Analysis of Tesla Model's Cylindrical Cells and Electric Motor

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Abstract. The article contributes with a review of Tesla model s and Tesla cylindrical cells represented by 4680 new high-performance battery. The reason Tesla uses cylindrical cells is explained by comparing the commonly used batteries of three types. A method to solve the uneven current distribution of cylindrical cells also be proposed. The report also introduces and compares three types of motors: IM, IPM and SPM, including the motors' structure, advantages and disadvantages of various types of motors, the relationship of speed and torque. As a new travel tool for future sustainable development and low-carbon society, electric vehicles have been well developed in recent years. The related technologies are becoming more and more mature and the industrial chain is becoming more and more perfect, the distribution of related supporting infrastructure such as charging piles is becoming much common. Therefore, the EVs have received more and more attention. The future development prospects of electric vehicles are certainly promising.

Keywords: EVs, Tesla, Cells, Electric Motor.

1. Introduction

As people's awareness of environmental protection grows, governments in both developed and developing countries are promoting electric vehicles (EVs). Studies have shown that the transport sector accounts for nearly 28 % of CO2 emissions globally, with road transport composing over 70 % of transport sector emissions [1]. Tesla is viewed as a dark horse in the auto industry. As a young brand founded in 2003, Tesla is committed to product innovation and sustainable development of electric vehicles [2]. Sports cars are automobiles that have a strong emphasis on dynamic performance, including driving, acceleration, top speed, and the thrill of driving. An electric car is one that uses an electric motor rather than a typical internal combustion engine. A battery pack or other form of energy storage powers the electric motor that drives an electric vehicle (as defined by the International Electrotechnical Commission). According to pertinent data, China's market share for electric vehicles has risen to 22.9% in recent years. The Tesla design is a good illustration of how an electric car and a huge sports car can coexist. On Tesla's official website, customers can find the two models that are now offered in regular and Plaid versions. Both models have a maximum range of about 630–650 km, but the Plaid version has three engines as opposed to the conventional version's two. The Plaid version, which has a peak power output of easily over 1000 hp, has substantially greater acceleration and a higher top speed than the standard version, which has a peak power output of roughly 670 hp. These results also emphasize the sporty nature of the Model s. The popularity of electric vehicles is increasing at a rapid rate due to technological advancements and consumer popularity. The 1980s and 1990s saw the creation of the first practical and safe lithium-ion battery (LIB) with LCO as the cathode and carbon/graphic as the anode. LIBs are widely used in both domestic and industrial electronic devices, vehicles and other electric fields due to their high energy density, high power density and long cycle charge life. Decades of development have increased the maturity of the LIBs industry. The cost of LIBs fell from more than $1000/kWh at the beginning of 2000 to about $200/kWh, and the specific energy density has been risen from 150 Wh/kg to approximately 300 Wh/kg during the past few decades. It is believed that lithium-ion batteries are likely to dominate the market for at least the next decade [3]. 4680 battery is a new high-performance battery jointly developed by Tesla and Panasonic Company. The study found that the battery can store five times as much energy, six times as much power and increase its range by 16 % [4]. The most important part of an EVs system is its motor drive system, which serves as its primary energy source [5]. There are several various kinds of engines that can be used to power electric cars, including synchronous permanent magnet (PMSM) motors, induction motors, and DC motors. The performance as well as the cost of the motor drive system must be balanced while choosing the type of motor [6].

The most basic type of motor is the DC motor. To shift direction, it uses mechanical brush commutation. It has a high failure rate, is prone to wear and strain, and is challenging to maintain. However, the huge volume, constrained speed range, as well as low energy density limit its use in electric vehicles; just a small number of e-bikes do. Because they can generate more torque by using more current, AC motors are typically regarded as being more powerful than DC motors. Therefore, EVs needing more power are better suited for AC motors. DC motors are better suited for home products with low power and quick response times, such fans.

