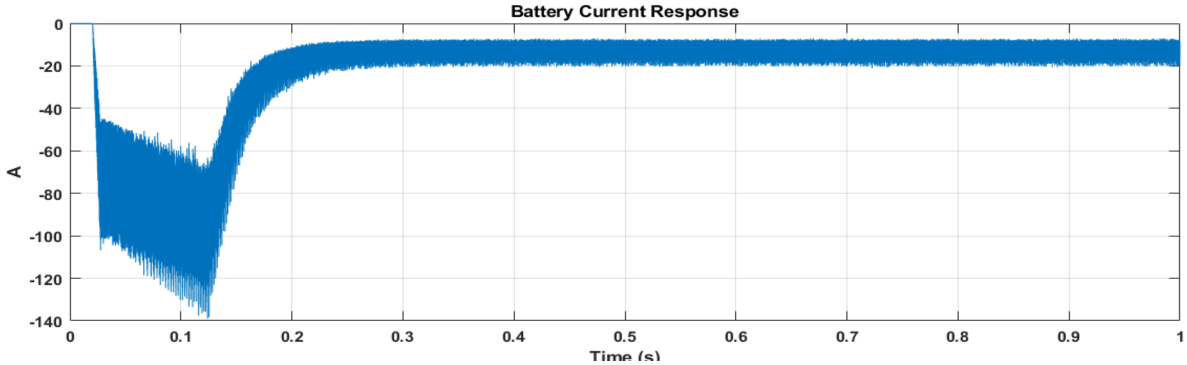

Fig. 3 Battery Current Response During Transient and Steady-State Operation

Figure 3 presents the battery characteristics during PMSM operation. During startup, the battery supplies a peak current of approximately 120 A to satisfy the high torque demand. Consequently, a temporary voltage drop is observed. As the motor approaches steady-state operation, the current demand decreases and the battery voltage stabilizes near its nominal value. The battery state of charge exhibits only a negligible reduction, confirming efficient energy utilization.

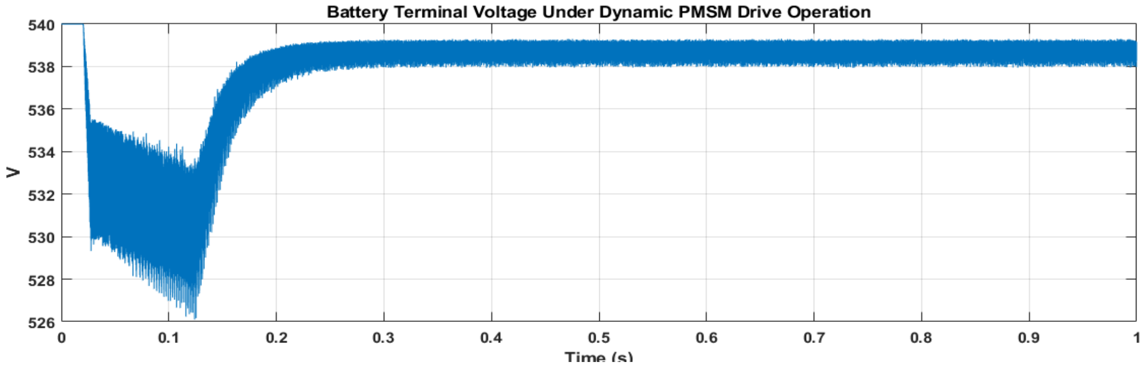

Fig. 4 Battery Terminal Voltage Response Under Dynamic Load Conditions

Fig. 4 shows the battery terminal voltage response of the PMSM traction drive under dynamic loading conditions. The nominal voltage is approximately 540 V, with a transient dip to 526–528

V during the initial acceleration phase (0–0.15 s), corresponding to high inrush current and peak torque demand. As the motor speed increases and current demand decreases, the voltage recovers and stabilizes around 538–539 V after approximately 0.25 s.

