ANALYSIS AND SELECTION OF ELECTRIC MOTORS FOR ELECTRIC VEHICLES IN VIETNAM

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ABSTRACT

Numerous domestic enterprises in Vietnam have invested in electric vehicle assembly production lines to address the significant increase in demand for electric vehicles and scooters in the nation. Businesses must autonomously produce essential components of electric vehicles, such as the electric motor, to accelerate localization efforts. In Vietnam, permanent magnet synchronous motors are utilized in battery electric vehicles (BEVs), while brushless DC motors are predominantly employed in electric scooters (ESs) currently. This study has examined both advantages and disadvantages related to torque characteristics, efficiency, and production costs, based on the design and operational principles of these electric motors. These features have been validated using numerical simulations with Matlab Simulink as the tool. A statistical analysis of the features of electric vehicles in Vietnam has been conducted to enhance the selection of the suitable motor type. The article's conclusion serves as a referenced document to aid domestic enterprises in focusing their efforts on the research and development of electric car motors.

Keywords: *Battery electric vehicle, electric scooter, brushless direct current motor, permanent magnet synchronous motor, Matlab Simulink*

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1. INTRODUCTION

In recent years, the global proliferation of battery electric vehicles (BEV) has accelerated significantly. In 2023, 20% of newly manufactured vehicles globally are BEVs [1]. Between 2023 and 2024, the market share of BEVs in Vietnam doubled and is anticipated to persist in its upward trajectory [2]. The production of new ESs is also experiencing a considerable increase, in addition to BEVs.

Vietnam has hosted numerous firms manufacturing electric motors for many years. Nonetheless, the majority of these electric motors are single-phase AC motors designed for residential use or three-phase squirrel-cage AC motors intended for industrial purposes. Beginning in 2022, certain electric car motors have been manufactured locally. These electric motors presently satisfy the specifications for a restricted number of electric car types. The localization rate of certain BEVs and Ess manufacturers has attained 60% and is projected to surpass 80% by 2026. In the imminent future, investment in domestic electric vehicle motor manufacturing lines will undoubtedly escalate to satisfy production requirements, improve self-sufficiency, and elevate the localization rate.

The electric motor transforms electrical energy to driving torque to provide thrust during acceleration and to counteract resistance. This is a crucial element that significantly influences the operational capacity of electric vehicles. Choosing the suitable electric motor for each category of electric vehicle necessitates a decision based on specified needs, operational features, and manufacturing expenses. Brushed DC motors and three-phase squirrel-cage AC motors were utilized in electric vehicles until 2013, however they are no longer preferred for the development of new models [3]. Numerous studies indicate that brushless direct current (BLDC) motors and permanent magnet synchronous motors (PMSM) are the predominant types of drive motors utilized in electric cars globally [4-6]. The Switched Reluctance Motor (SRM) is under investigation and demonstrates significant potential for future application in electric vehicles [3, 7, 8].

This article examines both the advantages and disadvantages of torque characteristics, efficiency, and production costs in relation to the structure and operational principles of BLDC and PMSM. These qualities have been verified using numerical simulations utilizing Matlab Simulink. Statistical data regarding the attributes of domestic electric vehicles are examined to inform the selection of electric motor types for vehicles in Vietnam currently and in the future. This result is crucial in directing research and investment in new electric vehicle assembly production lines in Vietnam.

2. ADVANTAGES AND DISADVANTAGES OF BLDC AND PMSM

2.1. Structure and operating principle

Fig. 1 illustrates the energy conversion process in a electric car propulsion system. During drive mode, the chemical energy stored in the battery (E_{batt}) is converted into electrical energy (E_{e2}) in the form of direct current, which is subsequently changed by the power converter to motor-compatible electrical energy (E_{e1}). The motor transforms the received electrical energy into kinetic energy E_C.

