ANALYSIS AND COMPARISON OF ELECTRIC MOTOR TYPES FOR ELECTRIC VEHICLES

PHÂN TÍCH VÀ SO SÁNH CÁC LOẠI ĐỘNG CƠ ĐIỆN SỬ DỤNG CHO XE Ô TÔ ĐIỆN

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ABSTRACT

Nowadays, electric cars are a great alternative to internal combustion engine vehicles because they offer outstanding energy efficiency, reduced maintenance costs, and pollution-free operation. Manufacturers of electric cars can also overcome the limitations typical of electric cars as technology advances. Therefore, making them more widely used for mobility is growing. An electric vehicle's motor provides vital traction for the vehicle's motion system, making electric motors an essential part of electric cars. In this paper, different types of electric motors will be compared based on critical factors to be taken into account when choosing engines for electric cars. For specific parameters, a comparison is tabulated.

Keywords: *DC motor, Induction motor (IM), Permanent magnet synchronous motor (PMSM), Witched Reluctance Motor (SRM), Electrical vehices.*

TÓM TẮT

Ngày nay, xe ô tô điện là một giải pháp thay thế hay cho các phương tiện động cơ đốt trong, bởi vì phương tiện này mang lại hiệu quả năng lượng vượt trội, giảm chi phí bảo dưỡng và vận hành không gây ô nhiễm. Các nhà sản xuất xe ô tô điện cũng có thể khắc phục những hạn chế điển hình của ô tô điện khi công nghệ kỹ thuật ngày càng tiến bộ. Vì vậy, khiến chúng được sử dụng nhiều cho việc di chuyển ngày càng phát triển. Động cơ của xe điện cung cấp lực kéo quan trọng cho hệ chuyển động của xe, khiến động cơ điện trở thành một phần quan trọng của xe ô tô điện. Trong bài báo này, sẽ trình bày các loại động cơ điện khác nhau được so sánh dựa trên các yếu tố quan trọng được tính đến khi chọn động cơ cho xe ô tô điện. Đối với các thông số cụ thể, một so sánh được lập bảng.

Từ khóa: *Động cơ một chiều, động cơ từ trường, động cơ đồng bộ nam châm vĩnh cửu, động cơ từ trở thay đổi, ô tô điện.*

1. INTRODUCTION

It is critical to replace nonrenewable energy supplies (such as fossil fuels). The overall perspective of this demand is that renewable energy resources should be used more often. It is also well recognized that transportation accounts for most global energy use, prompting the development of innovative mobility solutions. Because electric vehicles (EVs) are less polluting and more efficient than cars with internal combustion engines, their sales have been steadily increasing in the automobile market [1]. Machines are classified into three categories based on how they drive: internal combustion engine vehicles, electric vehicles (EV), and hybrid electric vehicles. Unlike conventional cars powered by internal combustion engines, electric vehicles are powered by an electric motor or a group of electric motors. A hybrid electric vehicle (HEV) is powered by an electric motor and an internal combustion engine [2]. Although cars need continuous power in terms of acceleration, the IEVs are not suitable for generating this torque and speed. However, a longer constant range may be attained if specific motors are correctly constructed. Meanwhile, desired features of EV motor drives are high power density, fast torque response, high instant power, including constant-torque and constant-power regions, low cost, robustness, high efficiency over a wide speed range, high torque at low speeds for initial acceleration, and reliability [3]. Thus, to ensure the features of electric cars, the choice of type motor and drive motor for electric vehicles is necessary.

Acording to [4], the electric vehicle powertrain structure is mainly divided into the centralized and distributed electric transmission, such as Figure 1.

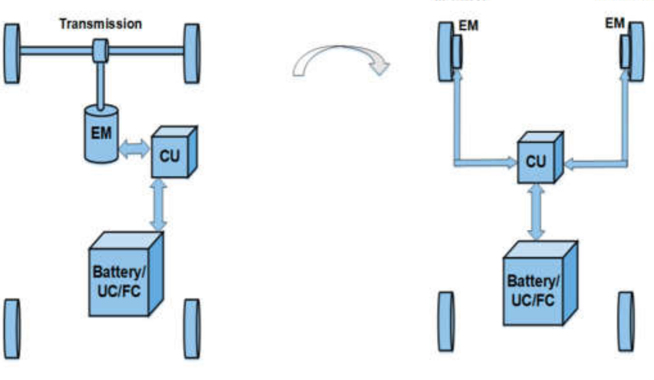

Figure 1. The electric vehicle powertrain structure

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In Figure 1 that, with a centralized electric drive system, replacing conventional internal combustion engines (DC and AC) with a motor that drives two wheels through a differential system to provide energy (torque) for two wheels [5]. Meanwhile, a distributed electric powertrain powered by multiple motors can be fed to the front or rear of the vehicle on two or four wheels, making the car a front-wheel drive, leading the rear-wheel drive, or four-wheel drive [6]. A distributed electric powertrain with a compact structure and layout flexibility shortens the mechanical transmission chain and improves space utilization. Distributed electric powertrains improve the vehicle's driving performance through differential steering, making the most of vehicle energy, improving transmission efficiency, and increasing range. The distributed drive system, according to different installation methods of the motor, can be divided into the motor drive at the wheel shaft and motor drive integrated with the wheel [8].