3.3 Loss Analysis

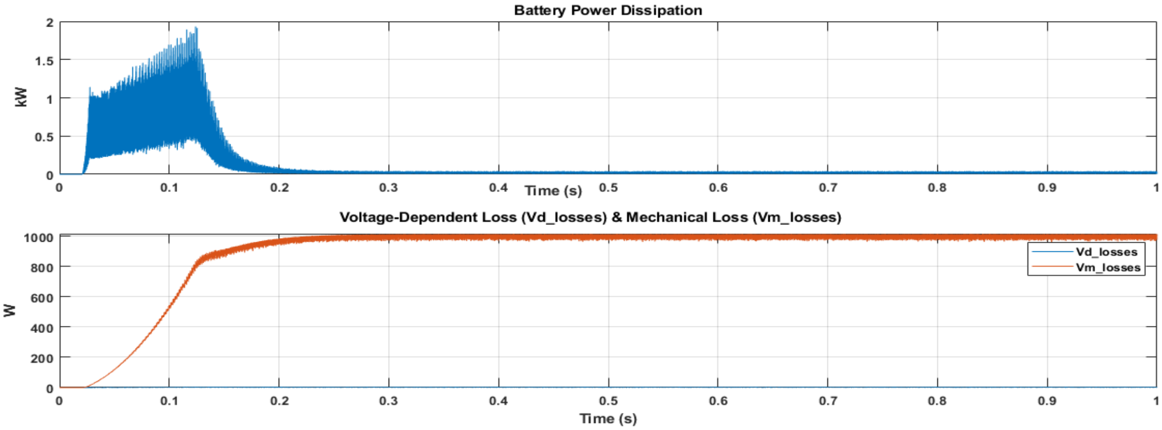

Fig. 5 Loss Analysis of PMSM Traction Drive

Fig. 5 depicts the combined loss components of the PMSM drive system. During the transient period, battery losses dominate, reaching a peak of approximately 2 kW due to high current demand during motor startup. As the system transitions to steady-state operation, battery losses decrease significantly, while mechanical losses increase with rotor speed and stabilize around 1000 W, becoming the primary loss component.

The electrical (voltage-dependent) losses remain relatively small throughout the operation. This behavior clearly indicates a shift in dominant loss mechanisms from current-dependent losses during transient conditions to speed-dependent mechanical losses in steady-state.

Table 2 :Summary of Loss Components

LOSS COMPONENT	PEAK VALUE	STEADY-STATE VALUE
BATTERY LOSS	~2 kw	~0.05 kw
ELECTRICAL LOSS	~4 w	~3 w
MECHANICAL LOSS	~1 w	~1000 w

3.4 Electrical Waveform Analysis

Fig.6 shows the three-phase stator voltages (v_a, v_b , v_c) generated by the inverter. During the initial transient period, the voltages exhibit distortion due to rapid changes in current and torque demand.

After approximately t ≈ 0.2 s, the waveforms become balanced and periodic with a phase displacement of 120°, indicating proper inverter operation. High-frequency switching components are present due to PWM operation at 20 kHz.

The results confirm that the inverter provides appropriate voltage excitation for stable PMSM operation.