2. Battery

2.1. Cylindrical battery

All models of Tesla electric vehicles without exception choose to use cylindrical batteries (Fig. 1), such as the battery of model 18650 and model 2170, which have been widely used before.

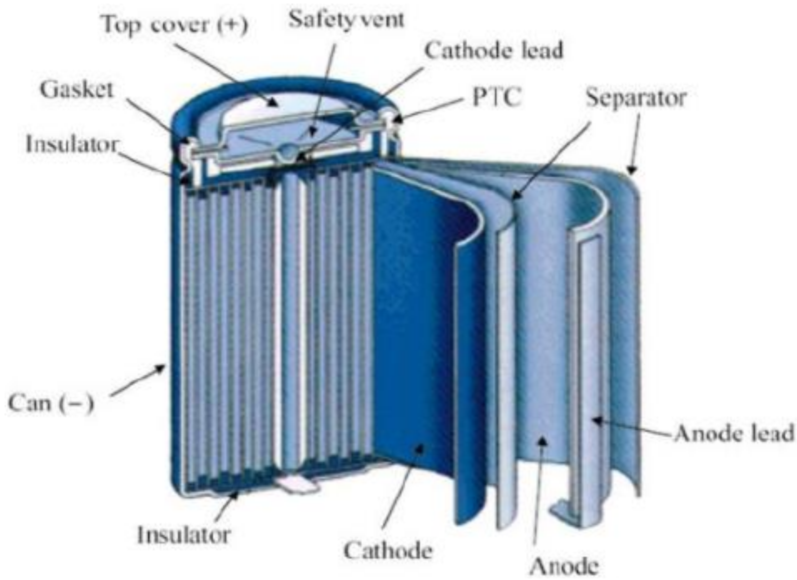


Figure 1. General structure of the cylindrical battery [7]

An anode, a spacer, and a cathode make up a cylindrical cell. The spacer is sandwiched in the middle, rolled up, and packaged in a cylindrical reservoir. The cell's circular cross-section does not utilize all of the available room. Additionally, the internal pressure is essentially spread equally throughout the cell thanks to its rounded form. This enables the cell to withstand greater internal pressures without discomfort. Cylindrical cells have a low packing density as a result. However, the spherical cross-section makes it possible for the coolant to flow freely across the remaining area. The new Tesla Motors 4680 has a vastly enhanced battery size when compared to prior Tesla Motors battery designs, which also results in it having the fundamental high-performance requirements (Fig. 2).

Figure 2. Size comparison of different models of Tesla batteries [7]

2.2. Prismatic Cells

The prismatic cell has a similar internal structure to the cylindrical cell, still roughly composed of a cathode, anode, and separator material. Unlike the cylindrical cell, the prismatic cell is confined to a square frame. An electric car brand from China BYD, which is Tesla's main rival, prefers the prismatic cells. Fig. 3 illustrates the structure of prismatic cells.

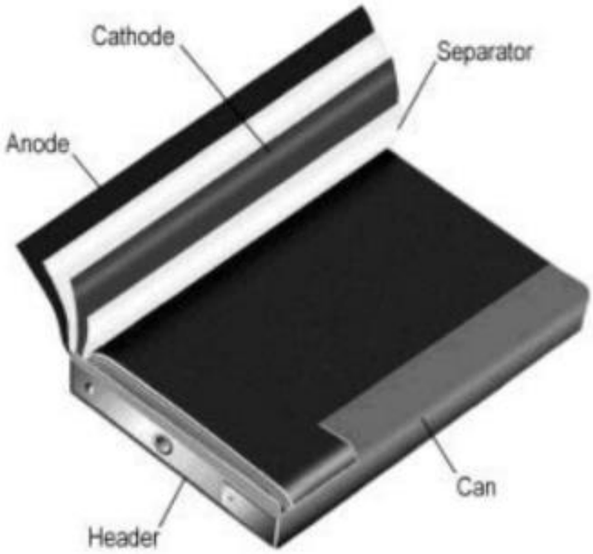


Figure 3. Structure of prismatic cells [7]

2.3. Pouch Cells

The biggest difference between the pouch cells and the other two is that it has a non-rigid shell, usually made of flexible electrolytes, usually wrapped in a film of plastic and aluminum, which makes it lighter than the other two (Fig. 4).