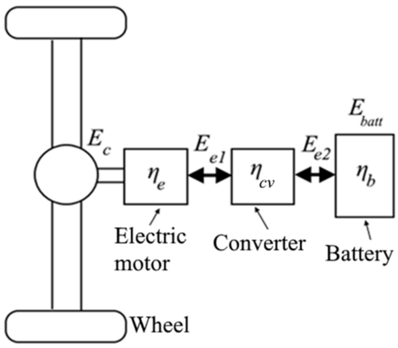


Fig. 1. Energy conversion in the electric vehicle propulsion system [9]

Both BLDC and PMSM used in modern electric vehicles utilize permanent magnets attached to the rotor. The rotor magnets are either positioned on the rotor surface (surface-mounted) as seen in Fig. 2 or situated beneath the rotor surface (interior). The magnets are composed of rare earth materials (NdFeB) that exhibit high magnetic field strength, minimal mass and dimensions, endurance to high temperatures, and superior demagnetization resistance compared to conventional permanent magnets [3].

BLDC and PMSM utilize concentrated and distributed windings in the stator, respectively. The stator of both motor types is energized by a three-phase H-bridge circuit, as seen in Fig. 2. The switching elements S_1 to S_6 of the bridge operate based on the Pulse Width Modulation (PWM) signals from the controller to supply current to the phases of the electric machine, as illustrated in Fig . 2. The phases of the BLDC motor receive direct current, but the phases of the PMSM are supplied with sine wave current, as illustrated in Fig. 3.

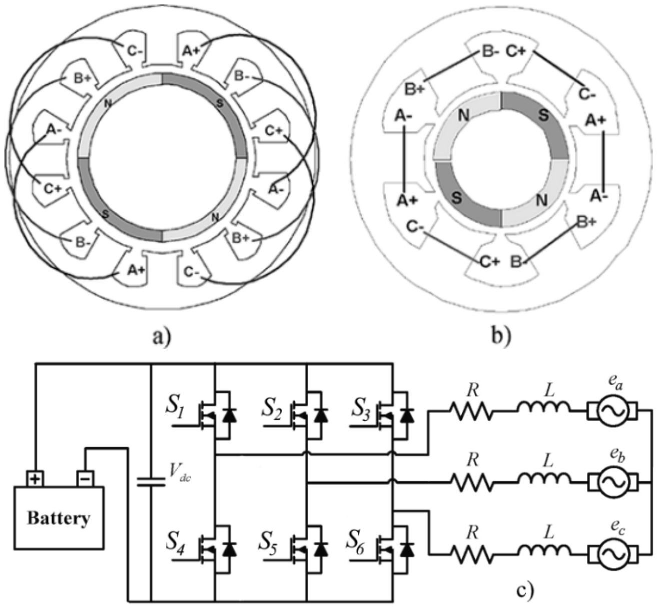


Fig. 2. Distributed (a) and concentrated (b) windings [10] along with the H-bridge circuit (c) [10]

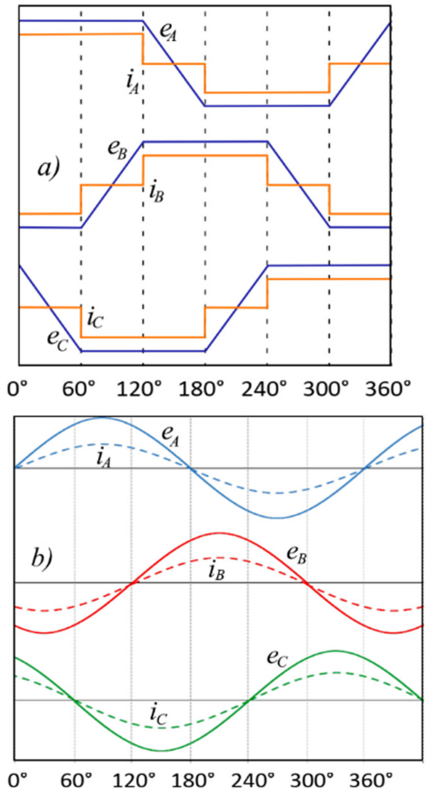


Fig. 3. The phase current and EMF signals of BLDC (a) and PMSM (b) [11]

The stator configuration and control current result in the electromotive force (EMF) produced in BLDC and PMSM exhibiting trapezoidal and sinusoidal shapes, as illustrated in Fig. 3. The equivalent circuit of the BLDC and PMSM is illustrated in Fig. 4.