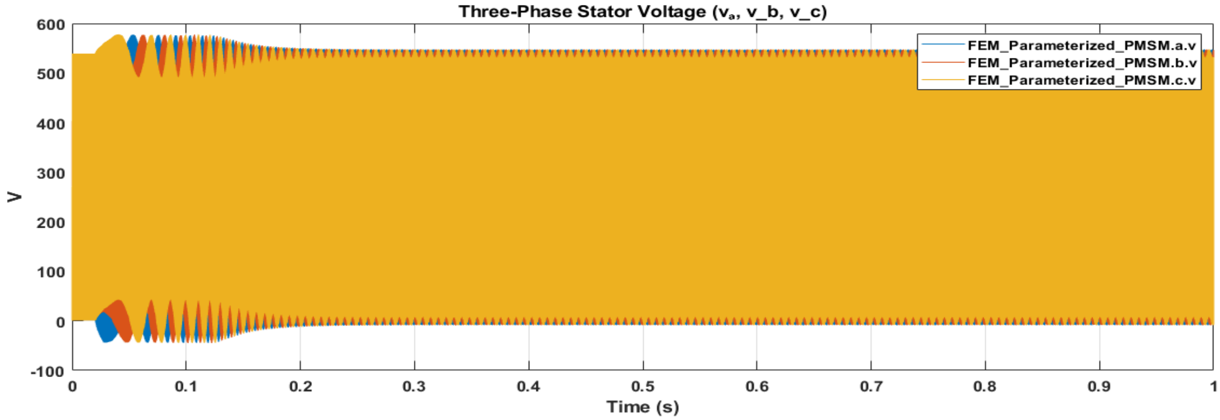

Fig. 6 Three-Phase Stator Voltage Waveforms

Fig.7 illustrates the back EMF waveforms of the PMSM. The amplitude increases during acceleration and stabilizes at approximately ±40 V once the motor reaches steady-state speed (~1100 rpm).

The waveforms are sinusoidal and balanced with 120° phase shift, confirming correct electromagnetic behavior and accuracy of the FEM-based PMSM model.

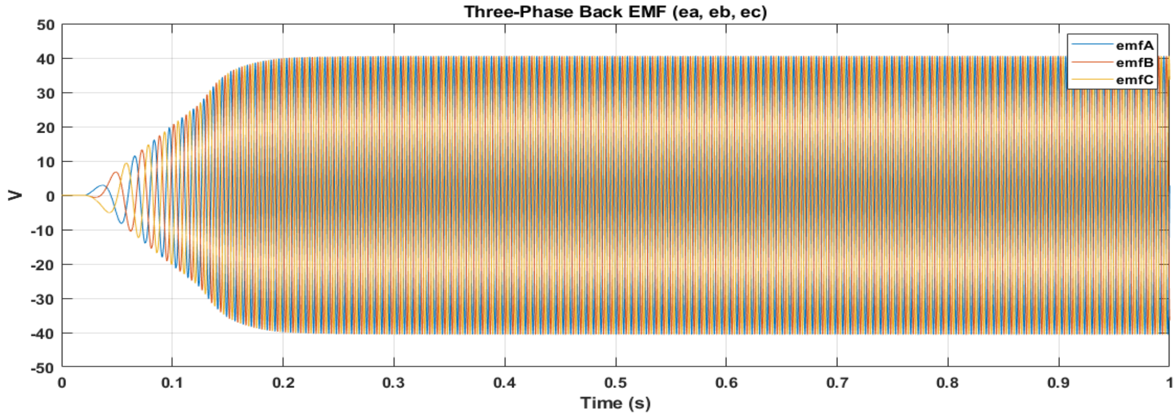

Fig. 7 Three-Phase Back EMF waveforms of the PMSM Drive

Fig.8 shows the stator currents (i_a, i_b, i_c). At the instant of speed reference application (t = 0.02 s), the currents reach peak values of approximately ±400–450 A, corresponding to high torque demand.

As the motor approaches steady-state, the current magnitude reduces to approximately ±80–100 A, and the waveforms become sinusoidal and balanced. The 120° phase displacement confirms proper inverter operation and effective current control.