In addition, AC motor drives offer various benefits over DC motor drives, such as better efficiency, reduced maintenance, robustness, dependability, higher power density, and efficient regenerative braking [7]. A survey on the selection of motors and drives in electric vehicles has been conducted in this study. The performance of AC and DC motors, as well as their drivers, have been compared. The electric motor drive system has outstanding advantages in terms of controllability (torque, anti-slip), allowing us to use advanced control methods to control the motor by improving the dynamic quality of electric cars. Therefore, the issue of which engine to use has always been cared for by many scientists and automobile companies

The current work analyzes the mechanical characteristics of motors (DC and AC) and motor drives used in electric vehicles through parts 2 and 3. Next, section 4 will provide comparison results of Motor Drives Used in EVs for desired characteristics and output through evaluation data on performance, capacity, torque, speed. Finally, this brief section will suggest which engine and electric transmission to use for current and future electric vehicles.

2. ELECTRIC VEHICLE MOTORS TYPES

2.1. DC motors

The DC motor has the outstanding advantage of being easy to control. The disadvantage of this motor is that it needs a set of manifolds and brushes, has low life, requires regular maintenance, and is unsuitable for hot, humid, and dusty conditions. As semiconductor valve technology, microprocessors, and control techniques develop strongly, DC motors are gradually being replaced by other types of motors. The brushless DC motor (BLDC) is a type of permanent-magnet synchronous motor with trapezoidal reactance. This makes the BLDC motor have the same mechanical characteristics as a DC motor, power density, high torque capacity, and high efficiency [8, 9].

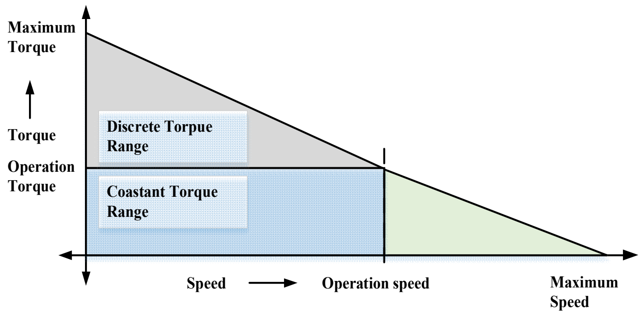

Figure 2. Ideal mechanical characteristics of DC motor

2.2. Induction motor (IM)

The characteristics of AC motors, such as squirrel-cage rotor (IM) asynchronous motors, have the advantages of low cost, everyday use, and ease of manufacture. It is possible to implement advanced vector control algorithms for IM engines with current technology, meeting the necessary technological requirements. The disadvantage of the IM motor is its low efficiency, especially at light load. Some US electric car manufacturers, such as Tesla motor, use this engine because it is suitable for the highway traffic system. With cars running in urban areas, the IM engine is rarely used [8, 9].