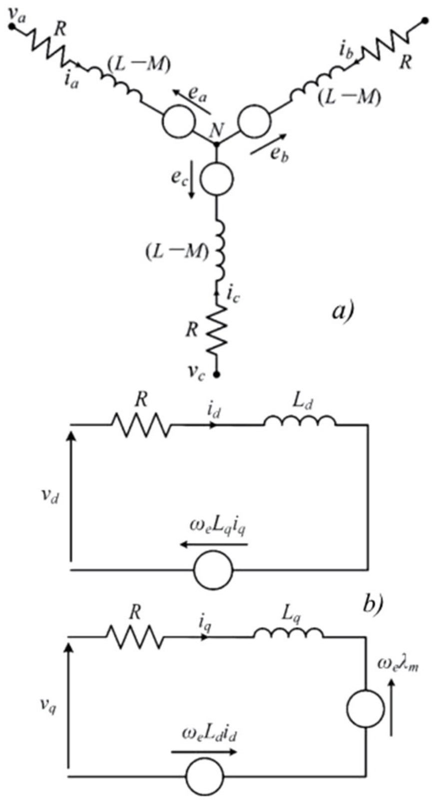


Fig. 4. The equivalent circuit of the BLDC (a) and PMSM (b) [3]

Every phase of the BLDC is equivalent to the electrical circuit of a DC motor (Fig. 4a). The equivalent circuit of the PMSM is dissected into two components, d and q (Fig. 4b), with each component functioning equivalently to a direct current circuit. The voltage balancing equations for BLDC and PMSM with surface-mounted rotor magnets are represented by Eqs. (1) and (2), respectively [3]:

$$\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} (L-M) & 0 & 0 \\ 0 & (L-M) & 0 \\ 0 & 0 & (L-M) \end{bmatrix} \frac{d}{dt} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \quad (1)$$

Where v_a, v_b, v_c; i_a, i_b, i_c; e_a, e_b, e_c represent the voltage, current, and instantaneous electromotive force in phases A, B, and C, respectively. R, L, and M represent the pure resistance, inductance, and mutual inductance of each phase, respectively.

$$\begin{cases} v_d = \left(R + \frac{d}{dt} L_d\right) i_d - \omega_e L_q i_q \\ v_q = \left(R + \frac{d}{dt} L_q\right) i_q + \omega_e L_d i_d + \omega_e \lambda_m \end{cases} \quad (2)$$

Where v_d, v_q; i_d, i_q; L_d, L_q; ω_e; λ_m represent the voltage, instantaneous current, self-inductance, electrical angular velocity, and magnetic flux through the PMSM coil in the d-q transformation, respectively.

2.2. Advantages and disadvantages

2.2.1. Moment characteristics

The torque of BLDC and PMSM is contingent upon motor speed, current, and the number of pole pairs. The instantaneous torque of these two motor types is determined using Eqs. (3), (4) consequently as follows [3]:

$$T_e = \frac{P_e}{\omega_r} = \frac{P}{2}\left(\frac{e_a i_a + e_b i_b + e_c i_c}{\omega_e}\right) \quad (3)$$

$$T_e = \frac{3}{2}\frac{P}{2}\left(\lambda_m i_q + \left(L_d - L_q\right) i_d i_q\right) \quad (4)$$

Where P represents the number of poles. Fig. 3 illustrates that the total $e_a i_a + e_b i_b + e_c i_c$ of the BLDC exhibits instability during the switching moment, even as the motor operates in a static condition. This results in the torque of this motor type oscillating significantly, as described by Eq. (3)(. Conversely, the torque of the PMSM, computed using Eq. (4), exhibits a significantly reduced amplitude of oscillation due to the regulation of the i_d and i_q components to stabilize the magnetic field. This benefit results in reduced noise and vibration levels during the operation of the PMSM in comparison to the BLDC.

The two motor types employ distinct approaches to enhance maximum speed. The technique employed in BLDC involves executing early switching (advance angle) to enhance the current in each phase. The maximum speed of PMSM can be increased by reducing the magnetic flux via the regulation of the i_d component. The torque characteristics of PMSM exhibit a expanded speed range in comparison to BLDC (12).

The investigation indicates that the torque-speed characteristics of PMSM surpass those of BLDC. The reason for this originates from the control principle and the electromotive force produced in the motor. Nevertheless, to realize these advantages, PMSM require a controller with more sophisticated algorithms.