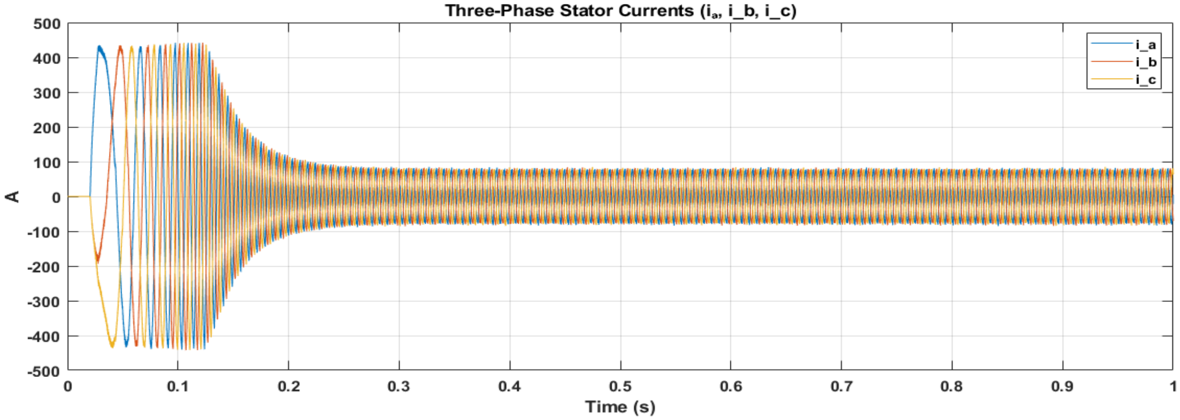

Fig. 8 Three-Phase Stator Current Response of PMSM Drive

4. CONCLUSION

A Field-Oriented Control based FEM-parameterized PMSM traction drive integrated with high-fidelity resolver feedback has been successfully developed and evaluated using MATLAB/Simulink. The FEM-based PMSM model accurately represents nonlinear magnetic characteristics and provides improved simulation fidelity. The proposed control system achieves fast speed response, accurate current regulation, and stable operation under dynamic loading conditions. Simulation results demonstrate that the PMSM reaches the desired speed of 1100 rpm within 0.24 s without overshoot and with negligible steady-state error. Battery performance analysis confirms stable energy delivery, while loss analysis reveals that battery losses dominate during transient operation and mechanical losses dominate during steady-state operation. The obtained results validate the effectiveness of the proposed PMSM traction drive for high-performance electric vehicle applications.

REFERENCES

[1] J. Ahn, G. F. Lukman, and S. Member, “Switched Reluctance Motor: Research Trends and Overview,” vol. 2, no. 4, pp. 339–347, 2018.

[2] M. Akrami, E. Jamshidpour, L. Baghli, and V. Frick, “Application of Low-Resolution Hall Position Sensor in Control and Position Estimation of PMSM—A Review,” Energies, vol. 17, pp. 1–20, 2024.

[3] M. A. Azom and M. Y. A. Khan, “Recent Developments in Control and Simulation of Permanent Magnet Synchronous Motor Systems,” Control Systems and Optimization Letters, vol. 3, pp. 84–91, 2025.

[4] M. Y. Bdewi, A. M. Mohammed, and E. M. Mohammed, “Design and Performance Analysis of Permanent Magnet Synchronous Motor for Electric Vehicles Application,” Journal of Physics: Conference Series, vol. 2020, pp. 394–406, 2021.

[5] U. P. C., D. Saji, G. Cleetus, and J. Andrews Chandy, “Field Oriented Control (FOC) of Permanent Magnet Synchronous Motor (PMSM) Applied in Electric Vehicle (EV),” Manipal Journal of Science and Technology, vol. 9, 2024.

[6] W. Cai, X. Wu, M. Zhou, Y. Liang, and Y. Wang, “Review and Development of Electric Motor Systems and Electric Powertrains for New Energy Vehicles,” Automotive Innovation, vol. 4, pp. 3–22, 2021.

[7] W. Cao, A. A. S. Bukhari, and L. Aarniovuori, “Review of Electrical Motor Drives for Electric Vehicle Applications,” Mehran University Research Journal of Engineering and Technology, vol. 38, pp. 525–540, 2019.

[8] C. C. Chan, “The State of the Art of Electric Vehicles,” Journal of Asian Electric Vehicles, vol. 2, pp. 579–600, 2004.

[9] S. Chen, Y. Zhao, H. Qiu, and X. Ren, “High-Precision Rotor Position Correction Strategy for High-Speed Permanent Magnet Synchronous Motor Based on Resolver,” IEEE Transactions on Power Electronics, vol. 35, pp. 9718–9728, 2020.

[10] P. Do Chi, H. B. Huu, V. D. Quoc, and D. B. Minh, “Analytical and Finite Element Methods for Evaluative Electromagnetic Parameters of Inset PMSM and SPMSM,” Journal Européen des Systèmes Automatisés, vol. 58, pp. 337–343, 2025.

[11] C. Datlinger and M. Hirz, “Benchmark of Rotor Position Sensor Technologies for Application in Automotive Electric Drive Trains,” Electronics, vol. 9, pp. 1–29, 2020.

[12] N. Djagarov, “Traction Motor Drive of Electrical Vehicle: Types, Performances and Control,” in Proc. 8th Int. Conf. Energy Efficiency and Agricultural Engineering, 2022, pp. 1–14.