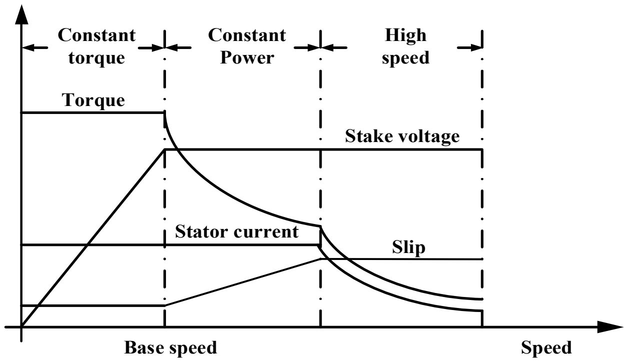

Figure 3. Mechanical characteristics of IM motor

2.3. Permanent magnet synchronous motor (PMSM)

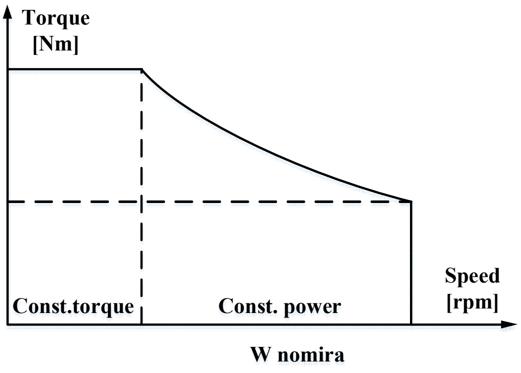

Figure 4. Mechanical characteristics of PMSM motor

Permanent magnet synchronous motor (PMSM) can be considered as the most suitable motor for electric vehicle application with high efficiency, large torque capacity, and can be controlled with good quality. In particular, the submerged permanent magnet motor (IPMSM) has many advantages suitable for electric cars. For example, two commercial models, Nissan Leaf and Mitsubishi MiEV of Japan, use this engine [10]. However, due to the size of the PMSM motor, it is not suitable for the technology to integrate the motor in the wheel [8, 9].

2.4. Witched Reluctance Motor (SRM)

Simple control, a large constant power area at high speeds, fault tolerance, effective torque-speed characteristics, and sturdy construction are all benefits of SRMs for EVs. SRM has acquired a lot of traction because of its increased torque component [9]. The efficiency of SRM is about 95%, making it comparable to the IM [10]. SRM is an ideal motor type for EV applications because of these characteristics. There is no need for maintenance since there is no brush, collector, or magnets. As a result, the cost of manufacturing is minimal. This motor can be sensorless controlled because of the high rotor inductance ratio. Because there are no copper losses in the rotor owing to the conductor in the rotor winding, the rotor temperature is lower than in other motor types. Low inertia is critical for capturing reference speed in changeable reference speed applications. SRM's rotor also has less inertia than other motors'. Because there is no link between the phases, the motor continues to run even if one of them fails [11]. Acoustic noise, vibrations, and high torque ripple are all concerns caused by the salient-pole rotor and stator. However, they are not critical for EVs.

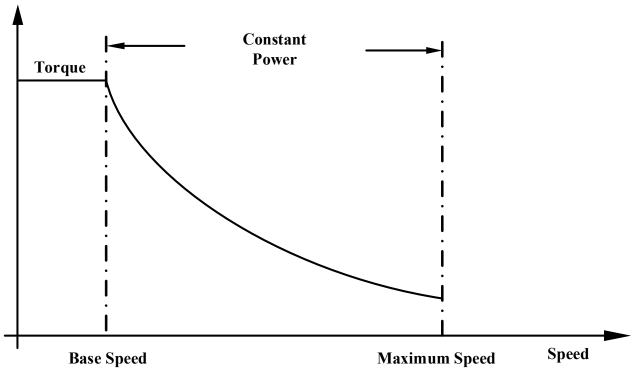

Figure 5. Mechanical characteristics of SRM motor

2.5. PM Brushless DC Motor (BLDC)

The PM BLDC motors have a high power density and efficiency. Due to the lack of rotor winding and rotor copper losses, their efficiency is better than IM. However, the existence of the PM field, which a stator field may lessenAs can be seen in Figure 6, the constant power area is quite brief. In Figure 6, shows how a conduction-angle control may expand the operating zone at constant power three to four times. The magnets of PM BLDC motors prevent the motor from producing a high torque. Furthermore, there are significant drawbacks, such as mechanical forces and magnet costs. The increase in centrifugal forces at greater speeds poses a concern in terms of driving safety due to the chance of magnets breaking. Magnets are also susceptible to high temperatures. Because of the high working temperature, the residue flux density decreases, lowering the machine's torque capacity [13].

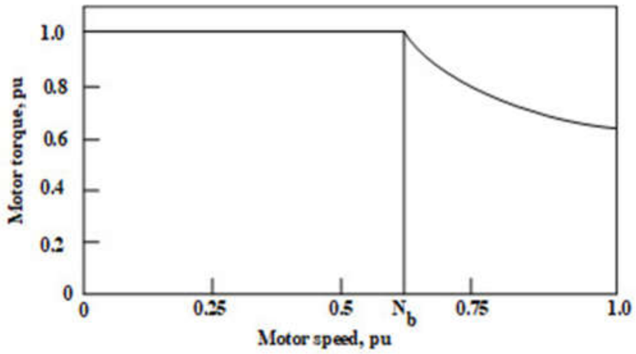

Figure 6. Typical characteristics of PM BLDC motor [12]