2.2.2. Efficiency

Energy losses throughout conversion operations are assessed by the operational efficiencies of the motor (η_e), the power converter (η_{cv}), and the battery (η_b). Fig. 1 illustrates that the system's efficiency is determined as:

$$\eta = \eta_e \eta_{bd} \eta_b \quad (5)$$

The motor's efficiency significantly influences the energy conversion efficiency of the electric vehicle, as indicated by Eq. (5). Consequently, the overal efficiencies is a critical attribute that requires assessment. In contrast to industrial electric motors, the speed of electric motors utilized in electric vehicles varies significantly across a wide range. This necessitates the analysis and evaluation of electric vehicle motor performance across the complete operational speed spectrum.

In contrast to brushed DC motors, BLDC and PMSM operate without brushes and commutators. These two motor designs also do not incorporate short-circuit bars in the rotor, unlike the squirrel-cage three-phase AC motor. Avoiding losses from voltage drop at the brushes and short circuits in the rotor enables BLDC and PMSM to attain elevated efficiency [3, 11].

During the rotation of the rotor within a step angle, only two phases of the BLDC motor are energized with identical voltage as in Fig. 5. Consequently, the magnetic field vector generated by the stator remains constant in direction. This results in the angle between the rotor and stator magnetic field vectors varying significantly around 90 degrees, hence diminishing the efficiency of the BLDC. Simultaneously, the application of the d-q transformation in the PMSM controller ensures that this angle remains consistently at 90 degrees, hence enhancing efficiency.

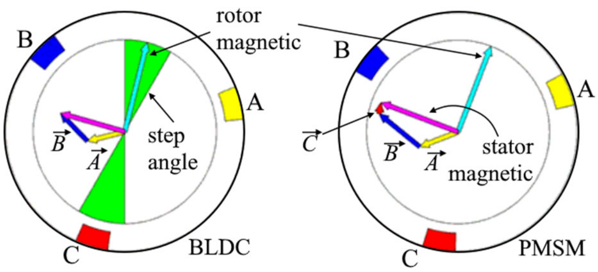


Fig. 5. Field vetors in BLDC and PMSM

Regarding efficiency, both BLDC and PMSM surpass brushed DC motors and three-phase induction motors. Due to superior torque characteristics and suitable control algorithms, the efficiency of PMSM surpasses that of BLDC. Throughout the complete operational speed spectrum, PMSM exhibits superior performance attributes, particularly at lower speed ranges.

2.2.3. Production cost

The production cost of electric motors is contingent upon the investment expenditures for research, materials, controllers, and manufacturing lines. BLDC and PMSM were created subsequent to brushed DC motors and three-phase squirrel cage AC motors. The enhancement of the architecture of these two motor types remains an ongoing area of research. This indicates that BLDC and PMSM incur more research investment expenses compared to the other two motor types.

The utilization of rare earth magnets substantially influences the material expenses of BLDC and PMSM. This component is produced by a sophisticated technical procedure and utilizes costly rare earth elements. These reasons elevate the expense of rare earth magnets, consequently raising the production costs of BLDC and PMSM. The predominant production of rare earth materials and rare earth magnets of China can elevate the financial risk associated with manufacturing these two types of motors.

The controller operates by utilizing input signals to modulate the current sent to the motor's coils. BLDC and PMSM utilize electronic switching, necessitating more intricate controllers than brushed DC motors and three-phase squirrel cage AC motors. PMSM necessitates control algorithms to execute intricate and accurate mathematical changes depending on rotor position rapidly. To fulfill this need, a microcontroller with robust computational capabilities, high-resolution rotor position sensors, and a power circuit capable of high-frequency operation is essential. Consequently, the PMSM controller incurs a greater manufacture cost relative to controllers for alternative motor types.

The establishment of an electric motor production line will entail expenses for design and planning, investment in machinery and equipment, installation and setup, infrastructure development, staff training, and maintenance. To reduce expenses, the corporation may acquire a used production line. During such period, capital expenditures can be minimized as only infrastructure and labor require additional investment. Nonetheless, the existing BEV engine production lines are entirely newly planned and developed. The rationale is that BEV technology has been undergoing constant evolution recently. Simultaneously, the ES production industry has previously attracted investment, particularly in China, resulting in the presence of numerous antiquated engine production lines for this category of vehicle.