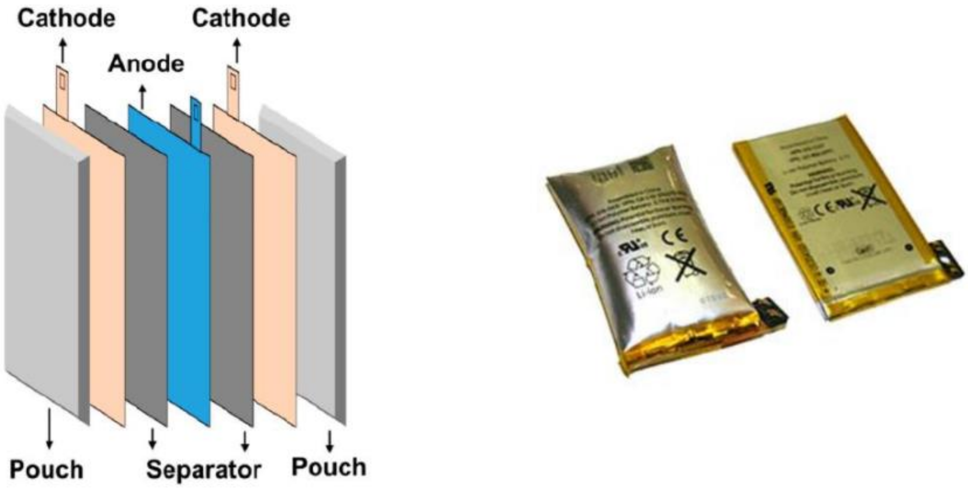
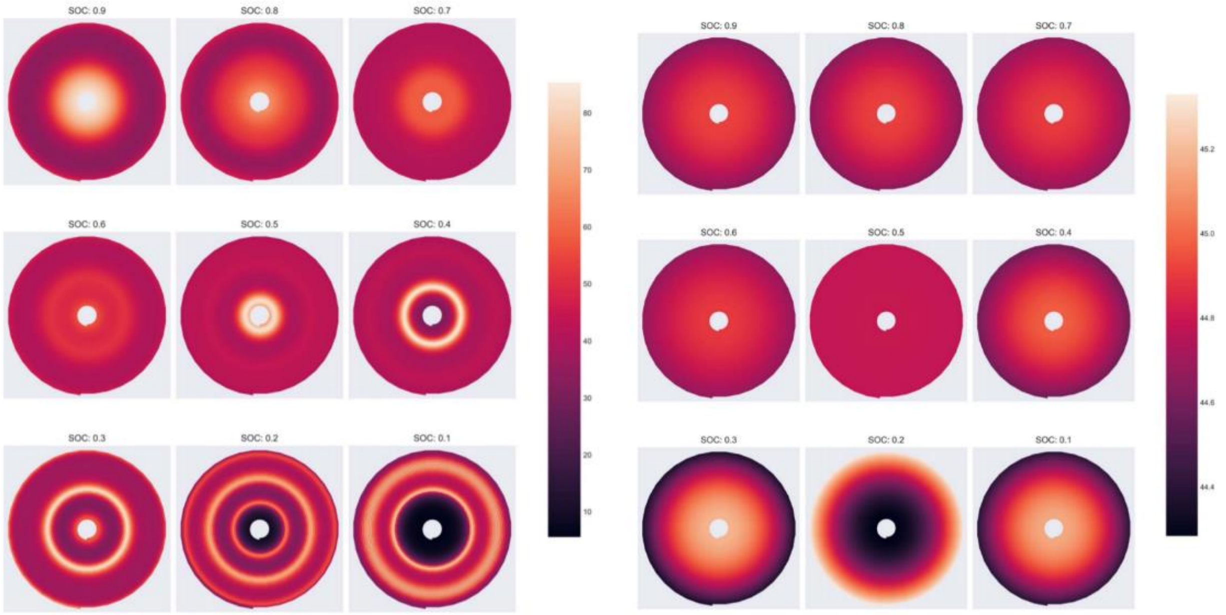