2.6. Axial flux permanent- magnet (AFPM)

Axial-flux permanent-magnet machines have several distinct characteristics. First, because field excitation losses are minimized, permanent magnets are generally more efficient, cutting rotor losses dramatically. As a result, machine efficiency improves dramatically, producing better power density. Because axial-flux construction uses less core material, the torque-to-weight ratio is high. AFPM machines are also smaller than their radial flux equivalents due to their thin magnets. The size and form of an AFPM machine are significant elements in applications with limited space. Hence compatibility is critical. They create far less noise and vibration than traditional machines [10]. In addition, the AFPM motor has advantages such as high efficiency, large size power ratio, high power density, long life, a small moment of inertia, wide operating speed range, torque/current ratio, large, low noise, stability, etc. Therefore, AFPM motors have been widely used in high-quality speed-controlled transmission systems such as electric vehicles, industrial robots, CNC machines, and other devices. Furthermore, medically turned flywheels in energy storage systems have almost absolute advantages in applications for electric cars [11].

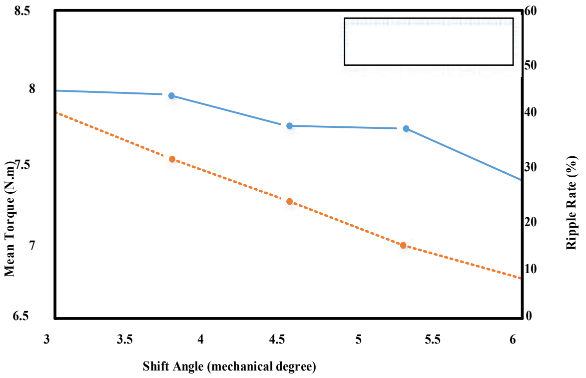

Figure 7. Torque profile characteristics of AFPM motor [12]

3. DESIRED OUT CHARACTERISTICS OF MOTOR DRIVE FOR EVs

3.1. Out Characteristic of Motor Drivers

Torque-speed or power-speed parameters are used to evaluate EV performance. The torque-speed curve is defined by two design factors: maximum grade and maximum speed. The vehicles must run at constant power for beginning acceleration and strong grade ability. Figure 8 depicts the required output characteristic of EV motor drives. The motor drive should have a lot of torque at low speeds for acceleration and cruising, a lot of power at high rates for cruising, and a broad speed range under continuous control.

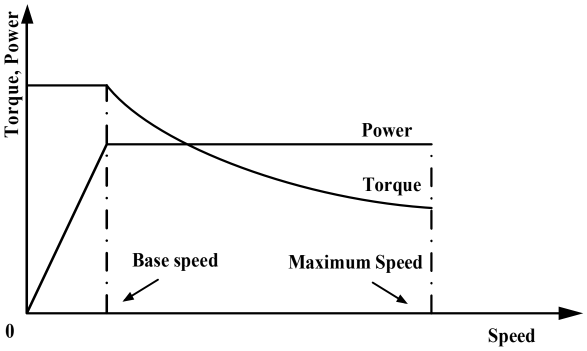

Figure 8. Desired output characteristics of electric motor drives in Evs

According to Figure 8, if the constant power region ratio rises, the power required for acceleration performance lowers, according to the output characteristic of EVs. As a result, the required torque, converter cost, motor size, and volume all rise. Passing performance (passing time and passing distance) suffers considerably as the constant power region ratio increases. A motor's maximum speed has a pronounced effect on the required torque of the engine. Low-speed engines with the extended stable power speed range have a much higher rated shaft torque. Consequently, they need more iron and copper to support this higher flux and torque. As motor power decreases (due to extending the range of constant power operation), the required torque increases. Therefore, although the converter power requirement (hence the converter cost) will decrease when the stable power range increases, the motor size, volume, and the price will increase. Increasing the maximum speed of the motor can reduce the motor size by allowing gearing to increase shaft torque. However, the motor's full speed cannot be increased indefinitely without incurring more cost and transmission requirements. Thus, there is a multitude of system-level conflicts when extending the constant power range.

3.2. Requirements of Evs on Electrical Motor Drives

The selection of electric motor drives for EVs is a crucial step that requires special attention. The automotive industry is still seeking the most appropriate motor drive for EVs or HEVs. Previous literature [15] discussed the important requirements of EVs on electric motor drives. Therefore, selecting the most appropriate motor drives for an EV is challenging. In this paper, the basic requests are summarized as follows high instant power and a high power density; a high torque at low speed for starting and climbing, as well as a high power at high speed for cruising; an extensive speed range with constant-power region; a fast torque response; a high efficiency over the wide speed range with constant torque and constant power regions; a high efficiency for regenerative braking; downsizing, weight reduction, and a lower moment of inertia; high reliability and robustness for various vehicle operating conditions; a reasonable cost; a fault tolerance, and suppression of electromagnetic interface (EMI) of motor controllers.