The capability to operate in motor mode is fundamental for the design and selection of electric machines for electric cars. The primary requirements for electric car motors are appropriate torque characteristics, elevated operational efficiency, and minimal production costs. Furthermore, there are additional needs not yet examined in this study, including: minimal volume and mass; reduced rotor inertia; and fault tolerance capability... The efficiency of brushed DC motors and three-phase squirrel-cage AC motors is insufficient for contemporary electric vehicle applications.

3. SIMULATION OF BLDC AND PMSM

Utilizing Eqs. (1), (2), (3) and (4), a simulation of a BLDC motor and a PMSM motor (both in-wheel type) for ESs has been conducted using the Matlab Simulink software, as illustrated in Fig. 6. To validate the attributes and performance, the motors were configured to identical speed and load torque circumstances. The other parameters, including power supply, power, number of pole pairs, resistance, and phase winding inductance, were identical in both variants. The parameters are elaborated in Table 1.

Table 1. Motors parameters

Parameter	Value, unit
Power	1.2kW
Source voltage	48V
Max. speed	800rpm
Number of pole pairs	26
Winding resistor	0.65Ω
Winding inductor	13mH

The phases of both motors are directly energized by a 3-phase H-bridge circuit. The elements in the bridge circuit are switched in accordance with the signals from the controller. The BLDC controller utilizes feedback signals from the motor, represented as square waves from Hall sensors (Fig. 6a). Simultaneously, the PMSM controller necessitates rotor position signals and phase current magnitudes (Fig. 6b). The PMSM control system incurs a greater hardware expense compared to the BLDC system.

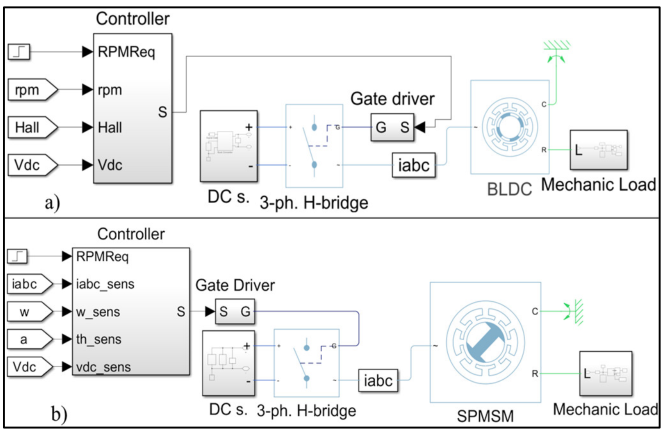


Fig. 6. Simulation of BLDC and PMSM with Matlab Simulink

The efficacy of the two systems is ascertained using the formula:

$$\eta = \frac{E_{batt}}{E_C} = \frac{\int V_{dc} i_{dc} dt}{\frac{1}{2} I \omega_r} \tag{6}$$

Where i_{dc} represents the instantaneous current intensity of the battery; I denotes the moment of inertia connected to the motor shaft. The simulation findings indicate that the efficiency of the BLDC control system is 85.5%, almost 5% inferior to that of the PMSM control system, which is 90.4%. By integrating Eq. (5) with the efficiency metrics of the power converter and battery in the simulation of the two motors, it can be deduced that the PMSM exhibits an efficiency roughly 5% superior to that of the BLDC. This is accomplished through the application of vector control in PMSM, as illustrated in Fig. 5.