Figure 4. Pouch cells [7]

2.4. Comparison and Discussion

From the point of view of battery production costs, cylindrical cells are relatively easy to manufacture and therefore have a cost advantage. At the same time, the cylindrical cells have good structural strength. Compared with the other two kinds of batteries, the cylindrical cells have strong tolerance in all directions. At this point, prismatic cells are inferior to cylindrical ones, which only have high strength towards the direction of compression in thickness but low strength in others. Prismatic cells are generally considered to have higher energy density and less charge-discharge power than cylindrical cells, and prismatic cells are generally larger in size than cylindrical cells. As a result, fewer prismatic cells are needed to achieve the same energy storage, which means less electrical connection costs, which is one of the reason prismatic cells are favored by some electric vehicle brands. For pouch cells, due to the lack of hard-shell protection, mechanical strength is not high to effectively protect the internal components. Therefore, in the process of work, mechanical collision can lead to leakage of gas, and the leakage of gas may be ignited, which is undoubtedly dangerous. Therefore, pouch cells are usually used in more stable environments. According to the research, the pouch cells is less sensitive to the temperature gradient than the cylindrical cells [5].

The cylindrical battery represented by Tesla battery has limitations from the perspective of thermal management. Due to the shape characteristics of the cylinder, its long length and cathodes and anodes will cause the uneven current distribution. The internal resistance will lead to the uneven temperature distribution. At the same time, the existence of insulation layer further aggravates the temperature difference between the inside and the surface of the battery. Long-term temperature difference will inevitably accelerate the degradation and reduce the cycle life. The 4680, a new battery jointly developed by Tesla and Panasonic, has a larger size (80mm in height). While the larger size provides better energy storage and higher output power, the problem of more pronounced internal current and temperature differences cannot be ignored. To solve this problem, Tesla has come up with a "tableless" approach to current collecting applying a current collector foil with a continuous array of current collectors extending from the foil’s edge [6]. The main purpose of this method is to make the current uniformly distributed inside the battery, so that the heat is also evenly distributed, effectively reducing the heat exchange inside the battery, and protecting the battery in a relatively stable environment. Fig. 5a is the current density without "tableless" current collection method, and Fig. 5b is the current density with the method. It is obvious that going tableless leads uniform current distribution.



(a) (b)

Figure 5. diagram of Current density snapshots with "tableless" current collection and without it [8]

3. Motor

One of the most popular varieties of DC motor is the brushless motor. The brushless DC motor's primary drawbacks include its noisy operation, narrow speed range, low efficiency, and expensive permanent magnet material. Some low power electric cars with less than 30KW of power employ brushless DC motors, which are suited for low power tiny domestic items as fans [9]. As a result, brushless DC motors are not the preferred option for electric cars now or in the near future. The third generation of permanent magnet materials is being used in brushless DC motor development, which is moving in the direction of energy efficiency, downsizing, and high efficiency. The brushless DC motor is increasingly often employed nowadays because of its compact size in control circuits to regulate the motor's speed, steering, current (or torque), and to safeguard against overcurrent, overvoltage, overheating, etc.