4. COMPARISION OF MOTOR DRIVE SYSTEMS USED IN EVs

To obtain the most appropriate choice for Evs among four types of motor drives, some publications give their contributions [8 - 15]. From the above-summarized features of four types of motor drives for EVs, Tables 1 - 4 lists weight factors in efficiency, weight, and cost of four motor drives, where five marks represent the highest efficiency, lowest weight, and lowest cost, respectively. The comparative criteria of motor on scale of 1-5.

4.1. Power-to-Weight Ratio

The peak power of an electric motor is commonly used to compute the power-to-weight ratio. Divide the peak of the motor's power output in kW by the engine's weight in Kg to get the power-to-weight balance for an electric motor. Furthermore, various electric motor manufacturers develop and build the same motor with the same ratings in different ways. As a result, there may be a minor weight discrepancy between them. Therefore, the mean weight of engines will be used to computer their power-to-weight ratios and the same power, voltage, and speed ratings [8 - 15].

Table 1. Comparision between four motors used in Evs for power-to-weight ratio

Index	DC motor	IM	PMSM	SRM	BLDC	AFPM
Weight	2	4	4.5	3	4.5	4.5

4.2. Efficiency

Table 2. Comparision between four motors used in Evs for Efficiency

Index	DC motor	IM	PMSM	SRM	BLDC	AFPM
Peak Efficiency (Percent)	85-90	>90	>92	<95	>95	<95
Efficiency at 10% load (Percent)	80-85	>90	>92	>90	70 - 80	94.6

The electrical efficiency of an electric motor tells us about the relationship between the power of the engine's electrical input and output. At the rated capacity of a motor, all-electric motors are intended to run at maximum efficiency. However, the performance of an electric motor in an electric vehicle will vary depending on the load. As a result, when selecting an engine for use in an electric car, its peak efficiency and efficiency at other loads must be examined. The following table shows the efficiencies of individual electric motors at peak load and at 10% load ($P_{\text{đm}}$ = 108kW, T_e = 242Nm) [8 - 15].

4.3. Cost of Controllers

The motor controller improves performance, efficiency, and controllability in electric cars. If an electric vehicle producer intends to develop a low-cost electric vehicle, the joint cost controller he chooses will ultimately influence the motor. The cost of controllers for various low voltage electric motors with the same voltage and output power ratings is given below for low voltage electric motors extensively used in electric vehicles (($P_{\text{đm}}$ = 108kW, T_e = 242Nm), [8 - 15].

Table 3. Comparision between four motors used in Evs for cost of controllers

Index	DC motor	IM	PMSM	SRM	BLDC	AFPM
Cost	5	3	3.5	3.5	5	3.5

4.4. Cost of Motors

One of the most challenging tasks facing electric vehicle makers is to offer consumers an electric vehicle that performs and a gasoline vehicle while remaining inexpensive. As illustrated below, the costs of several electric motors with the same voltage and output power ratings are compared with $P_{\text{đm}}$ = 108kW, T_e = 242Nm [8 - 15].

Table 4. Comparision between four motors used in Evs for motors

Index	DC motor	IM	PMSM	SRM	BLDC	AFPM
Cost	4.5	2	2	3	4.5	4

5. CONCLUSION

This paper with five electric motors for use in electric vehicles based on various factors such as power-to-weight ratio, torque-speed characteristics, efficiency, controller cost, and motor cost, according to the results of the comparative analysis. Firstly, the DC brushed motors are simple to regulate and provide excellent torque at low speeds, but they have a high maintenance cost, giant, and poor efficiency. Secondly, the BLDC motor offers a more excellent power-to-weight ratio, but it has a high maintenance cost and controller cost. Thirdly, the efficiency of a three-phase induction motor is more than 90% at peak load and 10% load. As a consequence, electric car manufacturers prefer to employ phase induction motors. Fourthly, the synchronous motors are more efficient at lower speeds, allowing for better battery use and driving range. The synchronous motors will be used when continuous torque is needed. Fifthly, the SRMs are a beautiful alternative to induction motors because they reduce motor and controller costs, high efficiency at peak load and 10% load, dependability, and fault tolerance. Lastly, the AFPMs motor has advantages such as high efficiency, large size power ratio, high power density, long life, a small moment of inertia, wide operating speed range, torque/current ratio, large, low noise, stability, but they have a high cost. Therefore, AFPM motors have been widely used in high-quality speed-controlled transmission systems such as electric vehicles.

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