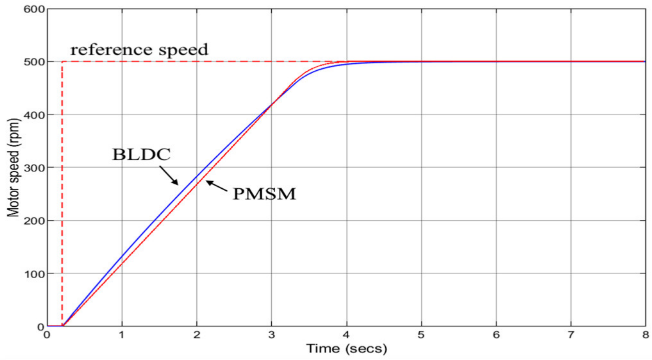
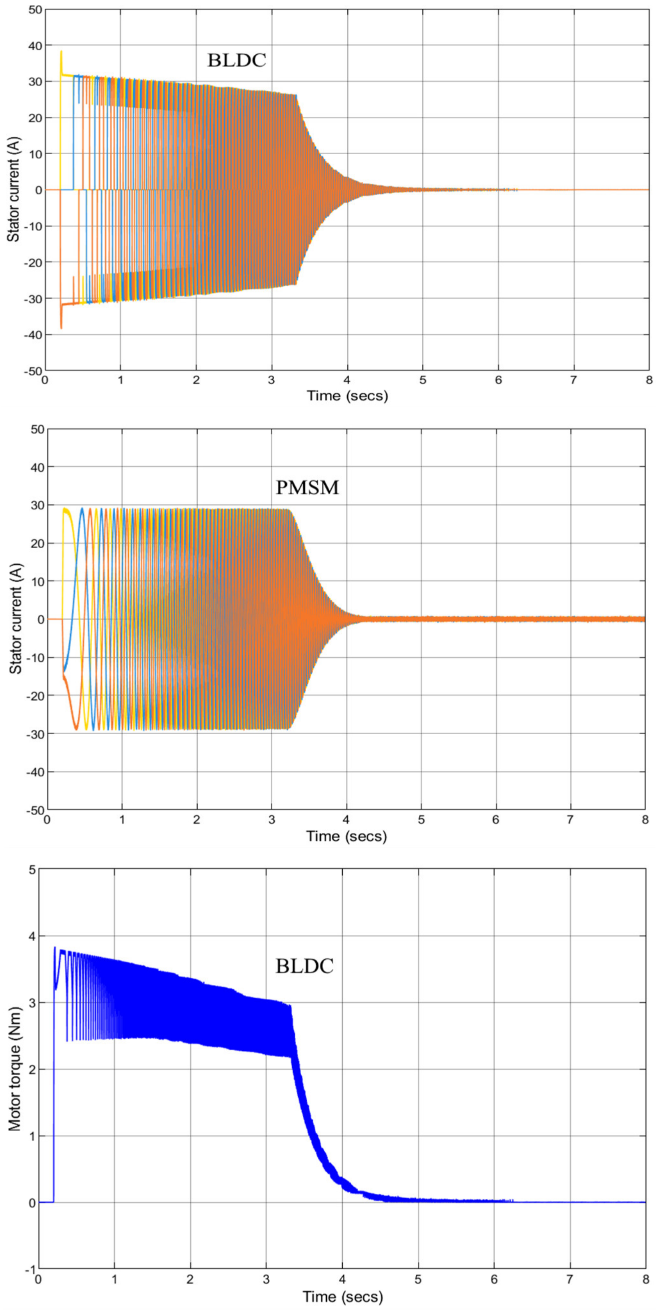


Fig. 7. Step response characteristics of the BLDC and the PMSM

The simulation findings of the step response for the two motors depicted in the Fig. 7 indicate that the BLDC and PMSM exhibit similar step responses. The rapid acceleration phase extends from the start of acceleration to the conclusion of the linear velocity region. During this phase, the velocity of the PMSM exhibits a more linear characteristic in comparison to the BLDC, albeit not markedly so. This response characteristic indicates that the acceleration demands of the ESs may be satisfied by both motor types.

Fig. 8 distinctly demonstrates the pulsed and sinusoidal characteristics of the currents in the BLDC and PMSM, respectively. During the early phase, the current of the BLDC demonstrates considerable variations, reaching a maximum of 38A. The amplitude of this current diminishes gradually during the rapid acceleration phase, subsequently experiencing a swift decline as it nears the target speed. This control characteristic results in substantial fluctuations in output torque (ranging from 2.5Nm to 3.8Nm) during the rapid acceleration phase. Simultaneously, the phase currents of the PMSM were regulated to fluctuate sinusoidally with a consistent amplitude of 29A during the rapid acceleration phase. This enables stable regulation of motor torque ranging from 2.9Nm to 3.3Nm throughout the process. The results indicate that the PMSM can sustain a consistent output torque with an oscillation amplitude about three times smaller than that of the BLDC. The simulation outcomes regarding operational efficiency and torque characteristics demonstrate that the study and comparison of the merits and demerits of BLDC and PMSM are scientifically substantiated and validated. The simulation model concurrently illustrates the disparities in control systems, resulting in variations in research and production investment costs for these two motor types. The distinctions outlined in the preceding text provide the scientific rationale for choosing the suitable electric motor for BEVs and ESs.