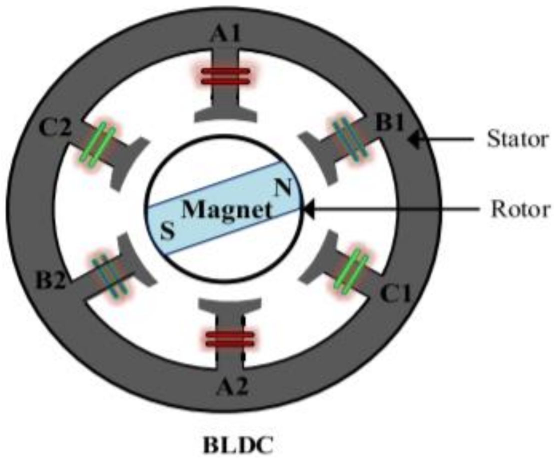


Figure 6. structure of BLDC [9]

Fig. 6 shows the structure of an EV system with its main components as well as their connections. The connections provided in Fig. 7 illustrate the various types of interconnections. Major system components such as motors, on-board controllers, power electronic circuits, power supplies and transmissions are displayed [10]. Power electronics supplies three-phase alternating current to the engine, which transmits mechanical/torque signals to a mechanical transmission system that turns the wheels.

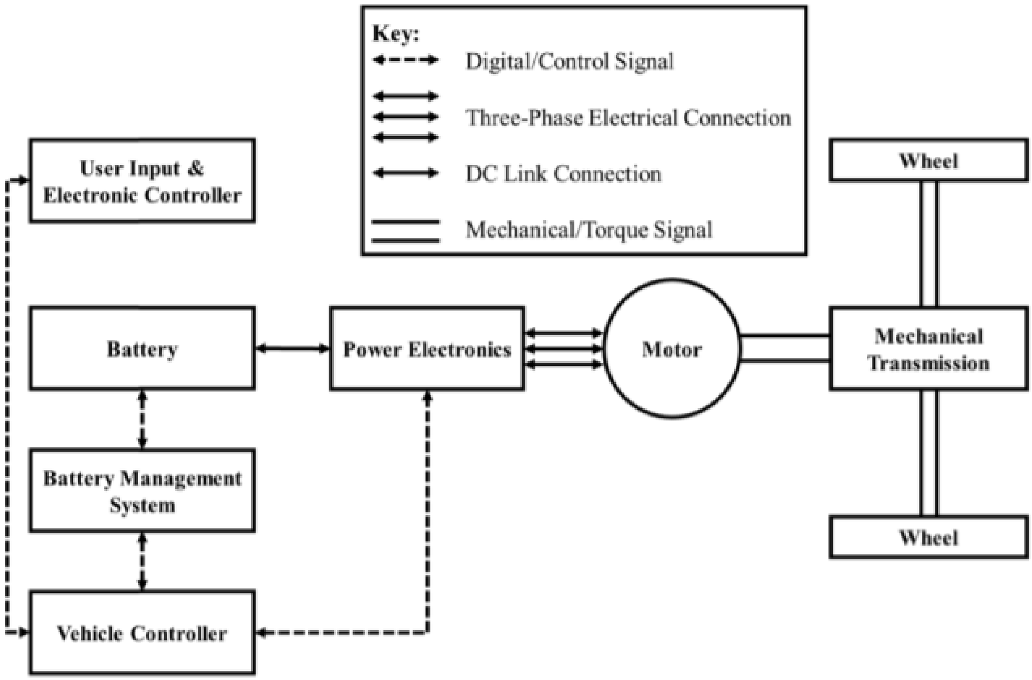


Figure 7. structure diagram of a common EV system [10]

Compared with the traditional internal combustion engine, the relationship between the torque and the motor speed is roughly illustrated in Fig. 8. At low speeds (when the vehicle starts), the EV provides a constant torque, which is usually larger than the IC. The torque determines the acceleration of the vehicle when accelerating. Therefore, the acceleration time from 0km/h to 100km/h of the EV is shorter than most ICs, or even shorter than many supercars.