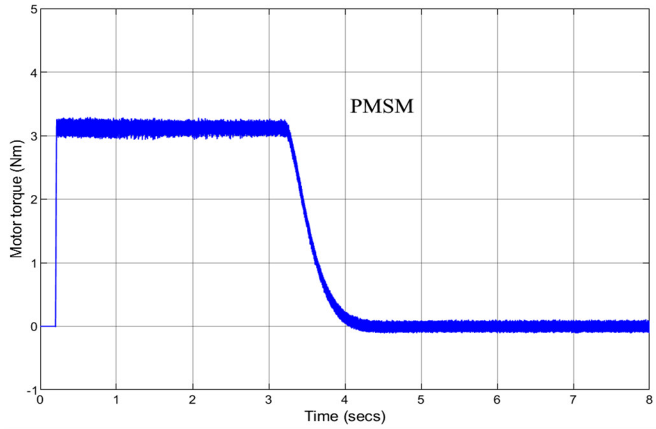


Fig. 8. Phase current, output torque of BLDC and PMSM

4. SELECTING MOTORS FOR ELECTRIC VEHICLES IN VIETNAM

4.1. Attributes of electric vehicles in Vietnam

The selection of electric vehicle's configuration, including the motor's type and specifications, influences performance as well as research and production expenses. Most BEVs and ESs in Vietnam are equipped with low to medium-sized electric motors and are economically priced. Table 2 presents a summary of several common BEV and ES models in Vietnam.

The electric vehicle models listed in Table 2 have all been manufactured within the last four years. ESs in Vietnam predominantly exhibit low power, ranging from 0.8kW to 1.2kW, a power-to-weight ratio below 5.5kW/ton, limited travel distances of 65km to 80km, speeds under 50km/h, and a cost not exceeding 20 million VND. Table 2 features only two models, the Pega S and the Vinfast Vento S, which possess a high cost exceeding 45 million VND. These models exhibit a power-to-weight ratio ranging from 12kW/ton to 13kW/ton, enabling a maximum speed of 90km/h, a brief acceleration period, and a trip distance of up to 160km. The statistical data indicate that the majority of electric scooters in Vietnam are designed for urban transportation, characterized by low power and cost. Several electric scooters are engineered with enhanced power and extended travel range to substitute motorcycles in both urban and rural settings.

The BEVs in Vietnam, as enumerated in Table 2, are only passenger cars with a power range of 20kW to 300kW and a reserve range of 120km to 530km. Two BEVs with a power output below 30kW, a power-to-weight ratio under 30kW/ton, a maximum speed of 100km/h, and a trip range of 120km to 200km - comparable to certain Ess - are exclusively appropriate for urban travel.

Table 2. Specifications of popular electric vehicles in Vietnam

	Model	Year	Max. speed (km/h)	Type/ Power (kW)	Weight (kg)	Power/mas ratio (kW/ton)	Range (km)	Price (mil. VND)
BEV	Wuling mini eV	2023	100	PMSM/20	960	20.8	120	240
	Vinfast VF3	2024	100	PMSM/30	1100	27.3	210	330
	Vinfast VF5	2022	130	PMSM/100	1500	66.7	320	468
	Vinfast VF6	2023	150	PMSM/150	1600	93.8	480	675
	Vinfast VF7	2023	150	PMSM/170	1800	94.4	430	850
	Vinfast VF8	2023	200	PMSM/260	2500	104	470	1120
	Vinfast VF9	2023	200	PMSM/300	2900	103	530	1700
ES	Pega S	2023	75	PMSM/4	300	13.3	120	45
	Vinfast Vento S	2022	90	PMSM/3	250	12	160	47
	Vinfast Motio	2024	50	BLDC/1,2	226	5.3	80	18
	Yadea G5	2021	40	BLDC/1,2	226	5.3	65	19
	Dibao GoGo	2021	45	BLDC/1,2	223	5.4	80	19
	DK Roma	2024	50	BLDC/0,8	218	3.7	70	17
	Dibao Pansy	2024	50	BLDC/0,8	238	3.3	75	19