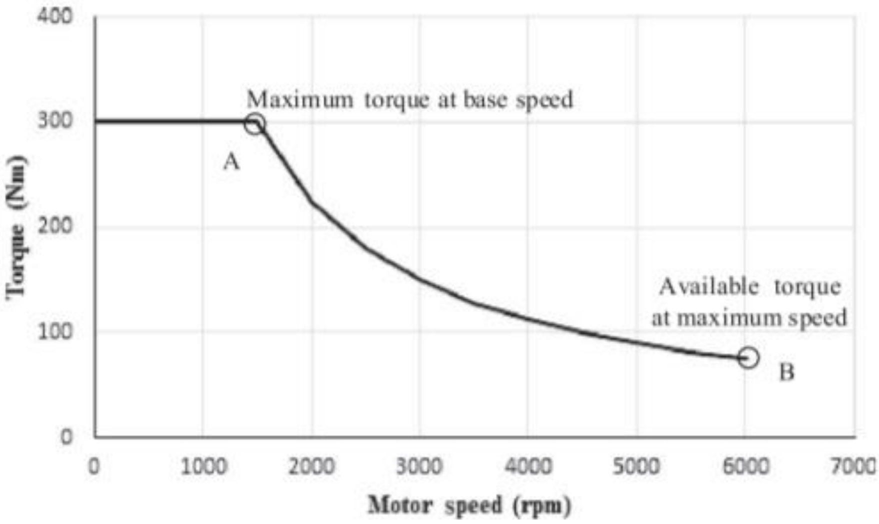


Figure 8. EVs motor relationship of speed and torque [11]

The two motor types that are used the most frequently in EV drivetrains are synchronous motors with permanent magnets (PMSMs) and induction motors (IMs). As an AC motor, induction motor produces electromagnetic torque as a result of the interaction between the induction current of the rotor's winding and the air gap's rotating magnetic field, converting electromechanical energy to mechanical energy. The three-phase induction motor's stator windings get a symmetrical voltage addition, which creates a spinning air gap magnetic field. The winding conductor then shuts off the magnetic field to create an induction potential. The rotor winding is short circuited, which causes the generation of the rotor current. The combination of the rotor current and the air gap magnetic field produces an electromagnetic torque that propels the rotator's spin. Induction motors are frequently referred to as asynchronous motors since their speed must be lower than the magnetic synchronous speed. Its benefits include acceptable operating qualities, a straightforward structure, easy manufacturing, a cheap cost, dependable operation, strong and long-lasting operation. The fundamental drawback of IM is its low work efficiency and material loss, particularly the substantial core loss [9]. The traction motor market for EVs/HEVs has nowadays been dominated by PMSM [11]. Because permanent magnet motors are generally considered to have higher torque density and higher performance than IM motors [12]. The NdFeB magnet utilized in permanent magnet motors has been used extensively in drive systems due to its high power and efficiency [13]. The PMSM offers excellent performance across the board, including high control precision, high power density, and low noise. Consequently, the drive system of electric cars frequently employed the synchronous motor with permanent magnet. Degaussing, torque rippling, fault tolerance, and the usage of expensive magnets (neodymium, samarium) are the primary downsides of PMSM [9]. A three-phase inverter circuit with six semiconductor switching devices that are managed by PWM signals produced by the motor controller controls the PMSM (Fig. 9).

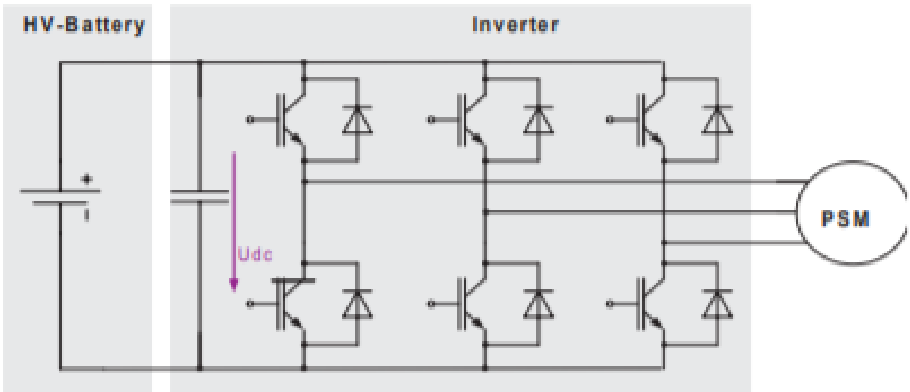


Figure 9. Three-phase PMSM inverter circuit [6]

According to the position of the PM equipment on the engine rotor, permanent magnet motors are classified as surface mounted PM (SPM) and inner PM (IPM) (Fig. 10).