The residual BEVs exhibit power outputs ranging from 100kW to 300kW, power-to-weight ratios between 66kW/ton and 104kW/ton, and travel ranges spanning from 320km to 530km, engineered for both urban and non-urban traffic conditions. The prices of these models range from 330 million VND to 1.7 billion VND, comparable to internal combustion engine vehicles. The majority of BEVs in Vietnam are engineered for both urban and suburban travel, exhibiting power and range comparable to conventional vehicles. Nevertheless, the power-to-weight ratio is still low to average in comparison to electric vehicles globally. For instance, the Tesla Model 3 and BYD Tang exhibit power-to-weight ratios of 377kW/2.3tons = 164kW/ton [13] and 380kW/2.6tons = 146kW/ton [14], respectively, significantly surpassing the Vinfast VF8, which has the greatest ratio in Vietnam at 104kW/ton.

4.2. Selecting motors

Presently, BLDC motors utilized for ESs in Vietnam are cost-effective, possess a low power-to-weight ratio, and function in urban settings. The primary rationale for this decision is to use existing BLDC motor production lines from China to minimize manufacturing expenses. This motor type does not attain high velocities comparable to PMSM but is appropriate for modest speeds in metropolitan regions of Vietnam. Furthermore, the disadvantages of this motor type, including significant torque variations and reduced efficiency demonstrated in the simulation, are slightly alleviated by the low motor power.

Several ES types intended to supplant motorbikes with a high power-to-weight ratio have included permanent magnet synchronous motors. The utilization of this motor type guarantees a seamless experience due to its excellent torque stability. The elevated engine efficiency concurrently enhances the travel distance. The expense of these models significantly exceeds that of alternative options. The rationale is partially attributable to elevated production line expenses. In the future, the investment cost for permanent magnet synchronous motor production lines will progressively diminish. Upon the complete depreciation of the existing BLDC production lines, enterprises should prioritize the selection of PMSM for investments in production lines and the exploration of new ES designs.

All BEVs in Vietnam presently have a power-to-weight ratio far superior than that of the ESs and are equipped with PMSM motors. When motor power is elevated, the superior efficiency throughout the full speed spectrum of this motor type significantly enhances travel distance. The capability to excel in elevated speed ranges is appropriate for the rapid travel velocities of BEVs. The capacity to stabilize torque enhances comfort during vehicle operation. Moreover, the disadvantage of elevated controller expenses and the necessity to invest in new production lines might be mitigated by the selling price of electric vehicles. To reduce the risk of reliance on rare earth magnets, electric car makers may investigate the viability of employing non-permanent magnet motors, such as switched reluctance motors (SRM).

5. CONCLUSION

This research analyzes the advantages and disadvantages of the torque-speed characteristics, efficiency, and production costs of BLDC and PMSM, based on their structure and operating principles, and validated using computer simulations with Matlab Simulink software. The results of the simulation indicate that these two motor types are utilized in all contemporary electric vehicles models due to their greater efficiency relative to traditional motors. PMSM exhibits exceptional speed characteristics, remarkable efficiency, and consistent output torque. The data regarding electric vehicles in Vietnam indicates that BLDC is preferred for small ESs due to its low power-to-weight ratio and suitability for urban mobility. Currently, PMSM is the exclusive option for BEVs in Vietnam. Furthermore, this motor type represents a novel option for certain high-power, high-cost ESs. This trend will gain further popularity in the future as the production costs of PMSMs decline. This is a consideration when investing in new designs and constructing the ES motor production line. In addition to BLDC and PMSM, electric vehicle producers ought to allocate resources towards the exploration of alternative motor types, such as SRM, to mitigate the risk associated with reliance on rare earth magnet materials.

The limited number of domestic companies producing BLDC and PMSM is obstructing the objective of enhancing the localization rate in the electric vehicle manufacturing sector. The government must enact supportive policies to enhance the supply chain for the electric vehicle sector. Moreover, other domestic firms must actively invest in research and innovate their production processes for various engine kinds.

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