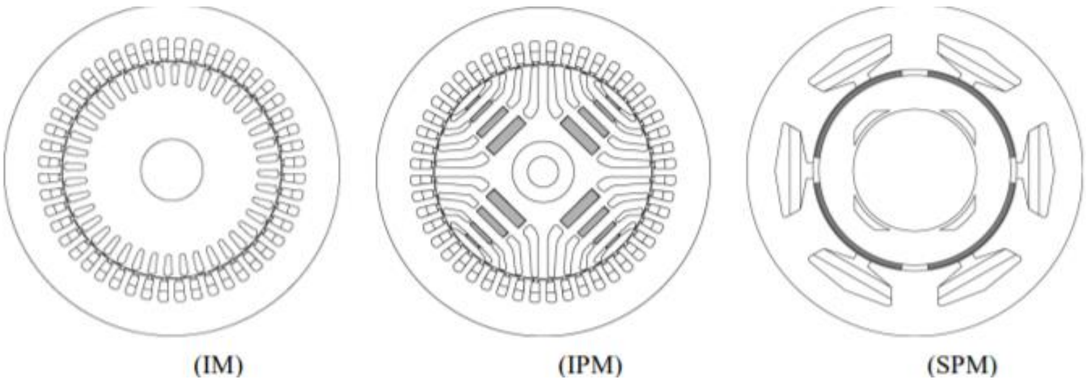


Figure 10. Cross sections of IM, IPM and SPM of the same size [12]

As shown in Fig. 11, SPM and IPM have similar torque at low speed. However, with the increase of speed, SPM's torque drops faster, while IPM can still maintain a high torque at a certain speed.

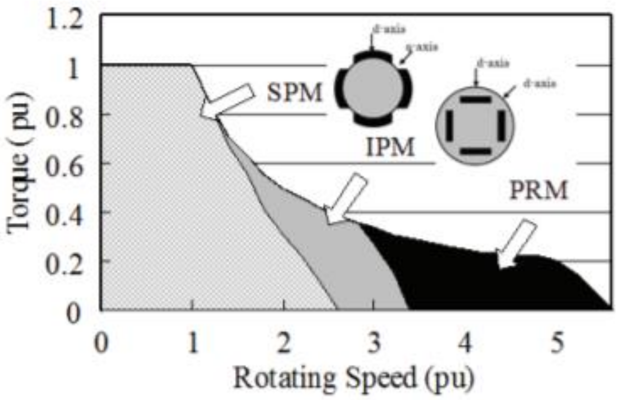


Figure 11. performance of SPM and IPM in speed and torque [13]

4. Conclusion

To conclude, the paper discusses electric vehicles, which are currently at the forefront of the industry and important components of future sustainable development, mainly from the two components of electric vehicles, battery and motor, and takes Tesla electric vehicles as a case for analysis. Comparing the advantages and disadvantages of batteries of different shapes, this paper briefly describes the reasons why all Tesla models choose cylindrical batteries. The production cost of cylindrical batteries is relatively low, and they have high strength in all directions, which is a necessary feature of batteries used in electric vehicles. At the same time, the problem of uneven distribution of current and internal temperature of cylindrical battery cannot be ignored, especially in the era background that the new high-performance battery represented by the 4680 large-size battery has become the mainstream of the future battery, the promotion and development of the new technology like "tableless" current collection is particularly important. In terms of motors, the paper introduces characteristics of brushless DC motor , and the scope of its application, and also compares three types of motors: IM, IPM and SPM, with a focus on comparing IPM and SPM motors in relation to torque and speed.

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